Stellingen

behorende bij het proefschrift van L.P.A. Steenbekkers
'Child development, design implications and accident prevention'.

1. Grote nauwkeurigheid van antropometrische data is wetenschappelijk gewenst, maar in de praktijk van het ontwerpen is het noch realistisch noch absoluut noodzakelijk.

2. Tijdens het ontwerpen voor veiligheid is het beter te werken met uiterste waarden dan met percentiel-waarden.

3. Bij het bepalen van de doelgroep van gebruiksgoederen voor kinderen vormen fysieke en psychomotorische kenmerken een belangrijker criterium dan kalenderleeftijd.

4. Kinderen wier ontwikkeling volgens de norm verloopt, zijn beter in staat te voorkomen dat bijna-ongevallen ongevallen worden.

5. Bij het vergelijken van lenigheid van kinderen, gemeten door middel van 'reiken in langzit', is het, gezien de verschillen in proportionering tussen leeftijdsgroepen, noodzakelijk te corrigeren voor afmetingen van lichaamssegmenten.

6. De indruk dat technisch inzicht van meisjes reeds op twee-jarige leeftijd gemiddeld minder ver ontwikkeld is dan dat van jongens, lijkt te duiden op genetische verschillen in cognitieve capaciteiten tussen de geslachten.

7. Individualisering is een biologisch proces dat bij de conceptie aanvangt en dat gedurende het gehele leven doorgaat en toeneemt.

8. 'Kinderen zijn hinderen' gaat niet op wanneer het hun participatie in een onderzoek betreft dat tijdens de lesuren maar buiten de klas plaatsvindt.

9. Zolang exactheid van meten maatstaf is voor de waardering van een wetenschap, zullen de sociale wetenschappen als minder waardevol beschouwd worden.

10. De overeenkomst tussen de studies Huishoud- en consumentenwetenschappen aan de Landbouwuniversiteit Wageningen en Industrieel Ontwerpen aan de Technische Universiteit Delft is groot: beide opleidingen worden laag gewaardeerd binnen de respectieve universitaire gemeenschappen, maar hoger daarbuiten.

11. Het formaat van de Nederlandse dagbladen is on-ergonomisch.

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Child development, design implications and accident prevention

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L.P.A. Steenbekkers

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1 Introduction

Daily-life products are used regularly and even almost continuously. Modern living means interacting intensively with many, varied, man-made utilities. The handling of durable products is expected to be influenced by both anthropometric and psychomotor variables of the user. These characteristics develop during childhood. This implies that the handling of products during this period of time will probably not always be optimal, because a child may use them for other purposes (using a toy as a step) or in ways other than intended (holding a hammer by the head instead of the handle). This may result in dangerous situations. The user might, however, be unaware of this danger, because this aspect has to be foreseen and learned. Learning to use products in a safe way is another long-lasting process, which is determined by many factors.

The fact that the interaction between children and products does not always occur in the right way and can even be dangerous is illustrated by the large number of accidents among children involving durable and non-durable products (Pors, 1990). These accidents occur for various reasons but might be attributable to the user and/or the product.
To gain more insight into this matter, the descriptions provided by parents of accidents involving their children and daily-life products were analysed in a pilot study (Steenbekkers, 1989a). Furthermore, a second goal of that study, namely to gain insight into the body dimensions of young children, was achieved by taking anthropometric measurements of children between 0 and 5.5 years of age in one province of the Netherlands (Steenbekkers, 1989b). The results of that study have been used in the present study to complete the age range studied (2 to 13 years) towards zero. A conclusion of the pilot study was that, on the one hand, not only physical characteristics but also (the development of) temperamental and psychomotor variables seem to play a part in the occurrence of accidents. On the other hand accidents also appeared to have happened because the products involved were not or were insufficiently adapted to the characteristics and capacities of the individual user.
Some characteristics which, according to the parents, were involved in the occurrence of accidents were: motor skills, physical flexibility and temperament of the child. Less clear from the accident descriptions but presumably of influence on the interaction with products is the role of technical comprehension. Data on these characteristics, as well as body dimensions and exertion of force might enable designers to create better adapted or better adjustable products or material environments for children. These safer products and environments might in the future contribute to the prevention of accidents among children.

Data on some of the above-mentioned characteristics have already been collected in several studies on growth and/or physical fitness, but they refer only partly to the target group of this study: children between 2 and 13 years of age living in the Netherlands.
Some of these studies are already several years old, which implies that the results might be less suitable because of the existence of a secular trend in growth of the body. Other studies refer to measurements of only a regional sample of the Dutch population or stem from other countries.

The Third National Growth Study of 1980 (Roede and van Wieringen, 1985) is an example of a Dutch nationwide study which, unfortunately for our research project, included only a limited number of anthropometric variables. Because the measurements were taken more than a decade ago, the results are no longer up-to-date. (The fourth study is now being prepared).
The same can be said of the mixed-longitudinal, interdisciplinary study on growth and development performed in the Dutch city of Nymegen (Prahl-Andersen et al., 1979).
A disadvantage of this study is that the population sample was regional. In this study, besides many other variables, the development of several physical characteristics of children from four to fourteen years of age was evaluated.
Gerver (1988) measured a number of body segments of children in the age range between 6 weeks and 19 years to determine body proportions for use in clinical practice. Unfortunately, the data refer to children living in only one municipality in the Netherlands.
Kemper et al. (1985) studied the growth, health and fitness of teenagers in a longitudinal study. Here, too, the sample was regional, consisting of children between 12 and 18 years of age from the region of Amsterdam.
A more recent Spanish study, to some extent comparable to the former, was performed by Carrió i Soldevila (1990). In this study the variables consisted of a number of anthropometric measurements and the results of physical aptitude tests. The children, between 4 and 14 years of age, came from an industrial part of the city of Barcelona.
Another study is the Hungarian National Growth Study of the 1980's (Eiben et al., 1991) in which the biological developmental status and physical fitness of 3 to 18-year-olds were assessed.

The studies mentioned above provide data that are not, or only partly, suitable for use by designers of products and cannot be used to reach the goals of this project.
To acquire data on physical and psychomotor characteristics of children which are suitable for use by designers of daily-life products, this study was set up. A second reason was to gain more insight into the relationships between different variables and their pattern of development. An attempt was also made to determine whether differences in characteristics exist between children who often have accidents and those who do not.

In chapter 2 the aim of this study is further elaborated. In chapter 3 the sampling procedure as well as the final sample of children between 2 and 13 years of age is described. The aim was to collect a sample representative of the socioeconomic characteristics of the adult population and the number of children per province, separated according to the degree of urbanisation.
The variables to be measured and the hypotheses to be tested are presented in chapter 4. Six groups of variables were chosen. The first group consisted of temperamental characteristics, which might influence the occurrence of accidents. Temperament was assessed by means of a questionnaire for both parents and the teachers of the children. This questionnaire also included a question about the accident liability of the child. The second group of variables consisted of 40 body measurements, which give some insight into the dimensions of segments of the body and changes in body proportions over the course of time. The third group consisted of forces exerted by the fingers or the hand; this might be useful when designing, for example, child-proof packaging. Another group of variables represented

aspects of motor performance. Lack of motor skills often appeared in the accident descriptions as the presumed reason for the occurrence of accidents. These motor skills are partly related to the next group of variables which measure physical flexibility. The sixth group of variables measured insight into some commonly used compatibility rules. This was included because handling products in a safe way requires insight into how products work or have to be controlled.

The exact methods of measurement used and the results of the measurements are described for each group of variables in chapters 5 to 10. Relationships between and within the groups of variables and a pattern of development are given in chapter 11. Differences in physical and psychomotor characteristics between children who were judged liable to have accidents and those who were not are described in chapter 12. The concept of accident liability is also discussed in this chapter and compared with that of accident proneness. In the next chapter, various hypotheses are tested. Some implications of the results of this study for the design and safety of products are given in chapter 14. In the last chapter the results and conclusions of the study are presented. Some suggestions for further study are given as well.

2 Object and aim of the study

Growth, the increase in size of the whole body or parts of the body, and development, functional changes in and refinement of different systems of the body in children, have always fascinated scientists. Many studies have been published in this field. Often these studies focus on 'single' aspects of development such as cognitive, specific social, somatic or motor development. Each of these aspects of development is still broad and interesting enough to be a separate object of study. The interrelationships between these fields are a different matter. The way in which these variables influence each other or co-variate and their mutual relationships are still only partly known.
The aim of this project was to describe the development of some physical and psychomotor variables as well as temperamental characteristics of children, living in the Netherlands, and to investigate the possible interrelationships between these variables.

The choice of the groups of variables to be measured was based on two aspects:
1. a possible relationship with accident liability,
2. suitability for use in the design process.
These two criteria will be explained below.

Accident liability, operationally defined as a frequency estimate during a certain period of time of the occurrence of accidents, will be related to physical characteristics and temperamental features in order to test for the presence of a relationship.
It should be stressed that accident-proneness, as an assumed personality trait, is not the same as accident liability. The concept of accident-proneness, an (innate) personal predisposition or destiny to have accidents, has been a subject of discussion for many years (Shaw and Sichel, 1971; Hale and Glendon, 1987). The relationship between accidents and personality has, however, not yet been proven and a reasonable doubt exists about the validity of this concept.
In contrast, accident liability is based on a direct frequency count of more or less serious accidents which have occurred in a given period of time; this count need not necessarily involve analysis of the causes and nature of the accidents. This frequency can be compared with the frequency of accidents among age peers to define the relative liability to have accidents. This approach is used in this project.

It is expected that physical, psychomotor and temperamental variables –within normal ranges– might influence the occurrence of accidents. Especially the development of these variables, and thus changes in these characteristics within a certain period of time, may partly explain these unfortunate happenings.
A change in body proportions might, for instance, result in changes in both muscle function and patterns of movement. The child has to learn to cope with these changes. During this learning period movements might be less fluid and coordinated, resulting in accidents due to, for example, stumbling. A somewhat retarded motor development might have a similar influence. Accidents with certain types of equipment or apparatus might occur due to a lack of skill and/or insight into the way in which this equipment has to be used and controlled. Another possible relationship is the influence of physical flexibility on the occurrence of

accidents. On the one hand, the possibility exists that accidents are due to less fluid movements as a result of diminished flexibility; on the other hand, a child may be able to reach farther and therefore put itself in dangerous situations. Other behavioural characteristics, and especially temperament, are also presumed to have an influence on the occurrence of accidents. A balanced development of all variables will presumably have a preventive effect on the occurrence of accidents.

Two observations contributed to the fact that the choices of the variables to be measured were determined by their suitability for use in the process of the design of daily-life products:
1. daily-life products are very often either involved in the occurrence of accidents or the cause of injuries and
2. data on (physical aspects of) user-product interactions are needed when designing products in order to adapt them to the possibilities and capacities of the human body. Such a design will contribute to the comfort and safety of the user.

In general, a study on growth and development requires longitudinal data. If, however, the results of such a study have to be used in relation to user-product interaction, cross-sectional data will meet the needs of (future) users of the data, since an actual databank on this population is needed. A designer of products for children needs to know several age-related physical and psychomotor characteristics. Moreover, the time and costs of a longitudinal study are prohibitive for most research organisations.

The target group of this study consisted of normal, healthy children, living in the Netherlands, between 2 and 13 years of age. This age group was chosen because these children are often the victims of accidents and little data on their physical and psychomotor characteristics are available. Younger children also have many accidents, but they were not the subject of study here. The reasons for this choice were:
1. it would be impossible to use identical measurement methods for these children and the older ones;
2. the causality of accidents involving this age group is less clear.

Nevertheless in a prior study anthropometric data on a large (n = 633) regional sample of children from 0 to 5.5 years of age were collected (Steenbekkers, 1989b). This unique data collection may in some respects complete insights pertaining to the lower part of the developmental range gained in the present study and can also be used for product design.

The questions of the present study were:
- How do certain physical, psychomotor and temperamental variables develop in the period of life between the second and thirteenth birthdays in children in the Netherlands?
- What relationships exist between the different groups of variables?
- Does a relationship exist between (development of) the above-mentioned groups of variables and the liability to have accidents?

The aims of the project were:
- To generate normative data on the development of the above-mentioned groups of variables, based on empirical assessments.
- To describe and test hypotheses on mutual relationships between these groups of variables as well as their relationship with accident liability.
- To provide suggestions for design and evaluation criteria that will lead to safer daily-life products for children.

3 Design of the sampling procedure and organisation of the fieldwork

Tables:

Figures:

3.1 Sampling procedure

A prerequisite of this project was to obtain a representative sample of healthy children, living in the Netherlands (both autochthones and allochthones), in the age range 2 to 13 years. The sample had to be as representative as possible with respect to sex, urbanization, socio-economic variables and the number of children in each of the regions of the Netherlands, because these variables are of influence on growth of the body (Roede and van Wieringen, 1985) and because geographical variance in the other groups of variables has not been demonstrated but is feasible.

The required precision of an estimate of a population parameter determines the sample size. Whenever precision is increased by a factor c, sample size is increased by a factor c^2.

A mathematical basis for sample size is, however, vague and various approaches are used. Sample size can be determined by using the confidence intervals for different statistics as starting-point, e.g. those for mean and standard deviation. Our idea was to have a sufficient number per age group to ensure an acceptable degree of empirical certainty.

In particular an estimation of the sample mean for the stature of 12.5-year-old boys (the group with the largest standard deviation for stature) should lie within the 95%-confidence interval of the mean ± 1.5 cm to obtain a useful estimation of the population mean. The formula to determine the accompanying sample size is (Churchill, 1983):

$$n = \frac{z^2}{h^2}\sigma^2$$

where $z = 1.96$ (eccentricity value of Gaussian distribution)
$h = 1.5$ (half precision)
$\sigma = 7.4$ (population σ for 12.5-year-old boys according to Roede and Van Wieringen, 1985)

This formula leads to a sample size of 93.5, rounded off to 100. Consequently the anthropometric sample should consist, for reasons of valid generalization, of 100 children per age group and sex, spread over the 12 provinces of the Netherlands. For reasons of time and costs, the psychomotor sample was restricted to 20 of each of the 100 children per age group.

For this purpose the country was divided into 4 regions, each consisting of 3 provinces. These were:

North: Groningen, Friesland, Drenthe;
East: Overijssel, Flevoland, Gelderland;
West: Noord-Holland, Zuid-Holland, Utrecht;
South: Zeeland, Noord-Brabant, Limburg.

The degree of urbanization in each of the 4 regions was established as well as the number of inhabitants and the distribution of ages of children, using data from the Central Bureau of Statistics (CBS) (1987). Subsequent calculations yielded the proportions per 100 children per region according to the population: 10 : 20 : 45 : 25.

In order to be able to determine the distribution of these children per region among the different degrees of urbanization, the urbanization per region was assessed. For this purpose the municipalities were divided into three groups:

a: < 20,000 inhabitants;
b: 20,000 – 50,000 inhabitants;
c: > 50,000 inhabitants.

	magnitude of municipalities [inhabitants]		
	< 20,000 (a)	20,000 - 50,000 (b)	> 50,000 (c)
North	43.1 %	32.2 %	24.7 %
East	21.8 %	39.1 %	39.2 %
West	26.4 %	18.6 %	55.0 %
South	47.0 %	31.6 %	21.3 %
Netherlands	32.5 %	25.3 %	42.2 %

Table 3-1: Percentage of inhabitants per region living in municipalities of different magnitudes.

The next step was to determine the most prevalent degree of urbanization per province. A municipality that best met the provincial characteristics of degree of urbanization and composition of the occupations of the inhabitants (being one of the socioeconomic variables) was chosen to participate in the project, with the condition that all 3 degrees of urbanization were represented per region. The municipality chosen was presumed to be representative of the region.

Before asking schools to participate, permission was requested from the Ministry of Welfare, Public Health and Culture, i.e. the Department of Youth Health Care, and the Ministry of Education and Science (Chief-Inspector of Primary Schools). The Primary Schools Inspectors of the districts in which the chosen municipalities were situated gave the names of one or more schools that could be contacted. The number of schools needed to obtain the required number of children was determined by the inspectors on practical grounds as well as their knowledge of a specific school, relative to the conditions of our project. The total number of schools contacted was 31, 29 of which participated in this nationwide project.

The contacts for the Health Centres for Infants and Toddlers extended from the Provincial Health Office via District Offices to Local Health Centres. Only one municipality per region was chosen (the one representing the degree of urbanization applicable for most of the children in that region), with the condition that all degrees of urbanization were present in the sample. The reason for this approach was the fact that the number of children per centre would be too small if the total number was spread out over all municipalities and that consequently the stress per centre would be disproportionate. Per municipality the number of participating centres, which varied between 1 and 3, was determined by the contact person at the District Office on the basis of the required number of children. Altogether seven centres took part in the study.

Table 3-2 shows the number of participating schools and health centres per municipality. The code for the magnitude of the municipality is given in parentheses.

All children in school (n = 7030) received a letter for their parents, containing information about the project. The parents were asked to permit their children to participate in the project and to complete the questionnaire on temperament (chapter 5). The children had to bring the written consent and the completed questionnaire back to school. The number of questionnaires returned was 4842 (68.9%). The composition of the non-response group is not known; this is also true for the reasons, besides loss or neglect, why these parents refused to allow their child to participate in the project.

region	province	municipality		number of schools	number of health centres
North	Drenthe	Beilen	(a)	2	1
	Friesland	Heerenveen	(b)	1	
	Groningen	Groningen	(c)	1	
East	Gelderland	Silvolde	(a)	1	
	Flevoland	Dronten	(b)	2	1
	Overijssel	Zwolle	(c)	2	
West	Utrecht	Breukelen	(a)	2	
	N.-Holland	Beverwijk	(b)	3	
	Z.-Holland	Dordrecht	(c)	5	3
	Z.-Holland	Delft	(c)		1
South	Zeeland	Borsele	(a)	5	1
	Limburg	Venray	(b)	3	
	N-Brabant	Oss	(c)	2	

Table 3-2: Number of participating schools and health centres in the municipalities chosen, per region and province. (a, b, and c refer to the magnitude of the municipality (table 3-1)).

The 4842 children, who were allowed to participate, were separated according to age and sex. Per age group and sex a predetermined number of children was chosen at random. These children were selected for in the anthropometric measurements. The age range for the groups in this sample was 12 months up to the age of 9 years, and 6 months for those from 9 to 13 years of age. The reason for this shorter age span was the fact that the puberal growth spurt is likely to start during this phase. The differentiation in dimensions of the body, also between boys and girls, will be larger; therefore the number of subjects had to be larger in order to obtain an acceptable measurement error. For all analyses, however, the children were again grouped according to year.

Of the children in the anthropometric sample, a random sample per age group and sex (1 out of 4 or 5) was chosen to participate in the psychomotor part of the project. This part consisted of the measurement of force exertion, motor performance, flexibility and technical comprehension. For this part of the study the age range was 12 months for 8-year-olds and older. Children between 2 and 7 years of age were divided into 6-month groups, because motor development is likely to be most prominent during this earlier phase of life. The teachers of all children in the psychomotor sample completed a questionnaire on the temperament of these children.
A number of children who, according to parents and/or teachers, were liable to have accidents were included in this part of the study if they were not part of the regular sample. Whenever time permitted, more children were assessed. The total number of children added to the regular sample was 117. In order to ensure that various aspects of the development of children were described without possible interference of this over-sampling, their data were only included in analyses concerning accident liability.

For children aged 2 to 4 years, contacted via the Health Centres for Infants and Toddlers, the procedure was somewhat different. Due to privacy regulations we were not allowed to draw a random sample from the list of registered children. Therefore, the employees at the

centres determined the samples, consisting of the required number of children (n = 550), on the basis of our conditions. The parents of these children received a letter from the centre asking them to participate in the investigation. If they agreed, they returned a form (n = 369; response 67.1 %). Afterwards an appointment was made with each family. Again no information was available on the non-response group.
The measurements were taken at the health centre. These children participated in all parts of the project, except for the measurement of strength and motor performance because the methods used appeared to be too difficult for them to understand. They thus participated in the assessment of body dimensions, physical flexibility and technical comprehension. In the meantime the accompanying parent completed a questionnaire on the temperamental characteristics of the child.

The children of this age group do not yet attend school; therefore teacher evaluation of the children's temperament or their accidents could not be made. Therefore it was not possible to classify them as liable (or not) to have accidents, according to the definition used, because only the judgement of parents on this liability was known (see chapter 5). The way in which the composite sample was obtained is presented schematically in figure 3-1.

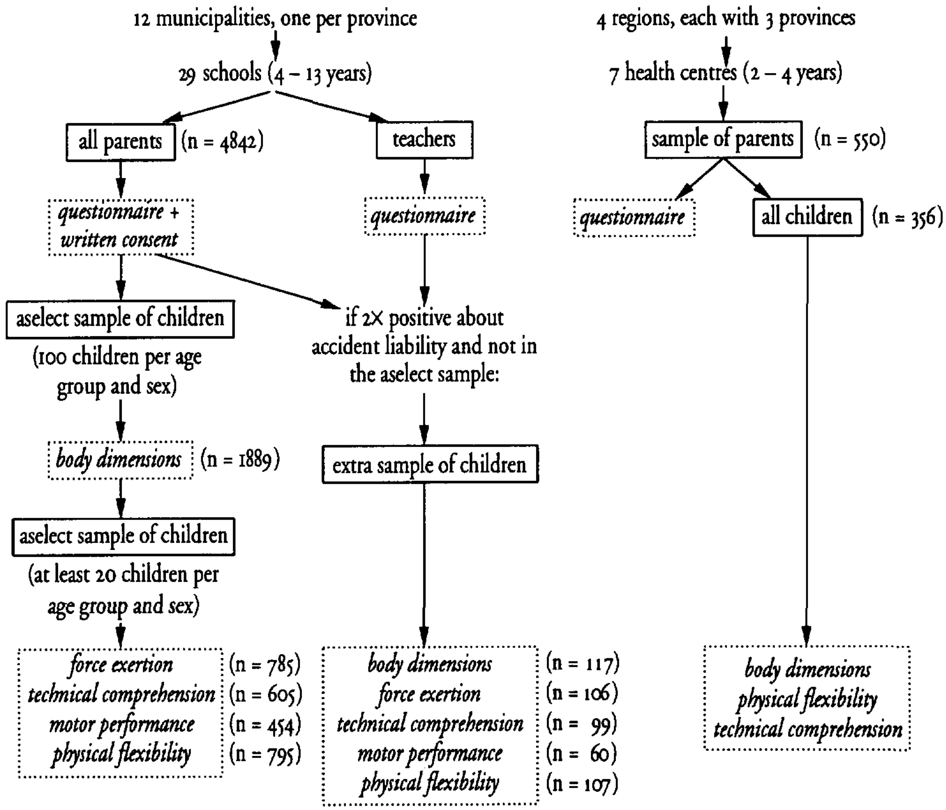


Figure 3-1: Diagram of sampling procedure.

3.2 Subjects in the sample

3.2.1 Number per age group

The number of children in the aselect sample, drawn from the 5211 children who were allowed to participate, was 2245 (see figure 3-1). Their distribution according to age group is given in table 3-3.

age [years]	boys number	boys sample percent	girls number	girls sample percent	boys + girls number	boys + girls sample percent
2.0 – 2.9	81	3.6%	92	4.1%	173	7.7%
3.0 – 3.9	97	4.3%	86	3.8%	183	8.2%
4.0 – 4.9	85	3.8%	79	3.5%	164	7.3%
5.0 – 5.9	86	3.8%	94	4.2%	180	8.0%
6.0 – 6.9	98	4.4%	92	4.1%	190	8.5%
7.0 – 7.9	106	4.7%	93	4.1%	199	8.9%
8.0 – 8.9	96	4.3%	95	4.2%	191	8.5%
9.0 – 9.9	122	5.4%	122	5.4%	244	10.9%
10.0 – 10.9	134	6.0%	136	6.1%	270	12.0%
11.0 – 11.9	143	6.4%	151	6.7%	294	13.1%
12.0 – 12.9	78	3.5%	79	3.5%	157	7.0%
total	1126	50.2%	1119	49.8%	2245	100.0%

Table 3-3: Number of children in the aselect anthropometric sample according to age and sex.

The target number of children per age group and sex was to be 100. Table 3-3 shows that this number was not achieved in all groups, especially among the elder children (100 per 6-month group). The strikingly low number of 12-year-old children can be explained by the fact that fewer 12-year-olds attend primary school. Nevertheless the number of children is large enough to be able to perform the planned statistical analyses.

The distribution between boys and girls is reasonably good: they are present in approximately equal numbers in the sample. In the population in the Netherlands the percentage of boys and girls within this age range is 51.1 and 48.9, respectively (CBS, 1987).

Of all individuals living in the Netherlands in 1990 7.8% was born abroad. The percentage of children between 0 and 19 years of age living in the Netherlands but born abroad was 5.3%. Of the children in this age group of non-Dutch nationality, 55.7% was born in the Netherlands; in the total population of all ages this percentage was 24.0 (CBS, 1991).
In the sample 4% of the children had at least one parent who was not born in the Netherlands; this was the criterion used to distinguish between autochthones and allochthones.

3.2.2 Number per province

The number of children per province is listed in table 3-4. This table refers only to children in primary school, because the sample of children under 4 years of age was collected at the regional level rather than the provincial level. Taking them into account would result in an unrealistic distribution over the provinces. The distribution in the Netherlands of children between 0 and 14 years (CBS, 1987) is also given.

province	boys n	boys sample percent	boys Dutch percent	girls n	girls sample percent	girls Dutch percent	boys + girls n	boys + girls sample percent	boys + girls Dutch percent
Groningen	26	2.8%	3.8%	26	2.8%	3.7%	52	2.8%	3.7%
Friesland	19	2.0%	4.6%	28	3.0%	4.6%	47	2.5%	4.6%
Drenthe	43	4.6%	3.1%	45	4.8%	3.1%	88	4.7%	3.1%
Overijssel	77	8.2%	8.0%	83	8.8%	8.0%	160	8.5%	8.0%
Flevoland	53	5.6%	1.2%	54	5.8%	1.2%	107	5.7%	1.2% *
Gelderland	36	2.8%	12.6%	33	3.6%	12.6%	69	3.7%	12.6% *
Utrecht	85	9.0%	6.5%	90	9.6%	6.5%	175	9.3%	6.0%
Noord-Holland	77	8.2%	14.5%	66	7.0%	14.5%	143	7.6%	14.5% *
Zuid-Holland	282	30.0%	21.1%	298	31.8%	21.2%	580	30.9%	21.2% *
Zeeland	120	12.8%	2.5%	100	10.6%	2.5%	220	11.7%	2.5% *
Noord-Brabant	43	4.6%	15.2%	45	4.8%	15.2%	88	4.7%	15.2% *
Limburg	79	8.4%	7.0%	71	7.6%	7.0%	150	8.0%	7.0%
total	940	100.0%	100.0%	939	100.0%	100.0%	1879	100.0%	100.0%

Table 3-4: Number and percentage of children (4 to 13 years) in the sample and percentage of children in the Netherlands (0 to 14 years) according to province and sex.
** = Sample percentage outside 95% confidence interval for the population percentage.*

Differences between percentages can be tested with the percentage test (Worcester et al., 1978), in which the 95% confidence interval (C) for the population percentage is computed using the formula:

$$C = p \pm 1.96\sqrt{\frac{p(100-p)}{n}}$$

where: p = population percentage
n = number of cases in the sample
1.96 = value for 95% confidence.

Table 3-4 shows that the composition of the sample at the provincial level does not quite agree with the overall distribution in the Netherlands. For half of the provinces the sample percentage fell within the 95% confidence interval of the population percentage. This was, however, not true for the provinces Flevoland, Zuid-Holland, Zeeland (oversampled) and Gelderland, Noord-Holland, Noord-Brabant (undersampled). The sample was, however, presumed to be sufficiently representative of the entire country, as far as geographical variation and the degree of urbanization at the regional level were concerned, for the aims of this study.

3.2.3 Number per region

Per region the three defined degrees of urbanization had to be present. The exact numbers of children in each category is given in table 3-5. This table again refers only to children in primary school. Per region the percentages are given for the sample as well as for the Dutch population of children between 0 and 14 years of age.

	degree of urbanization									total		
	<20,000			20,000-50,000			>50,000					
region	n	sample percent	Dutch percent	n	sample percent	Dutch percent	n	sample percent	Dutch percent	n	sample percent	Dutch percent
North	88	47.1%	43.0%	47	25.1%	32.3%	52	27.8%	24.7%	187	10.0%	11.5%
East	69	20.5%	21.8%	107	31.8%	39.1%	160	47.6%	39.2% *	336	19.9%	21.7%
West	175	19.5%	26.3% *	143	15.9%	18.6%	580	64.6%	55.0% *	898	46.7%	42.1% *
South	220	48.0%	47.0%	150	32.8%	31.6%	88	19.2%	21.4%	458	23.3%	24.7%
total	552	29.4%	32.5%	447	23.8%	25.3%	880	46.8%	42.2%	1879	100.0%	100.0%

Table 3-5: Number and percentage of children (4 to 13 years) in the sample and the percentage of the Dutch population (0 to 14 years) according to degree of urbanization and region.
** = Sample percentage outside the 95% confidence interval for the population percentage.*

Table 3-5 illustrates that the sample at the regional level was fairly representative of the Dutch population of children between 0 and 14 years of age. In region East a slight oversampling occurred in the larger cities, although the differences in percentages for the other municipalities did not exceed the 95% confidence interval for the population percentage. In the western region an oversampling in cities and an undersampling in rural areas took place. The total number of children in the western region was also slightly outside the 95% confidence interval of the Dutch population. It can nevertheless be concluded that the sample was representative of the Dutch population of children, as far as the degree of urbanization in the different regions in the Netherlands is concerned.

3.2.4 Socioeconomic differences

The socioeconomic status of a child's family may be of influence on his/her growth and development. This status can be defined and measured in several ways. Commonly used parameters for social and economic status are education, profession or income of the parents. To ask someone's income is still taboo in the Netherlands and a profession can be interpreted very loosely by respondents. Therefore the level of education of both the father and mother was chosen as the indicator of the socioeconomic status of the family. It was not possible to stratify the sample for this variable beforehand, so it was verified retrospectively. In tables 3-6 and 3-7 the levels of education are presented for the father and mother separately.

It has to be concluded that the educational level of the parents in the sample is higher than the educational level of adults in the Dutch population. There are several explanations for these differences:

1. the grouping into categories of educational level for the CBS might be based on different criteria than that in this project;
2. parents might have reported a higher educational level than they actually achieved;
3. the data on educational level of the Dutch population date from 1983 (CBS, 1987). In the period 1983 - 1990 the total level of education is likely to have risen somewhat.

	education of the father									sample
	no or lower education			secondary education			higher (non-academic) or academic education			sample
region	n	sample percent	Dutch percent	n	sample percent	Dutch percent	n	sample percent	Dutch percent	n
North	35	16.4%	16.8%	127	59.6%	67.1% *	51	23.9%	16.2% *	213
East	46	10.8%	17.0% *	206	48.4%	69.5% *	174	40.9%	13.5% *	426
West	149	14.9%	16.7%	497	49.7%	66.2% *	354	35.4%	17.1% *	1000
South	84	16.7%	16.9%	223	44.2%	69.2% *	197	39.0%	13.9% *	504
total	314	14.7%	16.9%	1053	49.1%	68.0% *	776	36.0%	15.2% *	2143

Table 3-6: Level of education of the father according to region.
** = Sample percentage outside the 95% confidence interval for the population percentage.*

	education of the mother									
	no or lower education			secondary education			higher (non-academic) or academic education			sample
region	n	sample percent	Dutch percent	n	sample percent	Dutch percent	n	sample percent	Dutch percent	n
North	35	16.4%	18.9%	146	68.5%	70.9%	32	15.0%	10.2%	213
East	36	8.4%	18.9% *	297	68.9%	71.0%	98	22.8%	10.1% *	431
West	160	15.8%	19.4% *	635	62.6%	67.6% *	219	21.6%	13.0% *	1014
South	104	20.5%	20.9%	318	62.6%	70.2% *	86	16.9%	8.9% *	508
total	335	15.5%	19.5% *	1396	64.5%	69.90% *	435	20.1%	10.6% *	2166

Table 3-7: Level of education of the mother according to region.
** = Sample percentage outside the 95% confidence interval for the population percentage.*

Despite an increase in level, the large differences in the third group remain too large. With respect to the socioeconomic level it has to be concluded that the sample was not sufficiently representative of the Dutch population. It is, therefore, advisable to check later on whether significant differences can be found between mean values per educational level for important variables in this study. If no systematic effects become apparent, this need not necessarily be considered a conclusion on educational level but instead an indication that stratification of the sample across this socioeconomic variable is not essential for the main results of our study.

3.2.5 Number of children per part of the project

As mentioned before the psychomotor subsample was part of the anthropometric sample. Table 3-8 shows the number of children participating in the different parts of the project.

age [years]	questionnaire parents		body dimensions		force exertion		technical compre-hension		motor performance		physical flexibility	
	boys	girls	boys	girls	boys	girls	boys	girls	boys	girls	boys	girls
2.0– 2.9	81	92	81	92			80	91			81	92
3.0– 3.9	97	86	97	86			97	86			97	86
4.0– 4.9	85	79	85	79	42	46	37	34	21	26	49	48
5.0– 5.9	86	94	86	94	53	59	44	46	39	38	53	59
6.0– 6.9	98	92	98	92	59	57	54	44	40	41	60	57
7.0– 7.9	106	93	106	93	51	42	34	32	40	31	51	42
8.0– 8.9	96	95	96	95	41	40	29	30	31	26	41	40
9.0– 9.9	122	122	122	122	41	42	26	34	30	31	41	42
10.0–10.9	134	136	134	136	36	39	30	30	24	29	36	39
11.0–11.9	143	151	143	151	40	44	29	35	31	31	40	44
12.0–12.9	78	79	78	79	30	23	20	17	26	17	30	23
total	1126	1119	1126	1119	393	392	480	479	282	270	579	572
extra added	67	46	70	47	60	46	56	43	36	24	61	46

Table 3-8: Number of children in each of the parts of the project according to age and sex.

The empty spaces of table 3-8 show, as explained before, that children under the age of 4 years did not participate in all parts of the project. Because a separate psychomotor sample was not drawn for this younger age group, all children in the anthropometric sample participated in the other parts of the project.
At the primary schools the psychomotor sample (for measurement of strength, motor performance, technical comprehension and physical flexibility) was a subsample of the anthropometric sample.

Not all children in this subsample participated in all parts of the psychomotor sample. This was due to differences in amount of time needed for each test. The number of children in each age group (except for age group 12) was larger than the required number of 20, except for motor performance. For this aspect the number of children per age group was less than the required number because motor performance could not be measured in two provinces, due to a lack of observers.

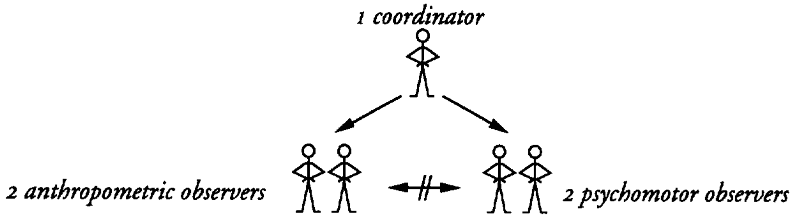
3.3 Teams of observers

The measurement sessions at the schools took place in the period from February 1990 to October 1990. At the Health Centres for Infants and Toddlers the measurements were performed in the period from September 1990 to February 1991.

The measurement teams, mainly students, were recruited regionally and worked in the region they came from. Two teams worked at the same time, each of them in a different region.

A team was divided into three 'sub-groups': two persons performed the body measurements, two others the psychomotor measurements. One person coordinated all activities and did the administrative work.
Within the sub-group that took the body measurements, the tasks were rotated. They all received special training in the performance of these measurements and the use and calibration of the apparatus. These training sessions were given at the universities where the students studied or at the Health Care Centres where the measurement sessions were to take place and were led by Houtkamp and Steenbekkers (Delft University of Technology). This also applied for those who were in charge of the psychomotor measurements. Training of the observers of motor performance, however, was given by the author of the test used (van Rossum, Free University Amsterdam). Tasks were not interchangeable between the anthropometric sub-group and the psychomotor sub-group.

The task of coordinator could be performed by all and this task rotated daily. It was, however, usually performed by one person from the anthropometric sub-group.



At the schools therefore a team of observers consisted of 5 persons. Anthropometric and psychomotor measurements of different children took place simultaneously during school hours.

At the Health Centres for Infants and Toddlers a team consisted of two persons, who could perform all measurements. They too were trained in the relevant aspects of the measurements. Because of the fact that appointments were made with the parents to come to the centres, the coordinator was superfluous.

In total 42 people were involved in the measurement of variables.

4 Selection of the variables and hypotheses

4.1 Introduction

One of the criteria for the variables to be measured in this project was relevance to the design of products, mainly daily-life durables. The reason is that in order to be able to design useful, comfortable and safer products, designers need information on the relevant population, especially data on (physical aspects of) user-product interactions. Or as stated in the concept norm NEN-EN 979: 'The well-being of people is greatly dependent on their geometrical relationship with their clothing, places of work, transportation, homes and recreational activities. To ensure harmony between people and their environments, it is necessary to quantify the size and shape of people for technological design of the work place and home environment' (1992, p.4). With regard to the physical characteristics of Dutch children, data suitable for these design processes are scarce.
Another criterion for the variables was safety for and accident liability of children.

It is believed that the development of physical and psychomotor variables as well as behavioural variables, especially temperamental characteristics, influences the occurrence of accidents involving daily-life products. In order to diminish the likelihood that children will have accidents, it is necessary to gain insight into the development of these characteristics. This knowledge, and above all incorporation of this knowledge in the design process, may contribute to the prevention of accidents in which products are involved. This is especially true for jamming and/or trapping accidents. A child's head stuck between the bars of his bed or playpen is a well-known example of an accident which can be prevented simply by reducing the distance between the bars. For this purpose the minimal breadth of the head of children in the target group has to be known and the product(components) dimensioned accordingly.

A third criterion for the variables in this project was the aim to gain more insight into patterns of development among the different groups of variables. In this connection the basic theory is that development in a population means increasing interindividual variance, implying also more differentiation. Although genetic diversity is phenotypically obvious in a population, the communality of biological and anatomical aspects is –at birth– clearer than that between the more cognitive or psychological aspects. It can also be theorized that the process of individualization of most of the physical and psychological aspects will continue but will be less prominent in the former. The more psychological variables already tend to be diverse from the start and continue to diverge even more during the period of development. This theory is represented schematically in figure 4-1.

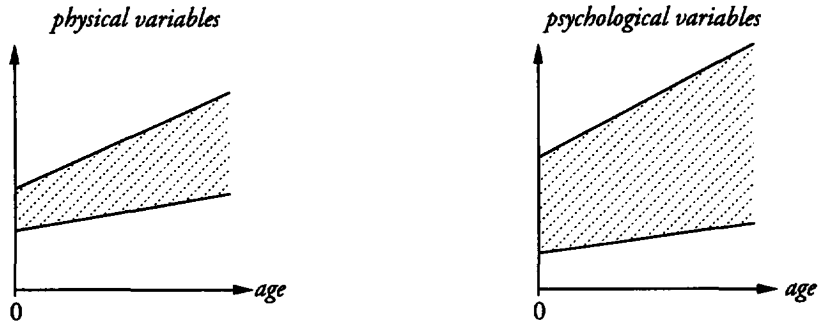


Figure 4-1 Schematic representation of increasing variance in different groups of variables.

4.2 Variables to be measured

4.2.1 Accident liability

The dependent variable in this study was accident liability. In literature this variable is operationalized in different ways. The frequency of accidents is supposed to be dependent on many variables; one of these is the exposure to risks. It is, however, not clear whether children who have certain personality characteristics tend to seek more risks. In this study the operationalization of accident liability is therefore simplified to the estimated frequency of accidents in a certain period of time (in this study during one year), which was judged (more or less unanimously) by parents and teachers. The concordance of judgement determines the degree of accident liability (see chapter 5). This judgement was made by estimating the frequency of accidents for a certain child relative to that of its age peers. It is therefore a relative and intersubjective measure.

The independent variables in this project were those psychological and physical variables (see figure 4-2) which are expected to play a part in the occurrence of accidents or injuries involving daily-life products. This expectation is based in part on descriptions of accidents given by parents of young victims (Steenbekkers, 1989a). The independent variables are described in the following section.

4.2.2 Temperamental characteristics

Temperament is an old concept in psychology. It can be defined as a more or less enduring personality trait, manifested as several observable characteristics. In the present study these are basic individual characteristics containing elements of emotionality, arousal, eagernesss to react immediately including less-socialized behavioural patterns, little regulation of long-term attention etc. and which are underlying behaviour. The preceding in more observable and specific terms also points at the individual ability to chose situations, mostly spontaneously and subconsciously, to estimate the force and direction of movements and to take into account the different effects of movements such that efficiency and effectiveness are maintained and the chances of causing undesirable effects are minimized. This 'temperament' can work more or less consciously and is probably partly learned (nurture) and partly intuitive (nature).

Temperament is likely to influence the occurrence of accidents (Manheimer and Mellinger, 1967). This influence can be two-fold. On the one hand, it is assumed that children who have an impetuous and bold character have accidents, because they do not see or care about risks. On the other hand, it is possible that children who are usually very quiet and attentive may concentrate on a particular situation and therefore do not see the occurrence of a risk in another adjacent situation. Therefore there may be many different relationships, involving various kinds of characteristics and behavioural patterns. The scope of this study did not allow real psychological testing, for example through standardized observations and inventories. It was thought to be sufficient to approach this variable by means of the judgement by parents and teachers of a limited number of items.

4.2.3 Body dimensions and body proportions

A body measurement, defined as the external dimension of one or more segments of the body, may be length, diameter, circumference or mass. A body proportion is the ratio between two body segments, thus describing the dimension of one segment relative to that of another; therefore it is a more complex index of body form or build and its changes.

The growth of children is strikingly perceptible in the increase in their size. The magnitude and rate of this change across age groups are important. Growth refers not only to the whole body but also to body segments.
Various successive national studies on total body height and weight have been performed (Roede and van Wieringen, 1985), but national data on body segments of children are not available or not suitable for a design process. This is the reason the present study was initiated. In addition to stature and body mass, some 38 dimensions were chosen (see chapter 6). These –mainly static– dimensions are often needed in a design –or redesign– process in order to be able to fit a product to the dimensions of future users. The design of school furniture, for example, requires data on popliteal height (height of the seat), buttock-popliteal depth (depth of the seat), hip breadth while seated (width of the seat), elbow height while seated (distance between seat and table top), etc.

4.2.4 Force exertion

Force exertion is defined as the maximum effort of muscle strength exerted on an external object, using different muscle groups in a predefined posture and during a predetermined period of time.

The development of a child becomes clear not only in the growth of its body but also in the exertion of forces. During successive periods of age strength increases. But, again, the absolute magnitude of the forces (as well as the means and variances) that can be exerted by these youngsters is not known.

This information is needed, for example, when designing child-resistant products.
For this reason 8 hand-arm forces were chosen to be measured: pushing, pulling and gripping forces and torque of the hands and fingers (see chapter 7). Of course, other types of force can be exerted, also by other parts of the body, but they are not included in this study because the variables chosen represent the forces needed for manipulation and are to some extent also representative of other body forces (Daams, 1994).

4.2.5 Motor performance

Motor performance can be defined as the extent to which the individual 'process' of changing posture and moving the body as well as use of the hand-arm when interacting with external objects can be judged as being smooth, coordinated and effective.

Motor development obviously takes place during infancy and childhood. Especially during the first years of life this development is very clear since it starts at birth and continues for many years. This development occurs on different levels and in a general sequence: attitudinal, locomotor and manipulative movements (Cratty, 1986). A distinction between gross and fine motor activities could also be relevant (Malina and Bouchard, 1991). It is not known whether and to what extent this development relates to, or even interferes with, the proper use of products. It also is not known whether it influences the occurrence of accidents (for example, stumbling). It is, however, plausible to assume some kind of relationship. This is why this variable was included in this project (see chapter 8).

4.2.6 Physical flexibility

Physical flexibility is defined as the sum of simultaneous, maximal ranges of movement of adjacent joints in a predetermined direction, starting from a standardised position.

Physical flexibility is often thought to decrease during life. Whether it already decreases during childhood or adolescence is not known. Therefore some measurements of the flexibility of the body were taken (see chapter 9). One such measurement was the 'sit and reach' distance, which is used in different studies as a measurement of general flexibility of the body. The second measurement was the ability to rotate along the z-axis of the body while standing.

4.2.7 Technical comprehension, i.e. knowledge of some commonly used compatibility rules

This is the individual ability to recognize and predict causes and effects when manipulating different types of common controls of equipment.

When using a product one has to know how to handle and control it. It is thus necessary to understand both the possible relationships between, for example, a button on the apparatus and the way it has to be controlled and the effect of this operation. This knowledge probably develops by trial and error during childhood. In this project we wanted to establish the extent to which children have already had the opportunity to learn this relationship (see chapter 10). The way in which the child learned was not a subject of investigation.

The above-mentioned variables are presented in figure 4-2 in order to show the conceived relationships between them and the purpose and line of reasoning of the study.

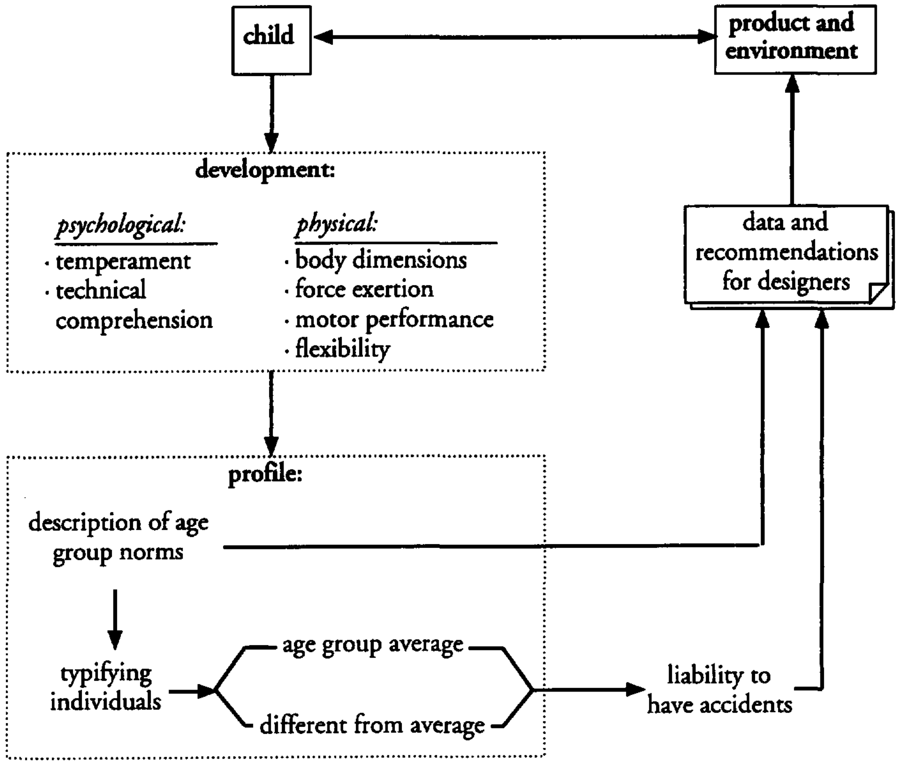


Figure 4-2: Line of reasoning in this project.

4.3 Hypotheses

Several of the main relationships between the various variables are laid down in hypotheses. They will be described and explained below.

Hypothesis 1
The variables investigated in this project were assumed to be interrelated characteristics of individuals, and were expected to have a more or less direct relationship with the phenomenon 'accident liability'. These variables can be assumed to be representative of an individual, in the sense that a more or less constant pattern of characteristics will typify the way in which a person develops. This pattern can be defined by physical as well as cognitive, personality and environmental factors.

The types of variables are numbered as follows:
1. accident liability
2. temperament
3. body dimensions
4. force exertion
5. motor performance
6. physical flexibility
7. technical comprehension.

Hypothesis 1: *There is a positive correlation between the diverse developmental aspects (variables of types 2 to 7).*

This hypothesis presents the idea of a holistic, balanced development.
For each of the groups of variables a representative score will be computed. For body dimensions only selected measurements, representative of body build and determined by a factor analysis will be used.
The total scores for each of the groups, force exertion, motor performance, flexibility and the temperamental characteristics, will be computed from the separate variables in each group.
For technical comprehension the total score will be based on the percentage of correctly performed operations of the controls.

This hypothesis was operationalized by computing the 15 intercorrelation coefficients for the total scores of these 6 'core' variables. The mean correlation of these 15 coefficients has to be significantly ($p < 0.05$, one-tailed) positive, i.e. larger than zero, in order to accept this hypothesis.

This first hypothesis leads to several questions about these correlations:
- are the correlation matrices equal for both sexes;
- are there systematic differences between age groups;
- are there differences between children who are judged to be liable to have accidents and those who are not liable to have accidents.

Hypothesis 2
The 6 groups of variables can also be grouped into four categories, each of them consisting of more or less the same type of variables:
1. *static anthropometric variables:* static body dimensions and force exertion;
2. *dynamic anthropometric variables:* functional body measurements and flexibility;
3. *psychomotor variables:* motor performance and technical comprehension;
4. *personality variables:* temperament as judged by parents and teachers.

The question could be raised which group of variables exhibits a higher internal correlation. If our theory on differences in developmental variance between static, biological variables versus dynamic, psychological variables, as explained in paragraph 4.1, is correct then the internal correlations can be expected to decrease from the anthropometric variables in group 1 towards the personality variables in group 4. The mean correlation between the variables in group 1 plus 2 is expected to be larger than the mean correlation between the variables in group 3 plus 4:

Hypothesis 2: $\bar{r}_{(group\ 1\ +\ group\ 2)} > \bar{r}_{(group\ 3\ +\ group\ 4)}$

Sub-hypothesis 2a
For the variables in group 1 plus 2 the correlations between the static measurements will be larger than those between the functional anthropometric measurements.

In group 3 plus 4 the psychomotor variables will exhibit a higher internal correlation than the personality variables.
The functional anthropometric measurements will in turn have a higher internal correlation than the psychomotor variables. In other words: the intercorrelation, i.e. mutual dependence, of physical variables is greater than that of psychological variables.

This results in the following sub-hypothesis:

Sub-hypothesis 2a: $\bar{r}_{group\ 1} > \bar{r}_{group\ 2} > \bar{r}_{group\ 3} > \bar{r}_{group\ 4}$

Sub-hypothesis 2b

The assumption that the physical component influences the psychomotor component more directly than the personality component leads to another sub-hypothesis:

Sub-hypothesis 2b: $\bar{r}_{((group\ 1 + group\ 2) \times group\ 3)} > \bar{r}_{(group\ 3 \times group\ 4)}$

The mean correlation coefficients per group of variables will be compared.

Hypothesis 3

In literature evidence is given for differences in capacities between boys and girls of the same age. Girls are supposed to be more flexible (Docherty and Bell, 1985) and to have more highly developed motor skills (Malina and Bouchard, 1991), and they are supposed to be less aggressive and impulsive (Rosen and Peterson, 1990). Boys are likely to be stronger (Ager et al., 1984) and to have more technical knowledge (Doornekamp and Stevens, 1989). Until approximately 10 years of age boys are also taller than girls (Tanner, 1990).

This will be tested by means of the next hypothesis.

Hypothesis 3: *The mean scores per age group of the variables physical flexibility, motor performance and temperamental characteristics* are larger for girls than for boys; for the variables body dimensions (until 10 years of age), force exertion and technical comprehension the mean values for girls per age group will be smaller than those for boys.*

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* The scoring of this variable is such that a negative score indicates a more temperamental child and a positive score is a less temperamental child.

T-tests ($p < 0.05$) will be performed to test the differences.

Hypothesis 4

It is already known that children from higher socioeconomic classes are taller than children from lower classes (Roede and van Wieringen, 1985). This may be explained by better nutritional patterns. With respect to cognitive development the expectation exists that children from higher socioeconomic classes are stimulated more to achieve good results both in and outside school.

Hypothesis 4: *Socioeconomic class of the parents influences the physical development of children as well as their technical comprehension.*

The socioeconomic class of the parents is operationalized by subjective assessment of the level of education. Taking into account the insufficient representativeness of the educational levels (see paragraph 3.2.4.), it nevertheless is to be expected that the level of education of the parents will correlate positively with the child's performance of the test of technical comprehension. This relationship is also assumed for the variables force exertion and motor performance and can be tested by correlating the total scores for each of these variables with the level of education of the parents.

Hypothesis 5

The fact that some children are judged more liable to have accidents than other children might be explained by a difference in the pattern of development.

Hypothesis 5: *The correlations between (absolute) deviations from the age group norm for each of the physical plus psychological variables (variables 2 to 7), on the one hand, and the judged liability to have accidents (variable 1), on the other hand, are systematically and significantly different from zero.*

For each child classified as liable to have accidents, the deviation from the mean value for its age group can be computed for each of the physical and psychological variables. The difference in mean (absolute) deviation scores between children who are liable to have accidents and those who are not is expected to be significantly ($p < 0.05$, two-tailed) different from zero for each independent variable.

Children who are liable to have accidents are expected to possess one or more of the following deviations from the mean:

- differently proportioned ($p < 0.05$, two-tailed),
- more or less flexible ($p < 0.05$, two-tailed),
- stronger or weaker ($p < 0.05$, two-tailed),
- underdeveloped psychomotor skills ($p < 0.05$, one-tailed),
- more temperamental ($p < 0.05$, one-tailed),

in comparison to children of the same age and sex who are not liable to have accidents.

It could be, however, that a systematic deviation from the mean value for the age group for all groups of variables represents a state of balance for the child concerned.

Sub-hypothesis 5a: *The predictive value of the variables for the liability to have accidents decreases from group 4 to group 1, meaning that personality factors (i.e. temperament) are more likely to predict the occurrence of accidents than physical variables.*

Hypothesis 6
It could be that older children know when their motor skills are not as highly developed as those of children of the same age and that they will adjust their behaviour to this lower rate of development. This adjustment will, however, require some 'learning' time, which implies that this compensating behaviour will not be apparent until later on. There might be a (short) period of time in which a less skilled motor performance is not yet compensated by a more careful behaviour, but in general the compensating behaviour will exist.

Hypothesis 6: *Retarded motor development will be compensated, to some extent, by a more careful attitude.*

A negative correlation is expected to exist between negative deviations from the age group norm for motor development and the score on temperamental characteristics, as given by the parents by means of the questionnaire.

Hypothesis 7
It could be expected that children in cities with many inhabitants and much traffic are more used to being careful in daily-life. They will show this behaviour also in non-traffic situations. At the same time there seems to be evidence for the fact that children in rural environments have more opportunity to play and thus to learn the capacities of their body, which will encourage them to exceed their bounds and thus take more risks. Therefore the higher the degree of urbanization, the fewer accidents will happen, due to the difference in behavioural characteristics of the children.

Hypothesis 7: *A negative relationship exists between degree of urbanization and the estimated occurrence of accidents.*

This hypothesis can be tested by correlating the judged accident liability with the degree of urbanization of the municipality where the child lives. A one-tailed test for significance has to be applied.

Our first four hypotheses concern general developmental theory, and the last three hypotheses relate to theories on the causation or probability of accidents. The formalized testing of these hypotheses is as important in this study as the collection of design-relevant data representative of all children in the Netherlands.

5 Temperament

5.1 Introduction

One aspect that probably influences the occurrence of accidents is the personality trait called temperament, as defined and described in paragraph 4.2.7. In psychology investigators often make use of questionnaires in order to assess personality traits such as introversion versus extroversion, neuroticism or temperament (Kohnstamm et al., 1989). Sometimes the subject has to complete the form himself but for children this task is often performed by the parents (Oberklaid et al., 1990). Teachers are also asked to fill in questionnaires about children in their classes, because they are supposed to be more objective than parents and they have more opportunity to compare a child with children of approximately the same age.

5.2 Method

The questionnaires are often based on the scale principle, in which the endings of the scale consist of opposite characteristics with 3 or 5 intensities in between. Therefore it is often a 5 or 7-point scale, the midpoint meaning 'neutral' or 'both in equal proportions'. An example is the 'Temperament questionnaire' by Achenbach (1988), which provides a description of the behavioural and emotional problems of a child.

To obtain an idea of the temperamental characteristics of a child that might possibly be related to risk-taking behaviour and the occurrence of accidents, we designed a questionnaire based on 5-point scales; 7-point scales were supposed to be over-accurate and too difficult to complete.
There were three versions of this questionnaire. The first version included 9 items. As a result of the use of this questionnaire in one school and analysis of the data, it was enlarged to include 14 items; this was the second version. In the final, third version one item was replaced by another, because it was too evident that it related to accident liability, which was to be judged.

Some items were taken from other questionnaires and adapted, others were our own choice. The 'positive' and 'negative' extremes of the scales were placed alternately to the left and the right side of the scale in order to avoid automatism when completing the questionnaire.

The choice of the items was based on characteristics that may lead a child to choose or avoid potentially hazardous activities. A child, for example, who is impulsive may be less able than other children to judge a situation in time to avoid an accident. Traits such as carelessness and restlessness may impair the child's ability to cope with hazards. Clumsiness can also be related to accident liability as well as (lack of) proficiency in athletics (Manheimer and Mellinger, 1967). Bijur et al. (1988) use the words 'aggression' and 'overactivity', consisting of 8 and 3 characteristics, respectively in relation to the prediction of injuries.

Figure 5-1 shows the items used.The versions in which each item was used and the original Dutch text are given in parentheses.

version	item		1 2 3 4 5	
(1 2 3)	1	very dexterous *(zeer handig)*	☐☐☐☐☐	very clumsy *(zeer onhandig)*
(1 2 3)	2	impulsive *(impulsief)*	☐☐☐☐☐	prudent *(afwachtend)*
(1 2 3)	3	able to concentrate *(geconcentreerd)*	☐☐☐☐☐	easily distracted *(gauw afgeleid)*
(1 2 3)	4	careless *(onvoorzichtig)*	☐☐☐☐☐	cautious *(voorzichtig)*
(1 2 3)	5	calm *(rustig)*	☐☐☐☐☐	restless *(onrustig)*
(1 2 3)	6	takes risks *(neemt veel risico)*	☐☐☐☐☐	takes no risks *(neemt geen risico)*
(1 2 3)	7	never stumbles *(struikelt nooit)*	☐☐☐☐☐	stumbles often *(struikelt erg vaak)*
(1 2)	8	accident-prone *(krijgt vaak ongelukjes)*	☐☐☐☐☐	not accident-prone *(krijgt nooit ongelukjes)*
(1 2 3)	9	lithe/flexible *(lenig)*	☐☐☐☐☐	cramped *(stijf)*
(2 3)	10	impetuous *(onstuimig)*	☐☐☐☐☐	controlled *(beheerst)*
(2 3)	11	anticipates *(kijkt en denkt vooruit)*	☐☐☐☐☐	is unprepared *(meestal onvoorbereid)*
(2 3)	12	lively/excitable *(doenerig en druk)*	☐☐☐☐☐	retiring *(stil en teruggetrokken)*
(2 3)	13	self-confident *(vol zelfvertrouwen)*	☐☐☐☐☐	uncertain *(onzeker)*
(2 3)	14	takes no initiatives *(neemt weinig initiatief)*	☐☐☐☐☐	adventurous *(zeer ondernemend)*
(3)	15	balanced character *(evenwichtig karakter)*	☐☐☐☐☐	easily unbalanced *(snel uit balans)*

Figure 5-1: Items of the questionnaire.

The questionnaires were handed out to children in primary schools. They were asked to give it to their parents and bring the completed form back to school. It is not known whether father or mother or both completed the questionnaire. For children under 4 years of age, the parents (in all cases but one the mother) were asked to complete the questionnaire when they came with their child to the health centre to participate in other parts of the investigation.

The parents had to indicate the extent to which a certain characteristic was manifest in their child by scoring each item.

The number of completed questionnaires returned was:

version 1: 1049
version 2: 910
version 3: 3252

The overall response was 68.7 %.

Teachers too were asked to fill in a questionnaire for some (6 - 8) randomly chosen children in their class. If we had asked them to complete a questionnaire for each child in their class, they probably would not have participated. Furthermore, the headmasters of the schools generally did not allow us to ask about more children.
The questionnaire for the teachers was equal to version 3 of the questionnaire for the parents. The teachers completed 755 questionnaires.

It may be said that this questionnaire has face validity. The items seem to indicate characteristics that, generally speaking, can be assumed to be related to, or constitute, temperament.

5.3 Analyses

Different analyses were applied to the three versions of the questionnaire in order to be able to compute a total score for temperamental characteristics, which could then be used to calculate, for example, correlation coefficients relating temperament to other variables such as motor performance and technical comprehension as part of the pattern of development. First, however, the data had to be checked for completeness and reliability.

5.3.1 Missing data

Generally speaking the questionnaires were completed in full. On 11 forms, however, the number of missing answers was unacceptable (more than 3 out of 9 or more than 5 out of 14). These forms were excluded from analysis. When there were fewer than 3 or 5 missing values, the missing value was filled in using the value for a completed item that correlated best with the missing item.

In addition, two questionnaires were excluded because all items had the same (extreme) value: all 1 or all 5. This implies that the questionnaire probably was not taken seriously.

5.3.2 Inter-judge correlations

Version 3 for the parents was equal to the questionnaire completed by the teachers. Thus it is possible to establish the inter-judge reliability at the item level. Item 8 was not present on these questionnaires. For the other items the correlation coefficients between the judgement of the parents and that of the teachers can be computed. The results were (n = 755):

	correlation coefficients
item 1	0.2482
item 2	0.4511
item 3	0.5290
item 4	0.3836
item 5	0.4844
item 6	0.4027
item 7	0.2183
item 8	–
item 9	0.3459
item 10	0.4326
item 11	0.3395
item 12	0.4578
item 13	0.2713
item 14	0.2738
item 15	0.2348

Although the values are low, all correlation coefficients are significantly positive, indicating that parents and teachers judged a child in the same direction; the low values may imply that the basis of comparison was different, probably due to differences in professionalism, use of different reference groups or involvement.

5.3.3 Test-retest reliability

Some parents and teachers completed version 3 of the questionnaire a second time, approximately one month after the first time. This enabled us to assess the intra-judge reliability at the item level. The correlation coefficients between the first and the second round were:

	parents (n = 328)	teachers (n = 147)
item 1	0.5480	0.5964
item 2	0.6562	0.7256
item 3	0.7058	0.7307
item 4	0.6883	0.6756
item 5	0.7076	0.7639
item 6	0.6158	0.6548
item 7	0.6086	0.5803
item 8	–	–
item 9	0.7602	0.7156
item 10	0.6511	0.7861
item 11	0.5383	0.6773
item 12	0.7080	0.7909
item 13	0.6880	0.6631
item 14	0.6497	0.4723
item 15	0.6249	0.5114

All correlations are significant; the reproducibility of the questionnaires was, however, rather low in comparison to general scientific requirements. For 8 out of 14 items, the teachers scored more consistently than parents. This suggests that teachers are slightly more consistent as judges.

5.3.4 Reliability analysis

With the help of standardized item scores, a reliability analysis of the total questionnaire was performed using the questionnaires for the teachers. When all items (n = 14) were included Cronbach's α equalled 0.8952. When items 1, 9 and 13 were excluded α increased to 0.9132.

For the questionnaires filled in by the parents α also increased when items 1, 9 and 13 were deleted. The values of α for the three versions are listed below; the value of α for all items is given in parentheses:

version 1: 0.7938 (0.7921)
version 2: 0.8586 (0.8450)
version 3: 0.8430 (0.8222).

These values indicate that the tests were sufficiently reliable to play a role in this study. To some extent this reliability also supports their validity, since apparently some consistent trait was being judged.

5.3.5 Factor analyses

For each of the three versions of the questionnaire for the parents, factor analysis (Principal Component) was performed in order to be able to compute a total score based on factor loadings. Factor analysis on the first version yielded a principal factor, explaining 37.6% of the variance; in the second version the factor explained 33.4% and in the third version 30.9% of the variance. All analyses revealed very low factor loadings (between 0.001 and 0.08) for three items: 1, 9 and 13. These 3 therefore had to be deleted.
Could plausible, ad hoc explanations be given on why these items had to be removed? For the item 'dexterous – clumsy' its removal is rather unexpected, because this item seems to fit wel conceptually. This is somewhat different for 'lithe – cramped', which is less operational than the former. This second, however, will be assessed separately and more empirically and will be tested on its relationship with accident liability.
Could it be, however, that these motor skills in the causal road towards accidents are being compensated for? Remains the question why this does not occur with the items which we kept. For the removal of item 13 'self-confident – uncertain' an explanation might be that both ends relate to high risk and only the middle to low. Actually no clear picture emerges, but it was anyhow advisable to go on with a more homogenous set of items.

The remaining items were subjected to another factor analysis. These analyses yielded two or three factors per version of the questionnaire; however, they were not interpretable. Therefore the one-factor solution was chosen as a basis of interpretation.
The factor analysis (Principal Components, one factor solution) for version 1 (items 2 to 7) yielded one factor, explaining 44.4 % of the variance. Version 2 (items 2 to 7, 10 to 12 and 14) also resulted in one factor, explaining 39.3 % of the variance. The one factor of version 3 (items 2 to 7, 10 to 12, 14, 15) explained 36.4 % of the variance.

The factor loadings for the questionnaires filled in by the parents and the teachers were quite similar, although those for the parents were somewhat more divergent. Therefore the factor loadings resulting from the factor analysis of version 3 of the questionnaires, containing items 2-7, 10-12, 14, 15, for both parents and teachers were used to compute the total score. This was done as follows: all item scores left can be standardized with mean 0 and standard deviation 1. The standardized scores were multiplied by the factor loadings and then added. This yielded a standardized total score. In this way the computed scores for parents and teachers were comparable. The factor loadings used to compute the total score for each version of the questionnaire were:

	version 1	version 2	version 3
item 1			
item 2	1.7191	1.3948	1.5130
item 3	-1.6113	-1.0820	-1.2424
item 4	2.5127	1.6562	1.7527
item 5	-2.1531	-1.6308	-1.8254
item 6	2.2253	1.5959	1.6015
item 7	-1.8372	-1.1149	-0.9379
item 8			
item 9			
item 10		1.7078	1.8534
item 11		-1.1896	-1.3260
item 12		1.5923	1.5647
item 13			
item 14		-0.8325	-0.8328
item 15			-0.8946

The total score had a range of -30 to +30.
A total score equal to zero indicates that a child's temperament is 'neutral', meaning that the child does not exhibit characteristics or behaviour that is likely to influence the occurrence of accidents. A negative score indicates a more 'negative' behaviour pattern with respect to the supposed relationship with the occurrence of accidents. This implies characteristics such as taking risks, being careless or impetuous. A positive total score points towards more 'positive' behaviour, implying good powers of concentration, being careful, calm and controlled. This behaviour and these characteristics may keep children from having accidents.

5.3.6 Analysis of variance

In order to analyse possible differences in the judgement of parents between the different versions of the questionnaire, analysis of variance of the scores of the parents per version was performed. It showed a significant difference between the mean scores for version 1 and version 3 ($F = 5.7006$; $p = 0.0034$).
This implies that the three versions of the questionnaire did not yield the same results, so that combination of the scores for the different versions is not entirely justified. Despite these differences the scores will nevertheless be combined in subsequent analyses, as explained next, because the range of the scores is almost the same.

5.4 Results

5.4.1 Scores

The results refer to analysis of the questionnaires on children who also participated in other parts of the investigation (measurement of body dimensions, force exertion, motor performance, physical flexibility and technical comprehension).
The number of questionnaires of each version used to compute a total score, which can be related to the other groups of variables in this project, was:

version 1:	588	out of	1049;
version 2:	294	out of	910;
version 3:	1481	out of	3252.

In a histogram the distribution of the scores of the parents who judged their child's temperamental characteristics is presented. A similar histogram shows the distribution of the scores of the teachers.

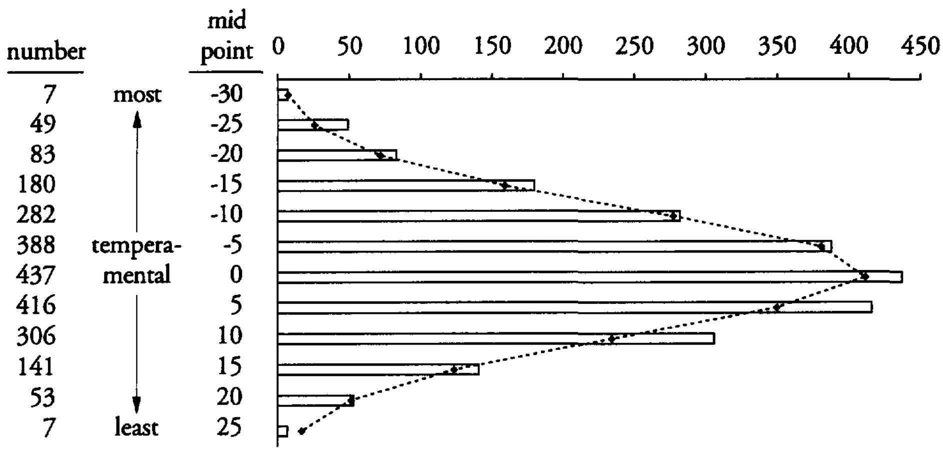


Figure 5-2: Histogram of the total scores by parents on temperament.

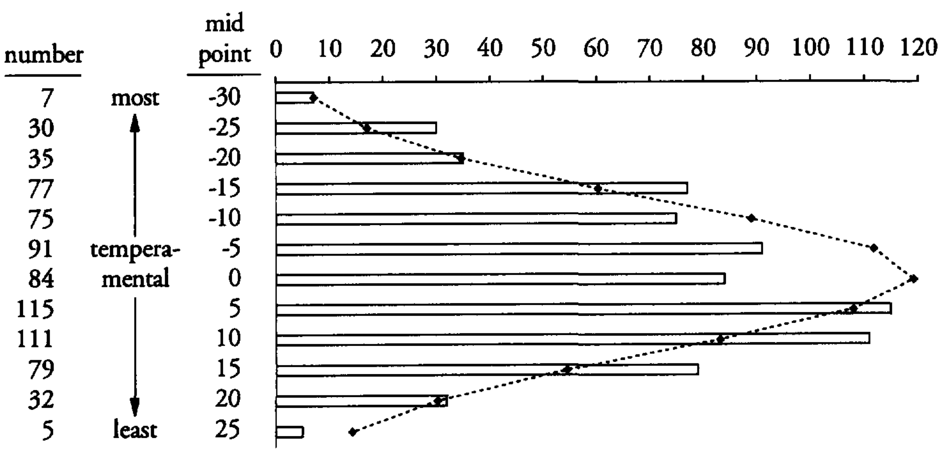


Figure 5-3: Histogram of the total scores by teachers on temperament.

Both histograms indicate that the scores were reasonably distributed over the attainable range, although slightly skewed to the right when compared with the normal distribution (the points and dashed line in the histogram).

The correlation between the total scores of parents and teachers, when judging the same child, was 0.6015 which is significant and allows for the not unexpected difference in opinion between 'family and professional'.

The minimum, mean and maximum scores per age group are listed in table 5-1.

age	score parents			score teachers		
[years]	min.	mean	max.	min.	mean	max.
2.0 – 2.9	-26.90	-2.04	19.28			
3.0 – 3.9	-26.72	-1.59	22.90			
4.0 – 4.9	-25.45	-3.05	18.98	-29.89	-1.49	24.62
5.0 – 5.9	-29.26	-2.86	19.69	-29.00	-0.28	23.04
6.0 – 6.9	-23.26	-1.91	21.79	-28.18	0.27	22.49
7.0 – 7.9	-29.26	-1.59	23.19	-26.71	-0.65	23.26
8.0 – 8.9	-26.34	-1.53	21.27	-28.24	-1.31	18.23
9.0 – 9.9	-28.18	-0.11	22.68	-28.18	-2.67	20.39
10.0 – 10.9	-24.25	0.87	24.62	-27.35	1.82	24.27
11.0 – 11.9	-29.26	1.38	23.93	-29.00	-0.95	18.87
12.0 – 12.9	-18.63	0.51	23.24	-20.88	2.29	16.78

Table 5-1: Mean score on judged temperament and range in score for parent's and teacher's questionnaire according to age group.

The tables show hardly any differences in score between the various age groups, although the mean scores exhibit a slight overall increase. The lack of difference between age groups is illustrated in figure 5-4.

One-way analysis of variance revealed no significant differences between the various age groups for all children together. When the data on boys and girls were analysed separately, using the Scheffé Multiple Range test, a difference was found only for girls 2, 4 and 10 years of age. None of the other age groups differed significantly. This is not completely surprising, since the judgements were actually given relative to age peers according to instructions. This nevertheless did not exclude beforehand some indication of an age effect.

However, when the values for boys were compared with those for girls, the results were quite different. Figure 5-5 shows that the mean values per age group for girls were always higher than those for boys.

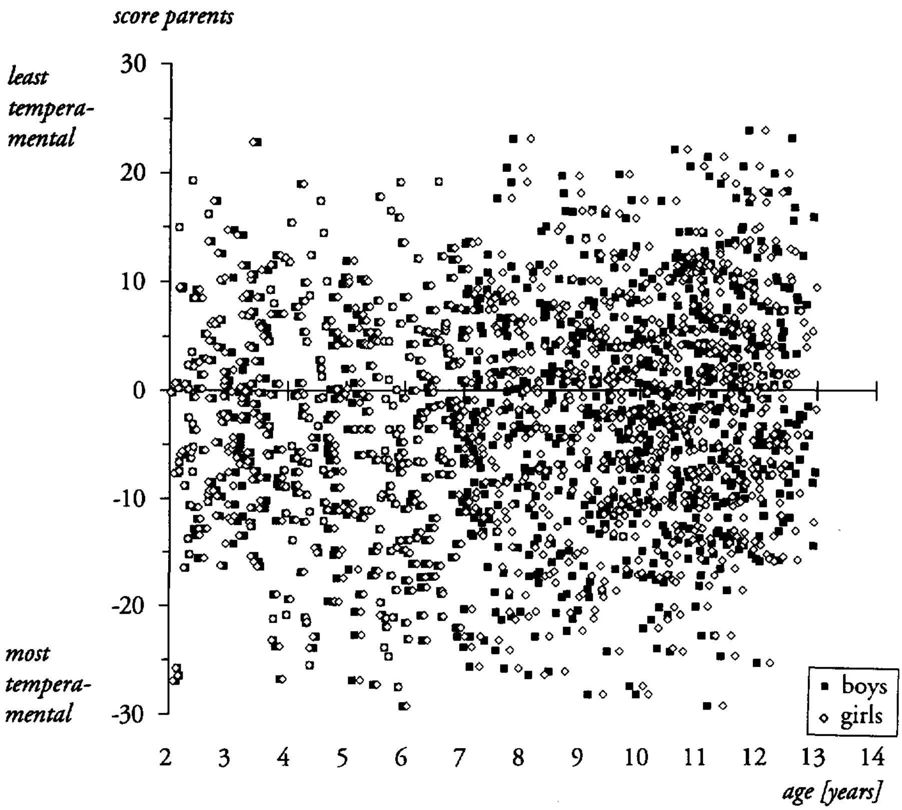


Figure 5-4: Scores on temperament by the parents according to age of the child.

5.4.2 Accident liability

The questionnaire also included a separate question for both parents and teachers about whether the child was liable to have accidents. The question to the parents was formulated as follows: Are you of the opinion that your child has more or less serious accidents more often than usual. (In Dutch: 'Bent u van mening dat uw kind vaker dan gebruikelijk is, allerlei ongevalletjes overkomt?') Teachers had to indicate which children in their class had more accidents than other children of the same age.

When both parents and teachers agreed, a child was indeed assumed to be more liable to have an accident. These children were, according to hypothesis 5, expected to have a negative score on the questionnaire. When only the parent or the teacher said that a child had more accidents, its liability was considered to be doubtful. The number of children in each category is listed in table 5-3.

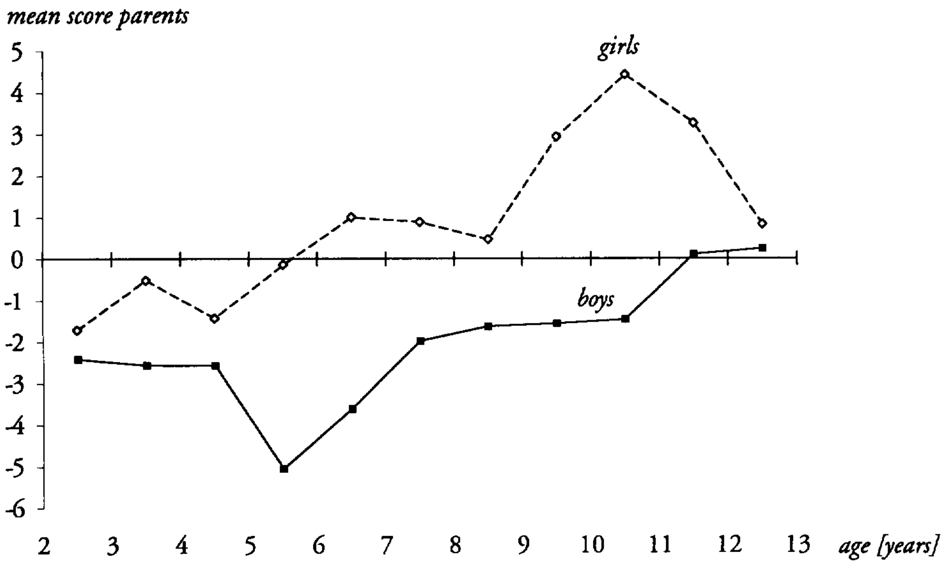


Figure 5-5: Mean score on temperament by parents according to age group and sex.

age [years]	absolutely not boys	absolutely not girls	doubtful boys	doubtful girls	absolutely boys	absolutely girls
	liability to have accidents					
4.0 – 4.9	33	37	10	4	5	3
5.0 – 5.9	30	41	12	10	4	1
6.0 – 6.9	39	34	12	6	2	5
7.0 – 7.9	29	31	11	6	10	5
8.0 – 8.9	23	26	11	13	6	1
9.0 – 9.9	23	29	16	6	5	2
10.0 – 10.9	26	29	13	5	3	3
11.0 – 11.9	20	27	11	7	3	6
12.0 – 12.9	18	17	6	2		

Table 5-3: Distribution of children according to accident liability and age.

The fact that the same parent had to answer questions on both temperament and accident liability of the children may have resulted in contamination of or spurious correlations between the answers. For the teachers, however, the two kinds of questions were not asked at one go, so here this effect is probably minimal. Because of the relatively large correlation between the scores of parents and teachers on the questionnaire, we assume that this effect of contamination in the questionnaires of the parents has been not of a size to reject the data.

Now a preliminary analysis can be carried out on the question whether judged temperament and accident liability as judged are indeed related. In the next two tables data on judged temperament are given according to sex and 'liability group' seperately for parents and teachers.

liable to have accidents	boys n	boys min.	boys mean	boys max.	girls n	girls min.	girls mean	girls max.
	score parents							
absolutely not	241	-27.48	-1.62	23.19	271	-28.18	1.83	22.18
doubtful	102	-28.18	-10.87	19.13	59	-29.04	-5.50	19.20
absolutely	38	-28.17	-11.94	12.27	26	-29.26	-8.08	8.33

Table 5-4: Mean score on temperament and range of scores by parents according to accident liability and sex.

liable to have accidents	boys n	boys min.	boys mean	boys max.	girls n	girls min.	girls mean	girls max.
	score teachers							
absolutely not	241	-27.06	-1.16	24.62	271	-20.33	6.00	24.27
doubtful	102	-29.89	-9.30	15.44	59	-29.00	-2.90	18.23
absolutely	38	-29.89	-12.76	9.84	26	-21.51	-8.51	17.51

Table 5-5: Mean score on temperament and range of scores by teachers according to accident liability and sex.

Generally speaking the scores for boys were lower (more temperamental) than those for girls, and the children who were absolutely liable to have accidents received on the average lower scores than children who absolutely were not liable to have accidents. This was true for all ages (see figure 5-6).

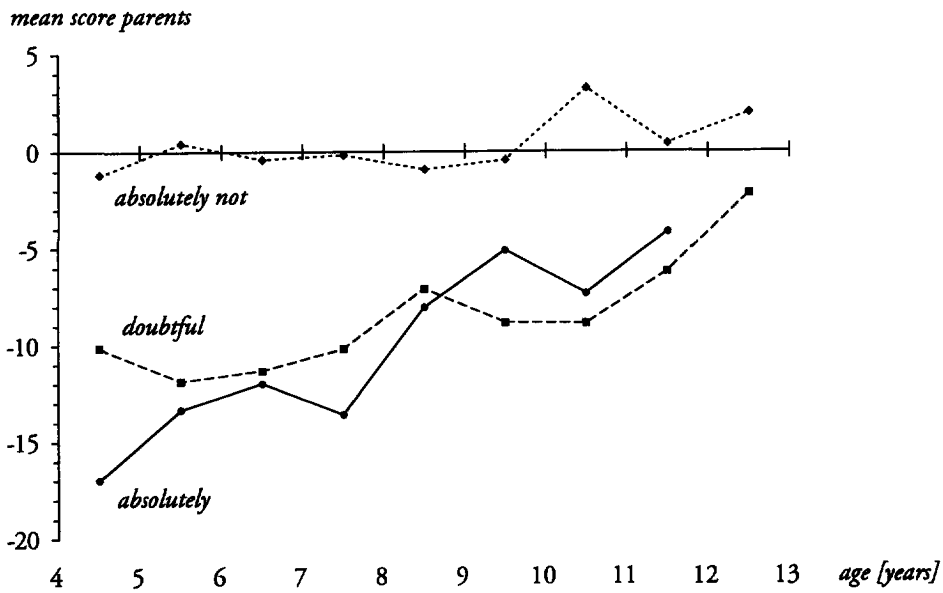


Figure 5-6: Mean score on temperament by parents according to accident liability and age.

These differences were tested by means of t-tests, used to test mean values. It appeared that there was a significant difference in mean score on temperament between children who absolutely were not liable to have accidents and the two other groups: those who were

absolutely liable to have accidents and the doubtful group. This applied to both boys and girls and for the scores by both parents and teachers.
There were no significant differences in score between the children who are liable to have accidents and the doubtful group.

These results are also an indication of the validity of the questionnaire, because they confirm that it does differentiate between the various accident liability groups.

5.5 Conclusions

5.5.1 Questionnaire to judge temperament

The questionnaire is assumed to provide insight into the temperamental characteristics of children, especially characteristics that may influence the occurrence of accidents.

The fact that there were three versions of the questionnaire is to be regretted. It would have been better to have used just one but that was not possible: given the amount of time available for this project, it was necessary to develop the questionnaire during the actual sampling period.
The results of the analyses suggest that version 2 is the most reliable one. The other two were, however, still worthwhile and could therefore also be included in the analyses.

5.5.2 Results

The results show that the questionnaire can be regarded as a reliable instrument for measuring temperamental characteristics that are related to accident liability. It differentiates between boys and girls, confirming the generally accepted rule that boys tend to show off and behave more 'carelessly', while girls concentrate more and are more careful. To what extent the judges also followed this rule remains uncertain.
The scores also increase with age. This suggests that older children more often behave in a way that is less likely to lead to an accident, which points towards the fact that they, possibly, know which behaviour is more dangerous and tend to take only 'acceptable risks'.
The above-mentioned facts fit the data on accidents among children: the number of accidents decreases with increasing age.

With respect to judged accident liability, the questionnaire may indeed differentiate between children who are and are not liable to have accidents. The children who are liable to have an accident, as assessed by parents and teachers, exhibit more 'negative' behaviour than children who are not at all likely to have an accident.

6 Body measurements

6.1 Introduction

The physical development of children becomes manifest as an increase in body size. Especially in the foetal stage this increase is enormous, but it remains apparent after birth. The growth rate decreases during childhood. At the beginning of puberty a growth spurt can again be seen, resulting in the individual's maximum adult height. During the latter years of adulthood the attained height diminishes slowly (Tanner, 1990).
Growth of the right and left sides of the body is more or less symmetrical. It varies, however, per (pair of) body segment(s) as well as per period of life. This results in different proportions of the body during various stages of development, which probably influences the pattern of movement. Whether this is true, and if so in which period of life, is not very clear. This is one reason why the body dimensions of children, in addition to other physical characteristics such as force exertion and motor performance, should be investigated.

Data on the physical characteristics of children are important for designers and manufacturers of daily-life products used by children. In order to be able to adjust products to the users, several characteristics of their physical capacities have to be known. Especially the variation in dimensions within an age group is important, for example, for the adjustability of products. This knowledge is often needed to make a product suitable for use, in a comfortable manner, by a large group of users.
During the several phases of growth a correct sitting posture, for example, is very important. This will contribute to the prevention of complaints of the musculoskeletal system, which may not become manifest until much later in life.
A second reason for needing to know body dimensions is safety. Proper application of this knowledge will possibly result in a decrease in, for example, entrapment accidents due to the improper design of products.

Another aspect of the study of body dimensions is the positive secular trend, which has been recognized during the past decennia (van Wieringen, 1972). A positive secular trend is defined as an increase in mean body height among persons of the same age of successive generations. Whether this increase is equally distributed over the whole body or only in certain segments is not completely known as yet. In order to be able to determine the exact distribution of the increase in body height over body segments, it is necessary to conduct this kind of investigation about every ten years.

Various body dimensions of children between 2 and 13 years of age were selected for measurement. The choice of this age range was based on two practical considerations, as already mentioned in the introductory chapter. The first reason was the fact that the lower age groups of this range visit health care centres for infants and toddlers and the rest attend primary school. The second reason was that only one method of measurement had to be used, because all of the children in these age groups are able to stand and sit without help. This does not apply if younger age groups are included because they have to be measured in supine position. The results of such measurements cannot be compared directly with the results of measurements of a child in the standing position. Furthermore, as part of a pilot study (Steenbekkers, 1989b), children between 0 and 18 months were measured in the supine position. To enlarge the age range towards age 0 these data have been included in appendix A, despite the fact that the children came from just one province of the Netherlands.

6.2 Principles governing the choice of measurements

In this study the following principles formed the basis of the choice of body dimensions to be measured:

1. *The data had to be suitable for use by designers during the design process.*
   If a daily-life product is to be suitable for use in a comfortable and safe way by members of the target group of users, a designer has to take into account the distribution of the physical characteristics of these intended users (Steenbekkers and Molenbroek, 1990). One aspect is the body dimensions of these users. For products that are manufactured in series (and thus are not designed for just one person), it is impossible to know all of the specific characteristics of each individual future user. Therefore, a random sample of the population of possible future users has to be measured to be able to estimate the (variation in the) dimensions of the entire population. For Dutch children, however, very little design-relevant data of this kind are available.
   The choice of the variables measured in this study was based upon their relevancy to the design of products for children and on the dimensions which influence child-product interaction (Steenbekkers, 1989b). In this respect safety criteria are of major importance. Evaluation of descriptions of accidents and near-accidents involving products can reveal those measurements which should be incorporated in the design to reduce the possibility of causing accidents (Steenbekkers, 1989a).

2. *Combinations of the measurements had to provide insight into the proportions of the body.*
   It is expected that changes in the proportions of the body influence motor behaviour. Measurements that when combined provide an indication of body build, such as length of the legs relative to length of the trunk, etc., should be included in this study. In addition, these relationships yield more insight into general auxology.

3. *Reproducibility of the measurements and the facility of measurement had to be acceptable.*
   A third principle guiding the choice of measurements was reproducibility and the facility of measurement. Especially for 'fleshy' dimensions (such as thigh thickness) it is known that the extent to which the tissue is depressed can lead to marked variations in measurements, which will influence their reliability and reproducibility. Some of these dimensions, however, cannot be left out, because otherwise an incomplete picture will be obtained. In comparison to static measurements, the reproducibility of functional measurements (such as step height, reaching height, etc.) is not very good. For such measurements the motivation of the person to be measured and the skill of the observer are very important and might interfere with objectivity. The facility of measurement is also a criterion. A certain measurement may be very useful in the design process, but when it appeared to be rather cumbersome or difficult to measure (for example, the distance between the ischial bones) unless very specialised and expensive equipment was used, the dimension was not included in this project. All anthropometric measurements in this project were recorded in millimetres, except for body weight which was measured in hectograms.

4. *The measurements should enable one to predict by means of computation other anthropometric dimensions.*
   Not all conceivable dimensions of the human body can be measured within a limited period of time. This is also not necessary, because some dimensions can be calculated fairly accurately from other dimensions. For example: the elbow height standing can be calculated by subtracting the elbow height sitting from the sitting height, and then subtracting this result from the stature. Multiple regression analysis can also be used to predict certain dimensions.

5. *Some of the measurements are mentioned in standards and laws, e.g. the Children's Toy Act and the Children's Bed and Playpen Act (Warenwet, 1985).*
   Some laws and standards for daily-life products give the required dimensions of a product, based on expected dimensions of (parts of) the body of the members of the target group. These dimensions have, however, rarely been determined by empirical measurement of a sample of the target group. Whenever possible these measurements were collected in this project in order to be able to verify the dimensions laid down in several laws and standards.

6.3 Choice of body dimensions to be measured

A comparison of the results with data from other sources requires comparable measuring methods. This can be one reason for choosing a specific measurement method. The requirement of comparability influenced the choice of measurements. The measurements finally chosen are listed below.
The identification of the measurements in other anthropometric sources is also given: these sources are the Dutch standard NEN 2736 (1987); the German standard DIN 33402 (1981); Anthropometric Source Book (ASB) (1978); Snyder (1977). When no numeral is listed the dimension is not included in the sources. Most measurements are static. Some, however, are measured in functional postures. They are denoted with '*' in table 6-1.

On the basis of the criteria discussed above 40 dimensions were chosen to be measured.

1. *Relevant to product design.*
   All of them are, in principle, useful for designers of products.

2. *Proportions.*
   A measurement of the dimension of a whole body segment can be used to compute body proportions too. An example is shoulder height sitting, which might be used as a measure of trunk length. When shoulder height sitting is divided by stature, it yields a value for trunk length relative to whole body length.

3. *Reproducibility and facility.*
   Although it is known that the reproducibility of measurements taken in functional postures is less than the reproducibility of those taken in static postures, some functional dimensions have been included in the list of measurements because these measurements in particular are required during the design process. The same applies to the somewhat 'fleshy' dimensions.

		NEN 2736	DIN 33402	ASB	Snyder
standing:					
1	body mass	5.1.1	-	957	1
2	stature	5.1.2	1.4	805	2
3	shoulder height	5.1.5	1.6	23	-
4 *	reaching height	-	1.3	911	3
5 *	step height	-	-	-	6
6	shoulder breadth	-	-	122	35
7	breadth across elbows	5.4.8	2.12	318	-
8	hip breadth	5.4.6	1.11	457	72
9	breast depth	5.1.9	1.2	236	-
10	head length	5.3.8	5.3	441	20
11	chin-crown length	-	-	-	-
12	head breadth	5.3.9	5.5	427	19
13	head height	-	5.4	595	25
14	foot breadth	5.3.7	4.2	356	87
15	foot length	5.3.6	4.3	362	86
sitting:					
16	hip breadth	5.4.7	2.13	459	11
17 *	reaching height	-	-	912	-
18	arm length	5.4.1	1.1	752	4
19 *	reaching depth	-	-	-	-
20	buttock-foot length	-	2.1	191	-
21	sitting height	5.2.1	2.1	758	9
22	eye height	5.2.2	2.2	330	10
23	shoulder height	5.2.3	2.3	25	-
24	elbow height	5.2.4	2.4	312	-
25	thigh thickness	5.2.9	2.11	856	13
26	buttock-popliteal length	5.4.10	2.8	200	-
27	buttock-knee length	5.4.11	2.9	194	14
28	popliteal height	5.2.8	2.6	678	-
29	instep height	-	-	-	-
30	knee breadth	-	-	-	-
measurements of the hand:					
31	hand breadth	5.3.2	3.19	411	48
32	hand length	5.3.1	3.15	420	47
33	middle finger length	-	3.11		55
34	little finger breadth	-	3.2	-	-
35	thumb breadth		3.16	-	52
36	hand thickness	-	3.17	423	-
37	hand diameter				49
38	grip circumference	-	-	-	-
circumferences:					
39	head circumference	5.3.10	-	430	18
40	upper arm circumference	-	-	113	-

Table 6-1: Measurements listed in other anthropometric sources.
** = functional postures*

4. *Calculation of other dimensions.*
   Calculation of other anthropometric measurements is mainly possible when the dimension is part of the standing or sitting position. (Mean) elbow height standing, for example, which is not included in the list of 40 dimensions but might be required by designers, can be determined as follows: mean stature minus mean sitting height plus mean elbow height sitting. To determine percentile values, the variance of each dimension and the correlations between variables have to be known.

5. *Mentioned in standards and laws.*
   Measurements mentioned in standards and laws are mainly related to crushing accidents; therefore those parts of the body which can be crushed between the parts of a product (e.g. little finger, hand or foot) were also measured.

6.4 Methods of measurement

Determination of the methods of measurement of the above-mentioned dimensions was based on existing methods in order to be able to compare our results with data from other sources. The sources were: the Dutch Standard NEN 2736 (1987), the German standard DIN 33402 (1981), Anthropometric Source Book (1978) and Snyder (1977). When no definition could be found in these sources, we adopted our own method of measurement.

The measurements were taken in the prescribed standing or sitting position (appendix B). Starting point for the standing position was a person standing fully erect in free space, the head in the Frankfort Plane. The latter means that the lowest margin of the left orbit and the upper margin of the outer cavity (tragion) of both ears lie in the horizontal plane. The child was therefore not allowed to stand against the wall, because this posture is less 'natural'. In the seated position the angles between the relevant segments were 90 degrees. This posture could be achieved by placing the child in a measuring chair: a cubical chair with adjustable back and footrests. These rests were adjusted in such a way that the child was in the required position.
Measurements that could be taken on either side of the body were taken on the right side. During the measuring session the children wore a t-shirt and shorts and were barefoot.

A session lasted between 10 (for a 12-year-old child) and 30 minutes (for a 2-year-old toddler), depending on the cooperation of the child. The measurements were taken by trained measuring teams, consisting of 3 individuals: an observer, a secretary and an organizer. All tasks could be performed by all members of the team, and roles were rotated regularly. During a two-day training programme they received information on the project and instruction on use of the apparatus and the methods of measurement. Furthermore attention was directed toward the social intercourse with the children. They spent considerable time practising the measurements, on both adults and (young) children, to increase both their measuring skills and their accuracy.

6.5 Apparatus

The apparatus used were:

1. *Digital scale*
   The digital scale was a 'TEFAL' with a range between 0 and 129 kg. Accuracy was plus or minus 0.5 kg. Before, during and after each measurement period the scale was calibrated, using standard weights.

2. *Automated anthropometer for height and depth measurements*
   The anthropometer for height and depth measurements was designed and made in our laboratory. The frame consisted of three aluminium u-shaped profiles with a toothed rack along the inside, which could be coupled to make different lengths. A holder with a cogwheel (figure 6-1) could be moved along the frame. Inside the holder was a sliding part consisting of miniature ball-bearings, in order to ensure free movement without cross-play. The cogwheel was coupled to a system called the shaft decoder. In the shaft of the decoder was a small disk with grooves. The frame of the holder included a small lamp on one side and a photoelectric cell on the other side. In between the lamp and the photoelectric cell the disk rotated. Behind the photoelectric cell was a counter which counted the pulses caused by the light passing through the grooves of the disk. The number of pulses was a measure of the distance covered; by means of the switch box, this number was automatically entered into the computer. In essence, therefore, the shaft decoder measured the movement of the holder relative to the frame electronically .
   A ruler was attached at 90 degree angle to the holder; it was made of brightly-coloured plexiglass and looked like a hand. Height measurements were measured relative to the floor, the seat of the measuring chair or the footrest by placing the lowest point of the anthropometer, fastened to a square plate to increase stability, on the surface and keeping the anthropometer vertical. The point on the body which had to be measured was indicated by the ruler. For depth measurements the square plate of the anthropometer was placed against the back of the measuring chair.
   The accuracy of this anthropometer over the entire range of 2100 mm was plus or minus 1 mm. This was determined by calibration of the system at 5 equally distanced and known points of the anthropometer. At each of these 5 points the measured value was compared with the value of the system to determine its accuracy. For all values within the entire range the accuracy appeared to be plus or minus 1 mm. This device was used to measure 17 body dimensions.

3. *Automated anthropometer for breadth measurements*
   The automatic anthropometer for breadth dimensions was a 'Harpenden' anthropometer with a modified holder. The original mechanical counter was replaced by a mechanically coupled, adjustable resistance which enabled movement of the ruler to be measured electronically. The rulers on the fixed and the sliding part also looked like a hand and were made of plexiglass in a fluorescent colour. The accuracy of this anthropometer over the maximum range of 566 mm was plus or minus 0.5 mm. The anthropometer was coupled via a switch box to the computer, which made automated feeding of the data

into the computer possible. This contributed to the reduction of administrative errors. This device was used to measure 11 dimensions.

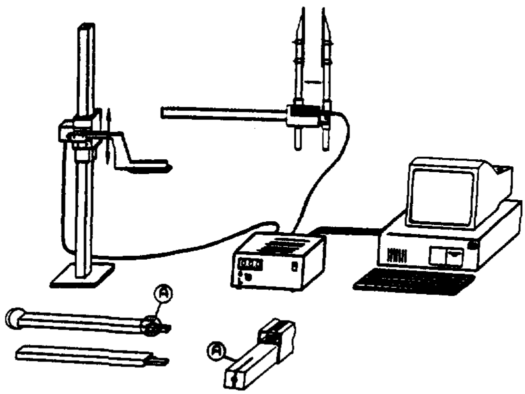
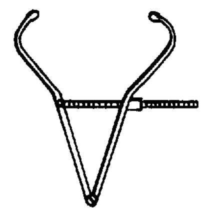
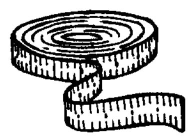


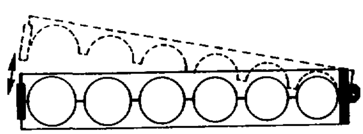
Figure 6-1: Automatic anthropometers.



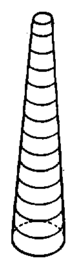
4. *Small calliper*
   The small calliper was a 'GMP', type 106. It had a maximum range of 300 mm, with graduations in millimetres. Reading accuracy was plus or minus 0.5 mm. This calliper was used for 7 (hand and knee) measurements.



5. *Measuring tape*
   To measure the 2 circumferences a tape with a length of 1000 mm and graduations in millimetres was used. The reading accuracy was plus or minus 0.5 mm.

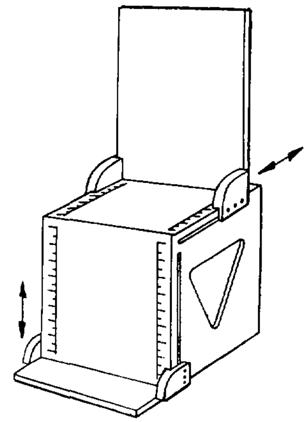


6. *Hinged plexiglass boards containing various-sized circular holes*
   The hinged plexiglass boards were made in our laboratory. The circular holes ranged from 25 to 72 mm in diameter in steps of 3 or 4 mm. The boards were hinged in order to be able to free a hand that was put into a hole that was too small. The diameter was written on the board near the hole. With this device hand diameters were measured.



7. *Measuring cone*
   The measuring cone, used to measure grip circumference, had notched numbered horizontal circles every centimetre. The reading accuracy was plus or minus 2.5 mm. The computer converted the measured value into the circumference of the circle.

8. *Measuring chair*
To be able to measure the children in the seated position, a 'measuring chair' was made. This chair had an adjustable back and footrest and consisted of a cube; it enabled the children to sit in the prescribed posture during measurement. On the seat and the back of the measuring chair was a millimetre scale, used to keep the adjustable parts of the chair in parallel. The chair was painted in bright colours en decorated with animal pictures.



9. *Computer and printer*
Hardware: The personal computer was an XT-version (trademark Hyundai) with a 20 Mb hard disk and a 3.5" floppy drive. A printer was connected to the computer.
Software: The software, necessary to measure semi-automatically and to enter the data into the PC, was written in our laboratory in 'Turbo-Pascal', version 5.5. The software was menu-directed.
The sequence of measurements was equal for all children and was displayed on the screen. It was programmed in such a way that, going from one measurement to the next, both changes of body position of the child and alterations of the apparatus were minimal. The computer indicated which apparatus to use, the position of the child (standing versus seated) and the measurement to be taken. For the sake of comparison a mean expected value for the age group of the child, based on anthropometrical data drawn from foreign sources, was given. The programme also provided a check on extreme values. If the measurement exceeded the range of the mean value plus or minus 4 times the standard deviation, there was an auditory signal and a message appeared on the screen. The measurement then had to be taken again. If the value was again extreme, it could still be accepted and entered into the computer by hand.
The data were regularly copied onto a floppy-disk to prevent them from being lost should problems occur with the hard disk. This was not an imaginary hazard since the computer was frequently moved from one place to the next. After a child was measured, the results were printed twice: one list was given to the child, the second was kept in a file as an extra backup of the results.

10. *Switch box*
The switch box was also developed and made in our laboratory. In front were a switch and a display. The switch was needed to choose which anthropometer was to be used. The values measured could be seen on the display. In back was a reset-button, used to reset the anthropometer for height and depth measurements. This was necessary at the start of each session and when the mains voltage was interrupted. The anthropometer for breadth measurements did not need to be reset.

Measurements performed with apparatus 2 and 3 were automatically entered into the computer. In total 28 out of 40 measurements were recorded automatically.

6.6 Possible errors

Forty dimensions of 2363 children were measured 'semi-automatically'. Moreover 206 children were measured a second time to obtain repeated measurements, about 10 % per age group. The data were analysed with the statistical programme SPSS-X. It goes without saying that out of 102,760 (= (2363 + 206) × 40) measurements some will be incorrect. The errors can be administrative, systematic or coincidental.

The administrative errors can be attributable to the observer or the secretary. The observer can read a value incorrectly or say it unintelligibly so that the secretary in turn enters the wrong value into the computer. Or the value is said correctly, but the secretary misunderstands it and enters the wrong value. Finally it is possible that the secretary hears the value correctly but enters it incorrectly.
By means of automated measurements, supplemented with a computer-directed control, such errors were reduced as much as possible. The non-automated measurements, however, were still susceptible to these errors.

Systematic errors can be made by an observer who systematically fails to follow the instructions or who systematically reads the values in the wrong way. Another possible cause of systematic errors is incorrect placement or calibration of the apparatus. An attempt was made to prevent the occurrence of these errors by training the measuring teams thoroughly, paying attention to all of the above-mentioned possible causes of errors. During the period in which the measurements were taken the measuring teams were checked regularly with respect to their measurement methods. In addition, each apparatus was calibrated regularly.

Coincidental errors can also occur due to the above-mentioned facts, albeit occasionally. It is very hard to anticipate these errors. The only possibility is to encourage the members of the teams to remain concentrated and work accurately. An impression of the coincidental errors can be obtained from repeated measurements. This might lead to correction of the data (see paragraph 6.7.2).

6.7 Checking the data

6.7.1 Method

The first check was to see whether, despite the automated measurements, extreme values occurred in the data set. This was checked by making histograms per age group and sex for each of the dimensions. Some extreme values were found, especially for the measurements that were entered by hand. In some cases this error could be corrected, for instance when the decimal point was put in the wrong place. In such situations the secretary probably did not respond adequately to the error signal of the computer. When it was not absolutely sure whether the error could be corrected, the results were deleted from the data set. This was necessary in only a few cases.
A second check concerned the measurements per child. Here the goal was to see whether measurements that are necessarily larger than others actually were larger. For example, the

sum buttock-knee length minus buttock-popliteal length is at all times positive. If this was not the case, at least one of the two values had to be wrong. The values were compared with other measurements of the body. In most cases it was possible to conclude which measurement was wrong and whether it could be corrected. When this was impossible the measurement was deleted from the data set. When it appeared to be hard to decide which of the two values was incorrect, both values were deleted. This, however, very seldom happened.

With the help of regression analysis it can be determined whether differences between two values are extreme. An example will illustrate this principle. A regression equation was, for example, calculated for the variables buttock-knee length, buttock-popliteal length and age, with buttock-knee length serving as the dependent variable. For all children the standardised deviation (z-score) from the calculated line was calculated. When this deviation was more than plus or minus 3, the values were studied more carefully. This type of analysis was applied to many combinations of related variables. For some variables extreme values were found and the procedure described above was followed. In just a few cases a value had to be deleted.

6.7.2 Reliability of the measurements

The repeated measurements give an impression of the reliability of the measurements. Two hundred and six children, divided at random over the age groups and sexes, were measured twice within one week. In most cases the measurements were taken by the same person, but sometimes this was not possible due to organizational circumstances. The correlation coefficients between the first and second measurements were computed. These are the results:

measurement	correlation coefficient	measurement	correlation coefficient
1 body mass	0.9992	21 sitting height	0.9941
2 stature	0.9993	22 eye height seated	0.9860
3 shoulder height standing	0.9968	23 shoulder height seated	0.9788
4 reaching height standing	0.9968	24 elbow height seated	0.8324
5 step height	0.8991	25 thigh thickness	0.9303
6 shoulder breadth	0.9879	26 buttock-popliteal length	0.9765
7 breadth across the elbows	0.9293	27 buttock-knee length	0.9866
8 hip breadth standing	0.9912	28 popliteal height	0.9887
9 breast depth	0.9510	29 instep height	0.8648
10 head length	0.9505	30 knee breadth	0.9555
11 chin-crown length	0.9709	31 hand breadth	0.9816
12 head breadth	0.9599	32 hand length	0.9920
13 head height	0.8188	33 middle finger length	0.9819
14 foot breadth	0.9666	34 little finger breadth	0.8219
15 foot length	0.9975	35 thumb breadth	0.8949
16 hip breadth seated	0.9786	36 hand thickness	0.8195
17 reaching height seated	0.9853	37 hand diameter	0.9533
18 arm length	0.9439	38 grip circumference	0.9698
19 reaching depth seated	0.9360	39 head circumference	0.9558
20 buttock-foot length	0.9884	40 upper arm circumference	0.9798

Table 6-2: Correlation coefficients between first and repeated measurements per dimension.

Generally speaking the reproducibility of the measurements was high, meaning that the first and the second measurements were almost equal. The correlation coefficients, however, do not provide information on possible systematic differences between the two measurements. To determine whether these differences were present, t-tests were performed to compare the mean values of the first and the second measurement. If it is assumed that within a period of one day to one week no measurable growth occurs, two-sided t-tests can be applied whereby:

H_0: Difference between first and repeated measurement is 0;

H_1: Difference between first and repeated measurement $\neq 0$.

In addition to the t-statistic and the p-value, the mean difference and the mean difference as a percentage of the mean value are given for each dimension (table 6-3).

Despite the fact that the mean values of the differences between the first and the repeated measurement were not large, the t-statistic for some dimensions proved to be large enough that the difference from zero was statistically significant: $p < 0.05$. As expected this is particularly true for the functional measurements and some of the 'fleshy' measurements. It is well known that the reproducibility of these measurements is not as high as that of the static and more 'bony' measurements. For some of the bony measurements, however, the differences were also significantly different from zero. For these measurements the conclusion must be drawn that the reproducibility was not as high as expected and thus systematic inaccuracies or errors must have occurred.

In order to make a correct estimation of the variance of the measurements within the population, a correction for measuring error can be made. This error is determined by the difference between the first and the repeated measurement. It was expected that the measuring errors would be normally distributed with a mean value 0 and a standard deviation s_v. Table 6-4 shows, however, that this was not true for most measurements. The correction of the standard deviation cannot, therefore, be made using the sums of squares, as recommended by Sittig and Freudenthal (1951). The correction of the standard deviation was computed as follows:

$$\sqrt{\text{var } t - \text{var } v} = Y$$

$$s_t - Y = \text{correction}$$

where:

s_t =	standard deviation of total
var t =	variance of total
$\bar{v}$ =	mean difference
s_v =	standard deviation of difference
var v =	variance of difference

For most measurements the correction which had to be made was so small that, in view of the practical application of these anthropometric data, it was not considered necessary. For three measurements the correction of the standard deviation would have been more than 5 millimetres, but because of the fact that, when these particular values are used in a design process, several centimetres are usually added as allowances, the correction was not applied.

	t-value	p	difference mean	difference %
1 body mass	-0.54	0.590	-0.016 kg	0.052
2 stature	-2.37	0.019 *	-0.128 cm	0.096
3 shoulder height standing	0.57	0.567	0.056 cm	0.053
4 reaching height standing	-3.67	0.000 *	-0.552 cm	0.347
5 step height	-3.39	0.001 *	-1.348 cm	2.508
6 shoulder breadth	-0.69	0.492	-0.032 cm	0.099
7 breadth across the elbows	-1.99	0.048 *	-0.202 cm	0.638
8 hip breadth standing	-0.08	0.940	-0.003 cm	0.011
9 breast depth	1.24	0.215	0.061 cm	0.377
10 head length	-0.02	0.986	-0.001 cm	0.002
11 chin-crown length	-4.05	0.000 *	-0.082 cm	0.361
12 head breadth	-0.07	0.941	-0.001 cm	0.006
13 head height	0.96	0.338	0.064 cm	0.315
14 foot breadth	-0.46	0.647	-0.009 cm	0.111
15 foot length	-4.01	0.000 *	-0.060 cm	0.293
16 hip breadth seated	-0.62	0.533	-0.037 cm	0.146
17 reaching height seated	-2.16	0.032 *	-0.380 cm	0.391
18 arm length	-2.22	0.028 *	-0.425 cm	0.788
19 reaching depth seated	-1.14	0.255	-0.424 cm	0.451
20 buttock-foot length	-0.83	0.405	-0.129 cm	0.163
21 sitting height	1.15	0.250	0.076 cm	0.107
22 eye height seated	-0.16	0.877	-0.015 cm	0.025
23 shoulder height seated	1.10	0.273	0.096 cm	0.220
24 elbow height seated	0.78	0.436	0.084 cm	0.467
25 thigh thickness	-2.31	0.022 *	-0.112 cm	1.105
26 buttock-popliteal length	-0.15	0.884	-0.015 cm	0.041
27 buttock-knee length	-0.55	0.583	-0.051 cm	0.111
28 popliteal height	-2.48	0.014 *	-0.174 cm	0.482
29 instep height	-2.48	0.014 *	-0.095 cm	1.296
30 knee breadth	-1.27	0.205	-0.023 cm	0.303
31 hand breadth	0.31	0.757	0.003 cm	0.052
32 hand length	-4.25	0.000 *	-0.078 cm	0.547
33 middle finger length	-0.77	0.443	-0.009 cm	0.150
34 little finger breadth	0.00	1.000	0.000 cm	0.000
35 thumb breadth	-0.59	0.557	0.003 cm	0.219
36 hand thickness	-1.58	0.117	-0.019 cm	0.953
37 hand diameter	3.39	0.001 *	0.048 cm	0.865
38 grip circumference	-2.48	0.014 *	-0.069 cm	0.721
39 head circumference	-0.83	0.407	-0.034 cm	0.064
40 upper arm circumference	2.36	0.019 *	0.091 cm	0.456

Table 6-3: Results of the t-test applied to the differences between first and repeated measurements per dimension.
** = significant difference ($p < 0.05$) between first and repeated measurement*

	s_t	var t	$\bar{v}$	s_v	var v	correction
1 body mass	10.45	109.13	-0.02	0.43	0.18	0.012 kg
2 stature	19.97	398.71	-0.13	0.77	0.59	0.017 cm
3 shoulder height standing	17.71	313.73	0.06	1.40	1.96	0.053 cm
4 reaching height standing	26.32	692.56	-0.55	2.09	4.38	0.086 cm
5 step height	12.28	150.91	-1.35	5.67	32.16	1.383 cm
6 shoulder breadth	4.11	16.90	-0.03	0.66	0.43	0.052 cm
7 breadth across the elbows	3.77	14.20	-0.20	1.46	2.12	0.294 cm
8 hip breadth standing	3.44	11.84	0.00	0.49	0.24	0.034 cm
9 breast depth	2.16	4.66	0.06	0.70	0.49	0.118 cm
10 head length	0.82	0.67	0.00	0.26	0.07	0.045 cm
11 chin-crown length	1.21	1.47	-0.08	0.29	0.08	0.031 cm
12 head breadth	0.65	0.42	0.00	0.18	0.03	0.026 cm
13 head height	1.57	2.45	0.06	0.95	0.90	0.325 cm
14 foot breadth	3.02	9.12	-0.06	0.21	0.05	0.008 cm
15 foot length	1.01	1.02	-0.01	0.27	0.07	0.035 cm
16 hip breadth seated	3.83	14.67	-0.04	0.85	0.73	0.096 cm
17 reaching height seated	14.58	212.69	-0.38	2.51	6.31	0.214 cm
18 arm length	8.23	67.67	-0.42	2.74	7.49	0.472 cm
19 reaching depth seated	14.40	207.45	-0.42	5.31	28.19	1.011 cm
20 buttock-foot length	14.37	206.51	-0.13	2.20	4.86	0.170 cm
21 sitting height	8.29	68.67	0.08	0.93	0.87	0.056 cm
22 eye height	7.99	63.86	-0.01	1.35	1.83	0.114 cm
23 shoulder height seated	5.96	35.53	0.10	1.25	1.56	0.132 cm
24 elbow height seated	2.56	6.56	0.08	1.52	2.32	0.501 cm
25 thigh thickness	1.72	2.97	-0.11	0.69	0.48	0.142 cm
26 buttock-popliteal length	6.79	46.07	-0.02	1.50	2.24	0.170 cm
27 buttock-knee length	8.05	64.80	-0.05	1.32	1.73	0.108 cm
28 popliteal height	6.79	46.06	-0.17	1.00	1.01	0.078 cm
29 instep height	1.16	1.33	-0.09	0.55	0.30	0.145 cm
30 knee breadth	0.87	0.76	-0.02	0.26	0.07	0.039 cm
31 hand breadth	0.78	0.61	0.00	0.16	0.02	0.012 cm
32 hand length	2.05	4.22	-0.08	0.26	0.07	0.013 cm
33 middle finger length	0.89	0.80	-0.01	0.17	0.03	0.013 cm
34 little finger breadth	0.22	0.05	0.00	0.07	0.00	0.004 cm
35 thumb breadth	0.18	0.03	0.00	0.08	0.01	0.039 cm
36 hand thickness	0.33	0.11	-0.02	0.17	0.03	0.047 cm
37 hand diameter	0.62	0.39	0.05	0.20	0.04	0.028 cm
38 grip circumference	1.63	2.66	-0.07	0.40	0.16	0.049 cm
39 head circumference	1.98	3.91	-0.03	0.58	0.34	0.091 cm
40 upper arm circumference	2.49	6.19	0.09	0.55	0.30	0.063 cm

Table 6-4: Correction of the standard deviation per dimension.

6.7.3 Observer effects

Thirty-six observers participated in this part of the project. All measurements were analysed to determine whether observer effects occurred. The differences between the first and the repeated measurements were analysed by one-way analysis of variance. An observer effect was found for ten of the dimensions. These variables are presented in table 6-5.

	F	p
shoulder height standing	1.1029	0.0003
step height	1.7326	0.0158
shoulder breadth	1.8953	0.0059
breadth across the elbows	2.0770	0.0019
breast depth	1.7090	0.0180
head height	1.6911	0.0200
foot breadth	2.1859	0.0010
thigh thickness	2.0940	0.0017
buttock-popliteal length	2.1386	0.0013
buttock-knee length	1.6488	0.0257

Table 6-5: Dimensions with an observer effect; results of the analysis of variance.

The differences between observers were not large enough for the Scheffé Multiple Range test to indicate pairs of observers with significantly different mean values at the 0.05 level. It is therefore neither possible nor feasible to correct the measurements of single observers.
It is presumed that some of the differences occurred due to varying measurement methods, especially dissimilarities in pressure on the tissue. These differences could possibly have been prevented by placing a pressure transducer on the apparatus.
Other differences might be due to incorrect positioning of the apparatus, especially choice of the point of the body that had to be measured or incorrect adjustment of the measuring chair.
It has to be concluded that not all observers were perfect. The degree of imperfection, however, apparently does not distort either the analyses or testing of the hypotheses on scale and numbers, as intended.

6.8 Results

The results of this section of the project are twofold. Firstly the values of each dimension, for boys and girls separately as well as for boys and girls together, constitute a national anthropometric 'databank'. This meets the descriptive requirements of the project. These results are presented in appendix B. Secondly, analyses were performed in order to describe the body in terms of a few parameters, thus adding to general auxological insights.

6.8.1 Analyses

Differences between boys and girls

The dimensions of both boys and girls increase, in both longitudinal and transversal samples, during successive ages. The differences between successive age groups were analysed by means of the t-test; the results are presented in appendix c for boys and girls. As expected, it can be concluded that for most dimensions the mean values increase significantly during successive ages. Striking exceptions are, however, the head measurements. These dimensions do not increase continuously during the period between 2 and 13 years.

The mean values for boys and girls per age group were also analysed by means of a t-test. Appendix D lists the results. They show that differences exist between the mean values for boys and girls, but neither at all ages nor for all dimensions. Exceptions are measurements of the head and some 'skeletal' measurements, such as knee breadth and thumb breadth. These dimensions are larger for boys than for girls at all ages. Measurements related to the upper leg are larger for girls, at least at some ages. At the ages of three and nine years the differences between boys and girls are the most prominent, i.e. the largest number of differing dimensions was found. Although theory predicts that the number of differences will increase consistently within the age range 2 to 13 years, this survey shows that this rule does not apply always and everywhere.

Descriptive indices of the body

The second part of the results is based on a number of analyses performed to discover whether it is possible to describe the body using only a few parameters. For this purpose partial correlation coefficients, controlling for age, were evaluated by factor analysis. This was done to keep 'age' from being a dominant factor in the factor structure. Factor analysis (Principal Component) yielded 3 factors, explaining 86.4% of the total variance. These factors could reasonably be interpreted as a 'length factor', 'volume factor' and 'head factor', respectively. The first two factors are far from unexpected, according to both geometrical analysis, which yields the longest axis and the surrounding mass as dominant, and several other factor analyses applied to anthropometrical data (Molenbroek, 1994). The third factor was, however, not anticipated. The presence of 8 hand variables could have resulted in a separate hand factor, but it now appears that 'growth programmes' assign development of the hand mainly to the category of 'length control'; some may include have a separate 'head category'.

Most of the variables are present in each of the three factors. The factor loadings for the factors are given below, provided that they exceeded 0.300.

The length factor includes the following variables:

	'length' factor	'volume' factor	'head' factor
28 popliteal height	0.822	(0.392)	(0.369)
4 reaching height standing	0.811	(0.442)	(0.362)
3 shoulder height standing	0.808	(0.456)	(0.351)
2 stature	0.807	(0.445)	(0.372)
17 reaching height seated	0.794	(0.461)	(0.353)
20 buttock-foot length	0.793	(0.450)	(0.355)
5 step height	0.792		
32 hand length	0.787	(0.425)	(0.388)
38 grip circumference	0.782	(0.337)	(0.322)
22 eye height seated	0.782	(0.483)	(0.327)
15 foot length	0.781	(0.438)	(0.398)
21 sitting height	0.778	(0.471)	(0.368)
27 buttock-knee length	0.775	(0.483)	(0.347)
33 middle finger length	0.773	(0.417)	(0.365)
26 buttock-popliteal length	0.772	(0.470)	(0.332)
18 arm length	0.766	(0.422)	(0.336)
23 shoulder height seated	0.766	(0.501)	(0.302)
19 reaching depth seated	0.749	(0.459)	(0.317)
31 hand breadth	0.690	(0.492)	(0.414)
29 instep height	0.658	(0.379)	(0.338)
6 shoulder breadth	0.655	(0.609)	(0.383)
14 foot breadth	0.646	(0.493)	(0.440)
37 hand diameter	0.604	(0.533)	(0.400)
30 knee breadth	0.595	(0.525)	(0.448)
36 hand thickness	0.594	(0.400)	(0.387)
35 thumb breadth	0.585	(0.397)	(0.450)
24 elbow height seated	0.510	(0.468)	

To the 'volume-factor' contribute:

	'length' factor	'volume' factor	'head' factor
40 upper arm circumference	(0.325)	0.837	(0.311)
7 breadth across the elbows	(0.384)	0.761	(0.365)
25 thigh thickness	(0.481)	0.751	
16 hip breadth seated	(0.529)	0.736	(0.321)
9 breast depth	(0.502)	0.701	(0.317)
1 body mass	(0.591)	0.700	(0.363)
8 hip breadth standing	(0.598)	0.692	(0.337)

The 'head-factor' consists of:

	'length' factor	'volume' factor	'head' factor
39 head circumference	(0.301)	(0.312)	0.844
10 head length			0.823
11 chin-crown length	(0.542)	(0.363)	0.671
12 head breadth		(0.335)	0.650
13 head height	(0.514)		0.591

For the first factor popliteal height had the highest factor loading (0.822). Upper arm circumference had the highest factor loading for the second factor (0.837), while the highest factor loading for the third factor was found for head circumference (0.844). These three dimensions are thus the best predictors of the three factors and, consequently, the other variables within each factor group. An advantage is the fact that these dimensions can be measured fairly easily. If sex had been included in the factor analysis, it would have appeared in the 'head factor'.

6.8.2 Proportions

The proportions of the body can be expressed in different ways (Malina, 1984). Examples of measurements of proportions are:

- the ratio between sitting height and stature as a measurement of the proportion legs to trunk and head;
- the ratio between shoulder breadth and hip breadth is a measure of the form of the trunk;
- the ratio between head height and stature indicates the proportion of the head relative to whole body length.

To gain insight into the change in proportions during the ages under study, these ratios were graphed as scatter plots. In order to be able to show the changes in proportions more clearly, the results for one-year-old children of the pilot project were included in the plots (provided the measurement definitions were equal) but not in the analyses. For each of these proportions an analysis of variance was performed to assess the influence of age and sex on the changes in these ratios.

In the first plot (figure 6-2) the mean ratio per age group and sex between sitting height and stature is plotted against age. As expected, the values decrease with age: in comparison to the older children, younger children have a relatively larger trunk and their legs are shorter. This is true for both boys and girls. The analysis of variance showed an effect of age ($F = 1718.42$; $p = 0.000$).

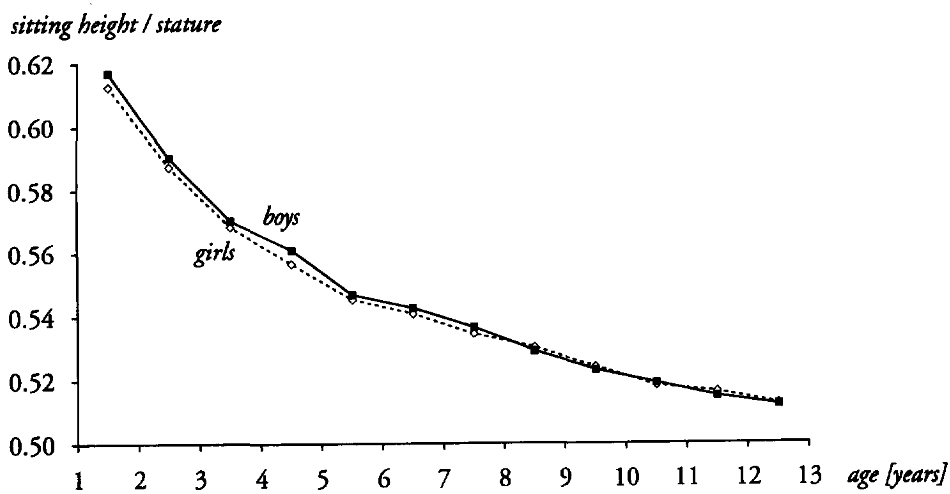


Figure 6-2: Mean ratio between sitting height and stature according to age and sex

The ratio between shoulder breadth and hip breadth standing is shown in figure 6-3. This ratio remains more or less constant during the ages under study. It is striking to see that girls have broader hips from childhood to puberty (and beyond (Tanner, 1990)). During and after puberty the difference in shape of the trunk between boys and girls becomes more pronounced.

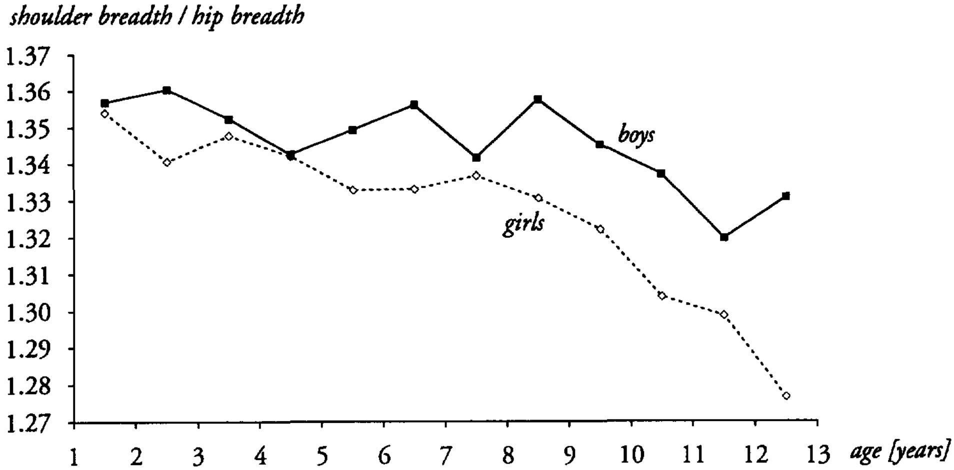


Figure 6-3: Mean ratio between shoulder breadth and hip breadth standing according to age and sex

The analysis of variance shows, besides the main effects of age (F = 46.882; p = 0.00) and sex (F = 83.390; p = 0.000), an interaction effect (F = 4.667; p = 0.010) between shoulder breadth and hip breadth. This can be explained by the fact that girls between 10 and 13 years old, differ markedly from the other children. Some of these girls will be in the growth spurt of their puberty, implying a widening of the hips. This is illustrated by the decrease in the ratio described here.

Figure 6-4 gives the ratio between head height and stature. This ratio decreases with age.The mean values for boys of all ages were larger than the values for girls. Therefore boys appear to have a relatively large head compared to girls. This difference is confirmed by the effects of age (F = 2474.30; p = 0.000) and sex (F = 114.14; p = 0.000) revealed by the analysis of variance.

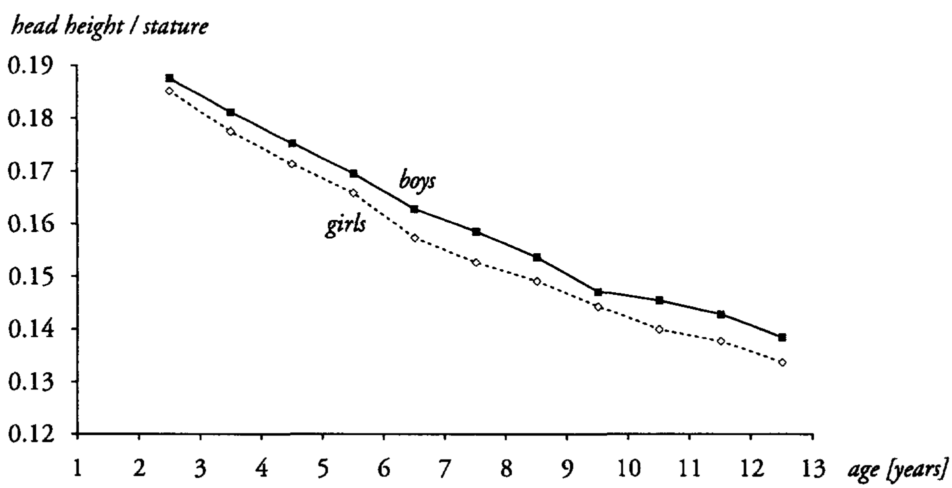


Figure 6-4: Mean ratio between head height and stature according to age and sex

Some other measurements were compared too: the ratio between buttock-knee length and popliteal height (figure 6-5) decreases markedly before the age of four and remains fairly constant from then on. It is striking, however, that the mean values for girls of all ages are larger than those for boys: girls have longer upper legs than boys, while the lower legs of boys are longer than those of girls. This was also illustrated by the analysis of variance, which showed an effect of both age ($F = 105.34$; $p = 0.000$) and sex ($F = 151.90$; $p = 0.000$).

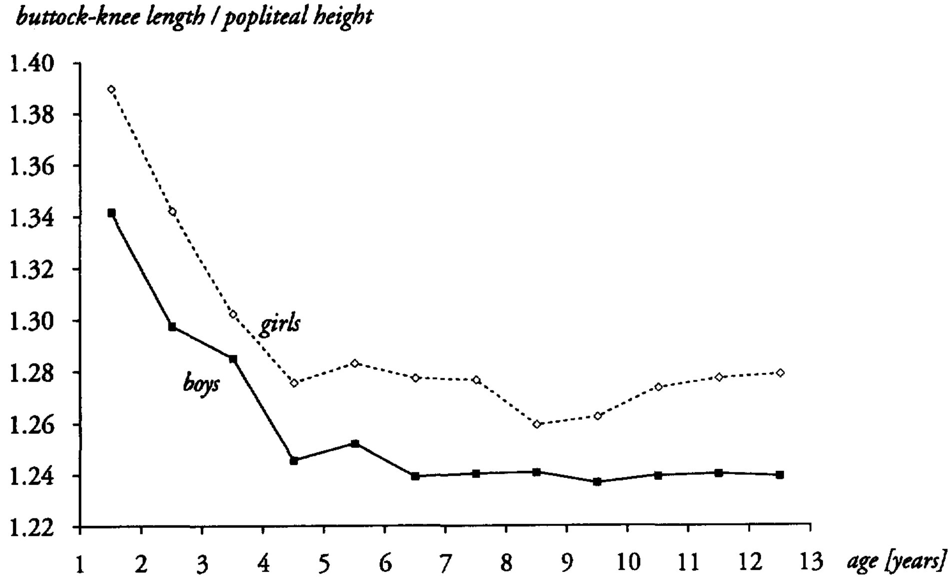


Figure 6-5: Mean ratio between buttock-knee length and popliteal height according to age and sex

6.9 Conclusions

6.9.1 Measurements

Taking anthropometric measurements is not always easy. It is well known that adequate training is necessary in order to obtain accurate and reproducible measurements. Still training does not guarantee that reproducibility is perfect. Other influential factors remain present, for instance, the person to be measured. The young ones are less easily measured. A standard posture can be obtained, but one cannot expect these children to maintain this posture, without the slightest movement, for a long period of time. This demands a lot of patience on the part of the teams. Reliable measurements require a lot of time. A related problem is the fact that young children are easily distracted.
It can be deduced that it makes more sense to measure, and this especially true for large epidemiological surveys, a representative (small) number of dimensions very accurately and precisely and then calculate the other data needed by using the correlation coefficients between the variables. The partial correlation matrix (controlling for age) is presented in appendix E.

To determine which dimensions are the most representative of all others, a factor analysis was performed. This reduced the number of variables to a few which provide a good impression of the overall dimensions of the body. These dimensions can be grouped into three categories: length-related measurements, breadth or volume-related measurements and head measurements. The most representative variables within these factors are popliteal height, upper arm circumference and head circumference, respectively.

Regression analyses with these dimensions serving as dependent variables resulted in the following linear equations:

stature =	28.76	+ 2.88 · popliteal height	r = 0.98
body mass =	-44.50	+ 3.79 · upper arm circumference	r = 0.96
head length =	0.11	+ 0.35 · head circumference	r = 0.85
head breadth=	1.72	+ 0.23 · head circumference	r = 0.71
head height =	-8.23	+ 0.53 · head circumference	r = 0.68
chin-crown =	-4.29	+ 0.51 · head circumference	r = 0.83
head circumference =	5.73	+ 1.60 · head length + 1.24 · head breadth	r = 0.92

The r-values denote the association between the variables in the equations.

6.9.2 Growth

It is obvious that all measurements increase with age. This is according to expectation. For most dimensions the increase in successive age groups was significantly different from zero for both boys and girls. Exceptions were found for the proportions, due to comparable increases in the composite measurements. The increase was, however, not similar for boys and girls. For most of the dimensions and at most ages boys had larger mean values compared to girls. Exceptions are hip breadth standing as well as seated, measurements related to the upper leg, and for some age groups, breast depth, shoulder height and elbow height. The mean dimensions of the head of boys of all ages are larger than those for girls. This is also true for the knee breadth, thumb breadth and, at most ages, the other measurements of the hand.

Another striking difference between boys and girls is the proportion between upper and lower leg. The average upper leg of girls is longer than that of boys, while the lower leg of boys is on average longer than that of girls.

6.9.3 Socioeconomic and geographical differences

It is generally assumed that social and economic factors can influence growth and development. In this project these factors were operationalized by the educational level of the parents. The highest educational level of either the father or the mother was used to define this variable. As explained in paragraph 3.2.4. this assessment could not be regarded as a very accurate one. Other possible influential factors are degree of urbanization of the municipality and region of the country. The influences of these factors were analysed. One-way analyses of variance were performed for three age groups and per sex as well as for boys and girls together, using only 5 'core' measurements: stature, body mass, popliteal height, head circumference and upper arm circumference.

For age group one, children aged 2 to 6 years, differences between regions existed for stature ($F = 3.34$; $p = 0.019$), body mass ($F = 3.10$; $p = 0.026$) and popliteal height ($F = 4.32$; $p = 0.005$). The mean values of these dimensions were higher for children in western Netherlands than children in the eastern part of the Netherlands.
For children between 6 and 9 years of age, only the head circumference ($F = 7.00$; $p = 0.0001$) was significantly different. Children in the western Netherlands had a larger mean head circumference than children in the north and the south.
Children between 9 and 13 years old exhibited differences in body mass ($F = 3.79$; $p = 0.010$), popliteal height ($F = 3.24$; $p = 0.022$) and upper arm circumference ($F = 5.14$; $p = 0.002$). Children in northern Netherlands appeared to be heavier than children in the south, and their upper arm circumference was larger than that of children in the south and the east.

To determine the influence of the degree of urbanization, comparable analyses were performed. For children between 2 and 6 years of age the popliteal height of children in urban regions was larger than that of children in middle-sized municipalities ($F = 4.31$; $p = 0.014$). For children between 6 and 9 years of age, the differences cannot be explained by degree of urbanization. The opposite is true for children between 9 and 13 years of age. A significant difference in stature was found between children in rural areas and children in urban areas, the latter being taller than the former. The children in rural areas were heavier than all other children ($F = 5.06$; $p = 0.007$). This was also true for the upper arm circumference ($F = 8.26$; $p = 0.0003$). In each of the age groups mentioned, the level of education of the parents, as assessed in this project, could not explain the observed variance in the mean values of the five variables chosen.

In table 6-6 the above-mentioned results are summarized; only significant values are given.

age group [years]:	body dimensions	region F	region p		degree of urbanization F	degree of urbanization p	
2.0–5.9	stature	3.34	0.019	*(west > east)*			
	body mass	3.10	0.026	*(west > east)*	4.31	0.0140	*(urban > middle)*
	popliteal height	4.32	0.005	*(west > east)*			
	head circumference						
	upper arm circumference						
6.0–8.9	stature						
	body mass						
	popliteal height						
	head circumference	7.00	0.000	*(west > north)* *(west > south)*			
	upper arm circumference						
9.0–12.9	stature				4.58	0.0100	*(rural > urban)*
	body mass	3.79	0.010	*(north > south)*	5.06	0.0070	*(rural > middle)* *(rural > urban)*
	popliteal height	3.24	0.022	*no groups*			
	head circumference						
	upper arm circumference	5.14	0.002	*(north > south)* *(north > east)*	8.26	0.0003	*(rural > middle)* *(rural > urban)*

Table 6-6: Influence of region and urbanization on some body dimensions of children between 2 and 13 years of age.

For children below 9 years of age a tendency seems to exist towards larger dimensions in the western part of the Netherlands. The children over 9 years of age seem to be taller in the northern part of the Netherlands. For this older age group there is also a tendency towards larger dimensions in the rural areas.

6.9.4 Ethnicity

The ethnic background of a child is a genetic factor that will also influence growth. Not all children in the sample had Dutch-born parents. The allochthonous group consisted mostly of Turks, Moroccans, Surinamers and Antilleans. An analysis was performed to determine whether these children showed a different pattern of growth. The number of these children in the sample was, however, not very large (table 6-7), requiring caution when interpreting the results.

age [years]	Dutch-born parents		NonDutch-born parents	
	boys	girls	boys	girls
2.0 – 2.9	71	79	6	10
3.0 – 3.9	91	74	5	8
4.0 – 4.9	90	73	2	3
5.0 – 5.9	86	87	0	6
6.0 – 6.9	89	86	3	3
7.0 – 7.9	105	93	3	2
8.0 – 8.9	93	92	3	3
9.0 – 9.9	123	117	3	7
10.0 – 10.9	133	127	4	2
11.0 – 11.9	139	144	5	7
12.0 – 12.9	71	70	2	3

Table 6-7: Number of children of Dutch and NonDutch origin in the sample according to age and sex.

In appendix F plots of the mean values per age group, sex and ethnic background are given for each of the five anthropometric dimensions: stature, body mass, popliteal height, head circumference and upper arm circumference.

An analysis of variance was used to test the influence of ethnic origin and sex on 5 anthropometric dimensions, using age as covariate. For all measurements ethnic background could be used to explain part of the observed variance. No interaction effects between ethnicity and sex were observed. The results are summarised in table 6-8.

	ethnicity		sex		age	
	F	p	F	p	F	p
stature	61.71	0	1.66	0.198	24,938.87	0
body mass	13.54	0	3.58	0.059	7,558.90	0
popliteal height	43.57	0	22.52	0	19,440.39	0
head circumference	18.32	0	188.28	0	1,675.88	0
upper arm circumference	8.18	0.004	10.26	0.001	2,168.62	0

Table 6-8: Influence of ethnicity and sex on five dimensions, with age as covariate.

The conclusion must be that there is a tendency towards differences in growth between children with Dutch-born parents and children whose parents are not of Dutch origin; the children of Dutch-born parents seem to have larger dimensions.

At this point a qualification has to be made. Ethnicity was determined by the land where the parents were born. This means that second or third generation allochthonous children were considered to have Dutch-born parents. It is, however, not likely that these children will yet have adopted the growth pattern of 'Dutch' children whose family has been living in the Netherlands for many more generations. It is even possible that genetic differences are still at work. Therefore, actually, two diffuse groups of children were compared, whereby the second, simply named 'NonDutch' but coming from different parts of the world, was even more heterogeneous than the first.

7 Force exertion

7.1 Introduction

One aspect of the physical development of children which is related to the handling and use of products is the exertion of force. Handling products generally implies that a specific type and amount of muscular action is needed to hold, carry, lift, or switch etc. Handling involves mainly forces exerted by the arms and hands, which are the forces studied in this project. Forces involving other parts of the body do not fall within the scope of this investigation, although force from the upper limbs could have some bearing on other forces (Daams, 1994).

Handling and using products requires the exertion of some force by the hand, fingers and even the arms or trunk. For example, pushing, pulling and gripping forces and torque can be required. For precision tasks exertion of thumb-finger forces seems to be important. In order to be able to handle a product in a comfortable manner –as far as the amount of force needed is concerned– the required forces should be less than the lowest maximum force within the target group. Designers, when designing a product, should bear those values in mind and not surpass the chosen lower percentile value of the frequency distribution (for a target group) of the relevant force(s). Furthermore hand forces have to be known for safety reasons. For instance a child should not be able to open child-resistant packages or tamper with and remove from products small elements that can be swallowed. In these cases the required forces should exceed the highest maximum force exerted by the target group.
The forces needed to handle products will, however, hardly ever be of just one kind. In most cases (varying) combination of forces, such as squeeze and torque or gripping and pulling forces, are required. Since measuring forces in combination would be too complicated, they were measured separately in this project. Further investigation into the combination of forces, however, is needed.
In addition to the fact that we wanted to provide useful measurements for designers, we also wanted to describe the individual capacities (i.e. forces) of children. For this reason the measurement of maximum forces is also necessary, because typifying children through capacities in force exertion can best be done by assessing maximum or sub-maximum forces, which are either of the short-term or long-term type.

7.2 Method

The exertion of force is influenced by many factors. In literature the influence of some of these factors on the measurement method is described, e.g. posture (Haslegrave, 1990; Gallagher, 1989), the instruction given (Berg et al., 1988), the duration of force exertion (Berg et al., 1988) and the feedback given (Peacock et al., 1981). Besides aspects of the method of measurement, characteristics of the subject also influence the amount of force that can be exerted, e.g. sex, the preferred hand and motivation. In order to make a comparison of the results of different studies, the methods used should be similar. However many different methods and groups of subjects have been described in literature, which implies that the results are not or barely comparable (Caldwell et al., 1974; Chaffin, 1975; Daams, 1990).

The aim of this project was to determine maximum, static forces exerted by children aged 4 to 13 years. The forces chosen, because of their relevance to handling and using products, were pushing, pulling and gripping force as well as torque of hands and fingers.
The results of the comparison of forces assessed by different measurement methods, as described in literature, are discussed. This was done to determine the measurement method

that is likely to result in the exertion of the most force. A number of factors have to be taken into account.

7.2.1 Posture

Few studies are known in which differences in force exertion between a standing and a sitting position have been evaluated. Ćatović (1989) described differences in the gripping force of dentists in a standing and sitting position. In the standing position the most force was exerted. It can be expected that such differences will also apply for other kinds of force exertion too. Despite this result we chose to define a sitting position. This choice was influenced by the instruments we had to use and the requirement of easy transportation and placement of the measuring devices.

Another aspect of the posture is the position of the body and the arms. The standard position is often described as standing or sitting erect, the upper arm vertical and the elbow flexed at a 90-degree angle.
In an investigation by Daams (1990) of force exertion in different standing positions, including this standard position, many subjects spontaneously remarked that this posture was so unnatural. A free posture, which proved to be highly reproducible, resulted in the highest force exertion. These findings have also been described by other investigators (Rohmert et al., 1987; Hennion et al., 1990). Despite these findings and in view of the fact that several people were to take the measurements in this project, the posture was prescribed as follows: the child sits upright, the angle between upper arm and forearm is approximately 150 degrees, the forearm is horizontal and parallel to the sagittal plane, the legs hang down freely. This posture was chosen because of the fact that adults in this sitting position were able to exert the greatest force (Morgan, 1963 in: Woodson, 1981). Data on force exertion by children could not be found and therefore the results for adults were used as a guideline. With regard to measurements on young children a remark has to be made concerning posture. For very young children it appeared to be very difficult to maintain a prescribed posture. In the light of the results of Daams (1990) this should not, however, be a disturbing disadvantage.

7.2.2 Instruction

The way the instruction is given may influence the magnitude of an exerted force (Berg et al., 1988). It must, of course, be clear to a child what is expected of him/her. This requires a clear explanation of posture and the way the force has to be exerted. Therefore an example was given by the observer, followed by an opportunity for the child to practice; at that time a correction of the posture could be made. The child was asked to push/pull/grip/turn as hard as possible. After this no further encouragement was given. It was also essential that no other children were present to encourage or influence the child.

7.2.3 Duration

In most studies force exertion is built up during a one-second period to maximum and lasts 3 seconds. We used this method too. The highest peak value in this 3-second period appeared on the display of the measuring device and was recorded. Between two attempts at force exertion with one hand, a rest period of at least 2 minutes was introduced, as recommended by Caldwell et al. (1974).

7.2.4 Feedback

Peacock et al. (1981) concluded in their study that only a combined auditory-visual feedback resulted in more exertion of force. Auditory or visual feedback alone did not result in more force in comparison with no feedback. In this investigation no direct feedback of the results was given.

7.2.5 Sex

In ergonomic handbooks a generally accepted rule is that the strength of women is approximately two-thirds of the strength of men. In most studies differences in strength were found; the magnitude of these differences, however, varies (Pheasant, 1983). Hosler and Morrow (1982), nevertheless, found that the strength of the legs of men and women is almost equal, provided a correction is made for body composition and body height. In that case only 2% of the variance was explained by sex. For arm forces one percent was explained by sex. When Bishop et al. (1987) made a correction for body fat (being an indirect indication for muscular mass), they also could not find a difference between men and women. Whether this is true for children is not known.

7.2.6 Preferred hand

Weiss and Flatt (1971) found differences between the preferred and non-preferred hand in the finger pinch grip of right-handed adults. For left-handed adults no differences were found. This difference was explained by the fact that left-handed persons are forced to use products that are made for right-handed use. Therefore they have to train the skills and strength of their right hand. The reverse is not necessarily true for right-handed individuals.

These differences in strength were, however, not confirmed in other investigations (Ager et al., 1984; Mathiowetz et al., 1986). It is not yet known whether this difference exists between children. Therefore in this study the forces exerted by both the preferred and non-preferred hand were measured.

With regard to the position of the fingers it was found by Hook and Stanley (1986) that the pinch grip force of adults is 72.5 % higher when the fingers remain flexed during force exertion compared to the force exerted when the other fingers are extended. It is expected that this will be true for other thumb-finger forces too. Because we tried to establish maximal forces, we decided that the idle fingers should make a fist.

7.2.7 Motivation

Motivation seems to influence force exertion. In this investigation measurement took place during school hours, so that children who were asked to participate were allowed to leave the classroom. For most of them this was probably reason enough to cooperate.

7.2.8 Measuring devices

In several studies the devices used are not described, although this is relevant information because the results of the measurements will be influenced by the kind of devices used (Mathiowetz et al., 1984). To measure pushing and pulling forces of the hands and fingers and the thumb-finger pinch force, an Erichsen push/pull measuring device with a maximum capacity of 500 N was used. Different knobs could be attached to the device (see measurements, appendix G). A Jamar dynamometer (maximum 900 N) was used to measure grip force of the hand. Torque of hands and fingers was measured with a Metek torque measuring device (0 - 6 Nm) (appendix G).

7.2.9 Measurements

It was the object of this part of study was to investigate the influence of age, sex and preferred hand on the magnitude of forces exerted while sitting.
The following forces were measured twice in a group of boys and girls aged 4 to 13 years:

- pulling force of the right and left hand;
- pulling force of thumb plus forefinger of the right and left hand;
- pushing force of the right and left hand;
- pushing force of the forefinger of the right and left hand;
- gripping force of the right and left hand;
- finger pinch grip of the right and left hand;
- torque with the preferred hand, turning clockwise and anti-clockwise;
- torque with thumb and forefinger of the preferred hand, turning clockwise and anti-clockwise.

		hand		preferred hand	
type	member	right	left	clockwise	anti-clockwise
pull	hand	2x	2x		
	finger	2x	2x		
push	hand	2x	2x		
	finger	2x	2x		
grip	hand	2x	2x		
	finger	2x	2x		
torque	hand			2x	2x
	finger			2x	2x

Table 7-1: Summary of the number and kinds of measurements per person and per hand.

Thirty-two times the child was asked to exert a force: 20 times with the preferred hand and 12 times with the non-preferred hand (see table 7-1). The children themselves indicated which hand was their preferred hand. When they could not do so, the writing hand was presumed to be the preferred hand. Because of the limited amount of time available for this part of the project and the required rest period between two measurements, the measurements were only performed twice instead of three times, which is sometimes recommended in literature (Caldwell et al., 1974). Some children participated twice within a period of one day to one week in order to obtain repeated measurements.
A description of each of the measurements is given in appendix G, together with the results of the measurements.

7.3 Analyses

Many different methods can be used to reduce the data of similar force measurements. In establishing test-retest reliability Mathiowetz et al. (1984) showed that the highest correlation between two instances of exerting force is found when the mean value of three measurements is taken. Other investigators (Newman et al., 1984) used the mean of the values for the right and the left hand as an indication of the strength of a person.
We performed several analyses in order to decide which method should be used to present our data. These analyses and the results are described below.

7.3.1 Administrative errors

The results of the measurements were written down on sheets of paper and entered into the computer afterwards. In order to be able to correct reading and/or typing errors, all data were entered twice by two different individuals, and the two files were compared. Differences were compared with the written data and corrected when necessary.

7.3.2 Extreme values

The first step in analysing data was to check for the presence of extreme values. For that purpose histograms were made for each age group and sex. When a value was larger or smaller than the mean value plus or minus 4 times the standard deviation, it had to be determined whether this value was a measuring error. This appeared to be true in some cases, e.g. when the measuring device had not been reset. These values were excluded from the database. Furthermore, an 11-year-old boy seemed to be extremely strong (approximately twice as strong as the next strongest boy). Subsequent inquiries revealed that this boy followed an extensive fitness training programme. In order to avoid extreme means for this age group, the results for this boy were excluded from analysis.

7.3.3 Preferred hand

A second analysis focused on the differences in force exertion between the preferred and non-preferred hand. The frequency distribution of the preferred hand is listed according to age group for boys and girls, respectively, in table 7-2.

	preferred hand			
age	boys		girls	
[years]	right	left	right	left
4.0 – 4.9	33	8	40	6
5.0 – 5.9	45	7	52	7
6.0 – 6.9	52	6	50	6
7.0 – 7.9	40	10	36	6
8.0 – 8.9	37	4	34	6
9.0 – 9.9	30	11	36	6
10.0 – 10.9	27	8	35	4
11.0 – 11.9	33	7	38	6
12.0 – 12.9	25	4	18	4

Table 7-2: Distribution of the preferred hand according to age group and sex.

Per age group and sex we performed a t-test in order to determine whether the mean values of the first and second trial executed with the preferred hand and the non-preferred hand, respectively, were different for right-handed children compared to left-handed children. Thus, for example, per age group and sex the mean value of the first and second trial of the pulling force with the right hand for right-handed children was compared with the mean values of both trials with the right hand for left-handed children. In only five out of 128 tests was a significant difference found. These five differences were in the expected direction (higher values for preferred hand than for non-preferred hand), and thus explicable, but coincidental with respect to age and sex. We therefore concluded that no differences exist between the forces exerted by the preferred and non-preferred hands.

7.3.4 Right and left hand

The next analysis concerned the difference between the right and left-hand forces, without taking into account which was the preferred hand. Per age group and sex we computed a mean value for each of the four measurements (2x right, 2x left) of one kind of force. An analysis of variance of these four mean values showed which one of the 4 values differed from the others.The results of these analyses are presented in table 7-3.

age [years] and sex	forces exerted by the hand				forces exerted by (thumb and) forefinger			
	pull	push	grip	torque	pull	push	grip	torque
4 boys	=	=	L ↓*	=	=	L2 ↓	L ↓	=
girls	=	=	=	=	=	L ↓	L ↓	L ↓
5 boys	=	=	L ↓	=	=	R1 ↑	=	=
girls	=	=	R2 ↑	=	=	L ↓	L ↓	=
6 boys	R1↑, R2↓	=	R2 ↑	L1 ↑	=	L ↓	L ↓	=
girls	=	=	L ↓	=	=	L ↓	L ↓	=
7 boys	=	=	R2 ↑	=	=	L ↓	L ↓	=
girls	=	=	L ↓	=	=	L ↓	L ↓	R1 ↑
8 boys	=	=	L ↓	=	L1 ↓	L ↓	=	L2 ↓
girls	=	=	L ↓	=	=	L ↓	=	=
9 boys	=	=	L ↓	1 ↓	=	L ↓	L ↓	L ↓
girls	=	=	L ↓	=	=	L ↓	L ↓	L ↓
10 boys	=	=	L ↓	=	=	R1 ↑	L ↓	=
girls	=	=	=	=	=	L ↓	=	=
11 boys	=	=	L ↓	=	=	L ↓	R2 ↑	=
girls	=	=	L ↓	=	=	L ↓	=	=
12 boys	=	=	L ↓	=	L1 ↓	L ↓	=	=
girls	=	=	L ↓	=	=	L ↓	=	=

Table 7-3: Comparison of the mean values of forces exerted by the hand and by (thumb and) forefinger per age group and sex.

= : *no difference between right and left;*

R : *both tests with right;* R1 : first test with right; R2 : second test with right;

L : *both tests with left;* L1 : first test with left; L2 : second test with left;

1 : *first test with right and first test with left;*

↓↑ : *this/these value(s) was/were lower/higher than the other values;*

* = *This, for example, means that the grip force of 4-year-old boys, exerted by the left hand, is lower than the grip force exerted by the right hand.*

The result was that only the grip force of the left hand was clearly lower than that of the right hand. For the other forces of the hand no systematic differences could be found.
For forces exerted by the finger there was a difference between the right and left finger in pushing force and some of the pinch and torque measurements.
It can be concluded that in some age groups differences exist between the left and right hand; generally speaking, however, these differences are not very large.
An explanation for these systematic differences between right and left can only be an actual difference in strength. Why these differences are not consistently apparent is not clear.
For subsequent analyses we used, in view of the results of the initial analyses, the median value of the four measurements of one kind of force exertion (2x right, 2x left) irrespective of the preferred or non-preferred hand.

7.3.5 Test-retest reliability

Seventy-nine randomly chosen children, out of the 889 children who participated in this investigation, were measured a second time one day to one week after the first assessment. The correlation coefficient between the median of the first assessment and the median of the second assessment was computed for each of the exerted forces (see table 7-4).
The conclusion must be that the reproducibility of the measurements was sufficiently high.

type	member	correlation coefficients
pull	hand	0.88
	finger	0.91
push	hand	0.92
	finger	0.96
grip	hand	0.97
	finger	0.91
torque	hand	0.86
	finger	0.88

Table 7-4: Correlation coefficients between first and repeated assessment.

7.3.6 Representativeness

In another analysis the possibility of using one type of force exertion to represent all the other forces, in order to predict other forces when only one of them is known, was evaluated. A correlation matrix was calculated for the variables.

	pull hand	pull finger	push hand	push finger	grip hand	grip finger	torque hand
pull finger	0.62						
push hand	0.72	0.61					
push finger	0.44	0.56	0.54				
grip hand	0.29	0.39	0.37	0.48			
grip finger	0.40	0.46	0.48	0.55	0.44		
torque hand	0.46	0.45	0.48	0.32	0.35	0.39	
torque finger	0.36	0.45	0.43	0.47	0.42	0.46	0.52

Table 7-5: Correlation coefficients between the forces measured.

In the correlation coefficients of table 7-5, age plays an important role, because children between 4 and 13 years of age have been grouped together and are considered as a homogeneous group. They should, however, be separated into different groups, each consisting of children in the same phase of life. The correlations should have been computed per age group in order to obtain more precise values, providing insight into the 'real' correlation between two kinds of forces. Therefore, in addition, a partial correlation table was drawn up, in which a correction was made for age and sex, because both variables influence the amount of force exerted (as will be shown in paragraph 7.3.7.).

	pull hand	pull finger	push hand	push finger	grip hand	grip finger	torque hand
pull finger	0.62						
push hand	0.72	0.61					
push finger	0.44	0.56	0.54				
grip hand	0.29	0.39	0.37	0.48			
grip finger	0.40	0.46	0.48	0.55	0.44		
torque hand	0.46	0.45	0.48	0.32	0.35	0.39	
torque finger	0.36	0.45	0.43	0.47	0.42	0.46	0.52

Table 7-6: Partial correlation coefficients between the forces measured after adjustment for age and sex.

It is clear that none of these forces correlates closely with other forces. Therefore none of them can be considered a good predictor for the others. However, there does seem to be a clear relationship between the pushing and pulling forces of the hand.

7.3.7 Results of the measurements

Tables of the median values of the four measurements (two with right hand and two with left hand) were prepared per age group and per sex. Both these tables and diagrams of the results can be found in appendix G.

For all forces, differences between boys and girls of the same age and differences between adjacent age groups were analyzed by means of the t-test. The results of these tests are summarized in table 7-9. It can be concluded that, in general, boys are stronger than girls.

With increasing age force exertion increases too, although this is less pronounced among the girls above 11 years of age.

age [years]	pulling hand		pulling finger and thumb		pushing hand		pushing finger	
	t	p	t	p	t	p	t	p
4			2.51	0.014	2.24	0.027		
5	2.44	0.017			3.42	0.001	2.02	0.045
6					2.28	0.025		
7					2.18	0.032		
8	2.37	0.021	2.64	0.010	3.69	0	3.36	0.001
9					2.84	0.006		
10					2.87	0.006		
11					2.68	0.009	2.73	0.008
12	2.42	0.019	2.09	0.041			2.82	0.007

7-7 a Differences in exertion of force between boys and girls of various ages

age [years]	pulling hand		pulling finger and thumb		pushing hand		pushing finger	
	t	p	t	p	t	p	t	p
4 – 5			-2.69	0.009	-2.53	0.013	-4.43	0
5 – 6			-2.68	0.008	-2.52	0.013		
6 – 7	-2.48	0.015	-2.71	0.008	-2.31	0.023	-3.41	0.001
7 – 8					-2.20	0.030	-2.87	0.005
8 – 9	-2.20	0.031						
9 – 10			-2.34	0.023	-2.55	0.013	-2.95	0.005
10 – 11								
11 – 12	-2.65	0.010	-2.54	0.013			-2.84	0.006

7-7 b Differences in exertion of force between boys of adjacent age groups

age [years]	pulling hand		pulling finger and thumb		pushing hand		pushing finger	
	t	p	t	p	t	p	t	p
4 – 5	-2.11	0.038	-4.31	0			-3.66	0
5 – 6	-2.87	0.005	-3.44	0.001	-3.71	0	-2.95	0.004
6 – 7	-2.25	0.028	-2.80	0.006			-2.93	0.005
7 – 8								
8 – 9	-3.40	0.001	-4.54	0	-2.87	0.005	-2.91	0.005
9 – 10					-2.49	0.015	-2.87	0.005
10 – 11			-2.05	0.043				
11 – 12								

7-7 c Differences in exertion of force between girls of adjacent age groups

Table 7-7: The t-statistic for differences between sexes and between age groups. Non-significant ($p > 0.05$) have been omitted.

grip hand		grip finger and thumb		torque hand		torque finger and thumb		total score	
t	p	t	p	t	p	t	p	t	p
								3.56	0.001
3.11	0.002	3.16	0.002	2.04	0.044				
				2.64	0.009	2.02	0.046	2.58	0.011
		2.13	0.036	2.82	0.006			2.21	0.030
4.07	0.000	3.23	0.002			2.85	0.006	4.05	0
3.25	0.002	3.44	0.001	2.38	0.020			2.84	0.006
2.33	0.023	3.46	0.001	3.63	0.001	2.75	0.008	3.41	0.001
3.30	0.001	4.13	0			2.72	0.008	3.18	0.002
2.30	0.026	2.12	0.039			2.51	0.015	2.63	0.011

7-7 a (continued)

grip hand		grip finger and thumb		torque hand		torque finger and thumb		total score	
t	p	t	p	t	p	t	p	t	p
-5.44	0	-4.56	0	-3.84	0	-4.69	0	-5.40	0
-3.12	0.002			-3.50	0.001	-3.94	0	-3.96	0
-5.36	0	-3.89	0					-3.66	0
-3.20	0.002	-2.03	0.045			-2.87	0.005	-2.76	0.007
-3.71	0	-2.28	0.025					-2.70	0.009
-2.65	0.010	-3.65	0.001	-2.33	0.022	-3.38	0.001	-3.52	0.001
-2.19	0.031								
-2.62	0.011					-2.35	0.022	-2.71	0.009

7-7 b (continued)

grip hand		grip finger and thumb		torque hand		torque finger and thumb		total score	
t	p	t	p	t	p	t	p	t	p
-4.77	0	-3.23	0.002	-2.90	0.005	-4.00	0	-4.53	0
-4.97	0	-3.91	0	-2.83	0.006	-3.73	0	-5.20	0
-3.56	0.001	-3.40	0.001			-2.96	0.004	-3.11	0.003
-4.23	0	-2.42	0.018			-2.50	0.015	-3.91	0
-2.98	0.004	-2.67	0.009					-2.75	0.007
						-2.17	0.033		

7-7 c (continued)

Table 7-7 (continued)

7.3.8 Typing individuals

In addition to collecting data suitable for use during a design process, we also tried to establish a total score for force exertion that could be used to describe the capacities of children at a given age.

In order to determine the best method for computing a total score, a factor analysis (Principal Components) of a partial correlation matrix was performed. This matrix had been corrected for age and sex in order to exclude the influence of these variables on the force exerted. This factor analysis resulted in one factor, explaining 53.2 % of the variance. Each of the variables had a factor loading between 0.16 and 0.19. These loadings were so similar that we decided to add the variables without using factor weights. Before being able to do so, the variables had to be independent of the scale and dimensionless. To achieve this, a z-score was computed for each of the median values of the forces for all ages together. This is a standardized score with mean 0 and standard deviation 1. In order to avoid a negative sum score, the quotient of the mean and standard deviation of each force was added to the sum of z-scores. This resulted in a scale between the values 3.09 and 53.90. These are the values someone would achieve who exerted the lowest and the highest maximum forces respectively. It should be noted that these values are dependent on the sample. The total scores for exertion of force per sex and age group are presented in table 7-8. In figure 7-1 the mean values of the total score per age and sex are plotted.

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0 – 4.9	41	2.38	6.20	9.92	14.15	46	2.34	4.92	8.97	14.01	2.39	9.42
5.0 – 5.9	53	2.42	7.29	12.62	16.98	59	2.30	6.61	11.04	14.94	2.48	11.79
6.0 – 6.9	59	2.78	10.06	14.58	19.36	57	2.45	8.61	13.32	18.05	2.69	13.96
7.0 – 7.9	50	3.75	12.18	16.93	26.51	42	3.45	10.61	15.26	21.86	3.70	16.17
8.0 – 8.9	41	3.84	12.21	19.14	27.75	40	3.51	9.68	15.83	22.25	4.02	17.50
9.0 – 9.9	41	3.97	13.82	21.47	28.64	42	3.88	12.89	19.02	27.78	4.09	20.23
10.0 – 10.9	35	5.95	16.61	25.63	35.32	39	4.32	14.93	21.53	30.54	5.52	23.47
11.0 – 11.9	40	5.14	20.51	27.05	39.39	44	4.99	16.66	23.53	34.15	5.33	25.21
12.0 – 12.9	30	5.90	19.35	30.63	42.48	23	7.41	12.46	25.81	40.68	6.96	28.54

Table 7-8: Standardized total score for eight forces exerted by boys and girls aged 4 to 13 years.

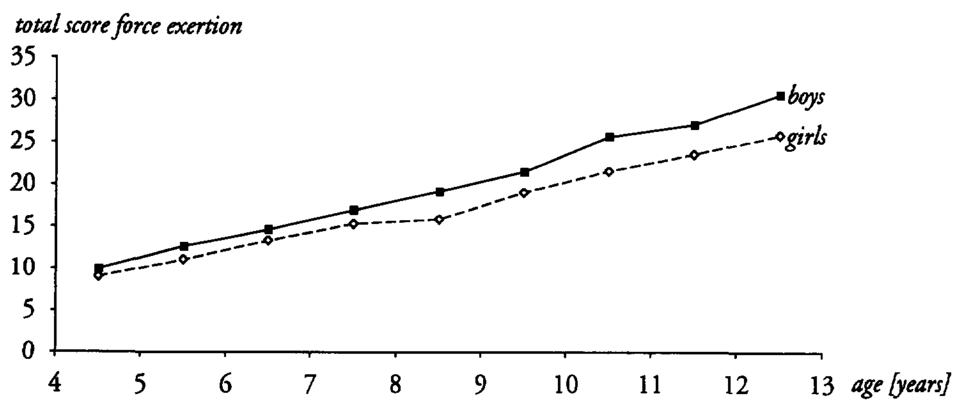


Figure 7-1: Mean values per age group and sex of the standardized total scores for force exertion.

7.4 Conclusions

7.4.1 Measuring method

In this study we chose a standard measuring posture. It appeared to be very difficult for the younger children to maintain this posture while exerting force. For them the aim seemed to be to push, pull, pinch or twist as hard as possible, not to do this while maintaining the required posture. However, when the posture diverged too much from the prescribed one, then the measurement was not valid and it was performed again.
The correlations between the first and second measurements were high. It is therefore concluded that the reproducibility of the measurements was good.

7.4.2 Development

As expected, the mean values for force exertion as well as the standard deviations of these values increased with age. This also appears from the correlation coefficients between standard deviation and age groups per sex, as shown in table 7-9 (the correlation coefficients between age and force exertion are also listed).

	correlation coefficients			
	with standard deviation per age group		with age	
	boys	girls	boys	girls
pulling force hand	0.93	0.92	0.93	0.92
pulling force thumb and finger	0.95	0.97	0.95	0.97
pushing force hand	0.78	0.92	0.78	0.92
pushing force finger	0.96	0.93	0.96	0.93
grip force hand	0.92	0.92	0.92	0.92
pinch grip finger	0.92	0.94	0.92	0.94
torque of the hand	0.96	0.92	0.96	0.92
torque of thumb and finger	0.88	0.89	0.88	0.89
total score on force exertion	0.94	0.92	0.94	0.92

Table 7-9: Correlation coefficients between force and standard deviation per age group and age per sex.

It can be concluded that, here too, the individualization of children increases with age. With the exception of the pushing force of the hand, the differences in correlation (and therefore the differences in standard deviations) between boys and girls are not very large.
The tables show that –as expected– boys are in general stronger than girls. It is striking, however, that the magnitude of the differences seems to be rather constant and that the differences are already apparent at the age of four (see also appendix s). As mentioned before, the difference in force exertion between males and females appears to be very small, provided that a correction is made for body composition, in this case body fat or muscular mass. If we assume that this is also true for children, then it has to be concluded that a difference in body composition already exists at the age of four. This parameter was, however, not explicitly measured in this study, but it can be estimated using anthropometric variables and ratio's.

In this study we used the Quetelet index as an indication for the proportion of fat in the body. The Quetelet index is defined as body mass/body $height^2$. The correlation coefficient between the Quetelet index and the total score for force exertion was 0.43 for boys and 0.45 for girls. Both values are significantly different from zero.
The correlation coefficient between age and Quetelet index is 0.38 ($p < 0.001$). Thus for the correlation between Quetelet index and force exertion, the age of the subjects is an explanatory variable. Therefore it could be interesting to compute a standardized score. For this purpose deviation scores (z-scores) for the Quetelet index per age group and sex were computed, to eliminate the effects of age. The correlations between the z-score and the total score for force exertion are:

all subjects	boys	girls
0.1122	0.0843	0.1548
(n = 722)	(n = 386)	(n = 386)
p = 0.002	p = 0.098	p = 0.002

The correlation coefficients reveal a slight positive relationship between the exerted force and the deviation score for the Quetelet index. Children whose Quetelet index is higher than that of children of the same age (and thus have relatively more fat tissue) are able to exert a (slightly) larger amount of force than children of the same age. This is especially true for girls. However, this is not in accordance with findings for adults, which suggest that a correction for the amount of muscle tissue is needed in order to get comparable values of force exertion for men and women (Hosler and Morrow, 1982 and Bishop et al., 1987).

7.4.3 Differences between the hands

A clear difference in the force exerted by the right and the left hand was not found in this project. This is also true for the possible difference between preferred and non-preferred hand. Differentiation of muscle tissue and/or training of the different muscle groups has probably not yet occurred or has not progressed far enough to be significantly effective.

7.4.4 Mutual predictability of forces

For those involved in product design the specifically required data on force exertion are not always available. Sometimes, however, certain measurements, may be provided. In such a case it would be useful to be able to predict the desired values from the data available. This study shows, however, that this is not possible for the force exerted by children aged 4 to 13 years. This is indicated by the fact that the correlations between the different kinds of force were low, when corrected for age and sex.

8 Motor performance

8.1 Introduction

Motor development can be defined as a systematic change in movement skills during life; this process leads to motor skills and automatisms, which enable us to perform efficiently several activities at one time. Many theories have been proposed to explain development and the differences in the rate of development between individuals. Some theories consider development as being mainly genetically determined, others believe it is more a question of learning.

Most theories on development in general, and motor development in particular, combine these two points-of-view and emphasize that some aspects of development are innate, while others are learned and developed by practice: a mixture of 'nature and nurture' as it were. This is illustrated, for example, by Gallahue's definition of motor development:

> *'A progressive change in motor control and motor behavior brought about by the interaction of both maturation and experience'* (Gallahue, 1982, p. 19).

In the next section phases of motor development are described.

8.2 Phases of motor development

The development of a child's motor behaviour is a sequential process. It proceeds from simple reflexes to the learning of postural movements, to locomotor movements and finally to (fine) manipulative movements. These facilities increase simultaneously with the development of motor control, which develops in a cephalocaudal direction (from head to feet) and also in a proximodistal direction (from the midline of the body to the extremities).

Four stages of development are usually being distinguished. During infancy it progresses from reflexive responses to rudimentary movement, which includes sitting, crawling, creeping, standing and walking. During early childhood the abilities to run, climb, jump, balance, catch and throw are developed. These skills are labelled general fundamental skills. These skills are common to all healthy children and normally develop in the same order in all children. The rate at which these skills develop will, however, vary. During late childhood more specific movement skills will appear, while the general fundamental skills become more refined, will appear more fluid and are more automatic. During adolescence the specific movements develop further and can be called specialized. This process depends on the amount of practice an individual has with specific skills, which is influenced by talent, motivation and stimulation as well as success and failure.

It can be said that motor behaviour develops within a continuum from rudimentary to specialized and also within a continuum from gross to fine. Gross motor skills incorporate large muscles, usually separate muscle groups simultaneously. Examples of gross motor skills are running, climbing, jumping, balancing and throwing. Fine motor skills involve small muscles and limited activities of the body extremities. Examples of fine motor skills are manipulating with cubes and writing.

Several attempts have been made to discover whether certain skills are the result of genetic predisposition or are learned. In order to investigate the role of heredity in motor skill development, twin studies have been performed. Sklad (1975) concluded from his investigation that dizygotic twins differed more in motor learning capacity than monozygotic twins; that the level and rate of learning exhibited higher genetic control among boys than girls; and that genetic influence on the learning of motor skills was task-specific. Gedda et al. (1964) –among others– point towards a possible heredity-environment interaction.
There have also been some investigations into the effect of early training on motor development. The classical study of Johnny and Jimmy by McGraw (1935) is an example of this kind of investigation. She concluded that behaviours not controlled by the cerebral cortex (such as reflexes) are not affected by either specific training or practice. A second conclusion was that rudimentary skills are not enhanced by early practice; therefore maturation dictates this type of behaviour. More complex behaviour (such as general coordination) can be enhanced by practice, but the degree of success depends on the task.
Today it is generally accepted that both heredity and environment determine the level of skill. The nature-nurture debate is still relevant to the kind of interaction as well as the degree, specificity and variation of the influence of specific aspects of both groups.

Generally speaking the sequence of the developmental stages is the same for all children. The rate of development will vary. As far as the rate of development is concerned, differences between the sexes can be distinguished. Zaichkowsky et al. (1980) listed some of these differences:

- During the infant stage of development few significant differences between the sexes in motor development exist, even though in most cases girls have a nervous system that is more mature than that of boys.
- During early childhood differences between the sexes appear: girls are more proficient in hopping, skipping and balancing, while boys excel in running and throwing.
- The late childhood years are characterized by larger differences between the sexes in a variety of tasks, such as running, jumping, throwing and some balance tests. These aspects of motor behaviour are performed better by boys than girls. When it comes to flexibility and fine motor tasks, girls appear to do better.
- During adolescence the differences become even greater. Boys improve their performance throughout adolescence, whereas girls peak at about age 14 and then either level off or even decrease in performance.

In general boys do better at strength-related gross motor tasks and girls do better at tasks that require flexibility and fine motor coordination. (Zaichkowsky et al., 1980).

In literature on differences between the sexes four reasons for the above-mentioned differences are given: body size, anatomical structure, physiological functioning and social and cultural factors. The authors in this field, however, do not always agree on the influence of these factors. For example Eckert (1973) mentioned body size as an explanation for different achievements relative to motor behaviour among children during early childhood, whereas Zaichkowsky et al. (1980) stated that during adolescence body size will have a positive impact on performance only for motor skills requiring strength. During adolescence, when the differences in the anatomical structure of boys and girls become more pronounced, the difference in body build will account for differences in performance. During childhood,

however, anatomical differences will contribute little to the differences in motor behaviour. The same can be applied to physiological functioning. Beyond the age of 12 boys have about a 30% higher oxygen-uptake capacity than girls. Therefore endurance-type activities will be performed better by boys than girls. Before the age of 12 physiological capacity does not seem to be a reasonable explanation for the observed differences in motor performance between boys and girls (Åstrand (1976), referred to by Zaichkowsky et al. (1980)). Recent research suggests that differences between the sexes in the brain may influence the observed differences in motor performance between boys and girls (Kimura, 1992). A difference in encouragement to excel in motor tasks between boys and girls might also explain the observed differences. Boys are stimulated to practice gross motor skills, while girls are expected to perform fine motor skills more often. Eckert (1973), however, showed that the 'plateau effect' of the performances of girls is not necessary. Bulgarian girls continued to improve their throwing and running skills through 16 and 18 years, respectively, whereas American girls levelled off at 15 and 13 years, respectively. This indicates that cultural values have an effect on performance.
Some authors believe that if boys and girls receive similar opportunities to participate and train as well as the same social approval, there would be no differences in performance throughout childhood and the early adolescent years (Eckert (1973), Wilmore (1974), Zaichkowsky et al. (1980)). The narrowing gap between athletic records also supports this view.

8.3 Measuring methods

In developmental psychology many testing methods have been designed in order to establish norms for motor development at different ages. Most tests are made to measure children in a rather limited age range. Some tests consist of items related to general aspects of motor behaviour, such as strength, speed, balance and coordination. Most tests, however, only cover one of these aspects of motor behaviour, mainly because of the fact that such tests are part of a study of overall development. In these cases the aim is to assess social, affective, cognitive and motor development, which almost has to imply that the test will not cover all aspects of motor behaviour separately.
Another peculiar aspect of these tests –when used to assess motor development– is the fact that they are meant primarily to screen children for retarded development.
These tests often consist of observation scales, the disadvantage being that children might not show their capacities in an unfamiliar situation or surroundings; moreover without adequate training, the observers might use different criteria, resulting in observer effects. Another negative aspect of observation scales appears when the parents are asked whether their child can perform a certain motor skill. Proud parents will probably tend to confirm this.

Wiegersma (1986) described several tests and observation scales which are used to evaluate motor skills. An overview of these tests is given below.

1. *Oseretzky's motor development scale, (Oseretzky, 1925).*
   The target group of this scale is children aged 4 to 16 years. It consists of 85 items, evaluating 6 components of motor performance:
   · static coordination
   · dynamic coordination of the upper extremities
   · general dynamic coordination
   · speed of movement
   · simultaneousness of movements
   · isolation of movements.

   For each age group six items were chosen as being representative of the components of motor performance; each one was supposed to represent two months of motor development. The test results presumably led to a motor quotient and a motor profile. Later studies proved that this test lacked a factor structure, and thus that is was impossibile to generate a valid motor profile of the person being tested. It was mainly used to diagnose motor retardation.

2. *Lincoln-Oseretzky motor development scale, (Sloan, 1954).*
   This is an adaptation of the Oseretzky scale, containing 36 of the 85 Oseretzky items. The principle of 'motor-development-age', as suggested by Oseretzky, was discarded. This scale was only intended to be used as a research instrument, that had to be improved before it possibly could be used for diagnostic purposes.

3. *The LOS-KF 18, (Eggert, 1974).*
   This is an abbreviated version of the Oseretzky scale, which seems to be suitable for individual motor diagnostics of the backward and/or learning retarded child aged 5 to 14 years. For normal healthy children the test is suitable for children up to 8 years of age. It gives a global impression of the motor skills of children.

4. *Bruininks-Oseretzky test of motor proficiency, (Bruininks, 1978).*
   This test consists of 46 items and is useful for testing children 4.5 to 14.5 years of age. The items are divided into 8 subgroups, aimed at measuring:
   · speed and dexterity
   · balance
   · bilateral coordination
   · strength
   · coordination of the upper extremities
   · reaction time
   · visuo-motor control
   · speed and manual dexterity

   This adaptation seems to be the most suitable one for normally developing children. A disadvantage of this test is that it is time-consuming (55 minutes per child). The short form of this test (14 items) still takes 20 minutes.

5. *Fostig Movement Skill Test Battery, (Orpet, 1972).*
   This test was also developed to screen children in the age range 6 to 12 years for motor retardation. Starting point of this test is recognition of the fact that motor behaviour cannot be seen as a one factor, because it consists of several aspects: coordination, dexterity, flexibility, strength, balance and endurance. For each of these aspects test items were developed.
6. *Hamm-Marburger Körpergeschicklichkeitstest für Kinder* (HMKTK), *(Kiphart and Schilling, 1970).*
   This test is described as a test for motor development, its items measuring 'general dynamic coordination and body control'. When the items are studied more carefully, however, balance seems to be the main aspect tested. The target group is children between 5 and 10 years of age.

It can be stated that the tests described all had one or more disadvantages, which made them unsuitable for use in this investigation. Either the test did not cover the whole range of ages, or the test was very one-sided because only some aspects of motor development were assessed or –and this was the main disadvantage– the test was meant to be used to screen for motor retardation instead of assessing the state of motor development of the child being tested. Other disadvantages are the need for special equipment and the long time required to test a child. These disadvantages were recognized by Zimmer (1981). She developed a test that would not require much equipment or time and would interest the children.

The test, called MT 4-6, was meant for children aged 4 to 6. It consisted of 18 items, measuring:
- manoeuvrability and motility of the body,
- dexterity,
- balance,
- reaction time,
- strength and speed,
- accurateness of movements,
- coordination.

8.4 Mot '87k

For our investigation we chose the MOT '87 (van Rossum, 1989), an adaptation of Zimmer's test of motor behaviour. The original version of the test consisted of 18 items, and its target group was normal, healthy children in the age group 4 to 6 years (Zimmer, 1981). Van Rossum made the test suitable for the age range 4 to 12 years by enhancing the difficulty of some of the items and adjusting the way in which they are scored. This resulted in two versions of the test, one for children in grades 1-4 (age 4 to approximately 8 years) and the other for children in grades 5-8 (age 8 to approximately 12 years).

Statistical analyses of data obtained with the MOT '87 have been published (van Rossum, 1987a, 1987b, 1990). Both versions of the test meet the following criteria:
1. The items of the test are congruent (the test is reliable in the sense of 'internal consistency').
2. The test is suitable for primary school children.
3. Little preparation time is needed.
4. The initial expenses for equipment are low.

The validity of the test was determined by measuring both 'normally developed children' as well as children who needed MRT (Motor Remedial Teaching). The latter group had significantly lower scores, which supports the empirical validity of the test. The separate items of the test show 'face validity': the test gives a convincing impression of measuring various motor performances.

The reliability coefficient α, for internal consistency, was 0.73 for the lower classes, when 16 out of 23 items were included. For the higher classes α was 0.74, when 19 out of 23 items were included. Because different items had to be deleted in order to obtain the highest α, only the items to be deleted from both versions of the test were not included when van Rossum composed the final version. The final version of the MOT '87 consists of 22 items, including one 'warming-up' item.

The test-retest reliability was established by testing children, from grades 3 to 7, twice within 35 days. The correlation between the two measurements was 0.87 for the lower classes and 0.77 for the upper classes. Within these two groups 72% and 75% of children, respectively, had a difference in total score between the first and the second measurement of 5 points or less. (The maximum obtainable score was 48 points). Van Rossum interpreted this as being an acceptable difference and judged the reproducibility of the MOT '87 to be sufficient.

Because of above-mentioned criteria the MOT '87 was chosen for our investigation. The most important reasons were its suitability for primary school children, so that only one test was needed, and the time required per child to perform the test.

Due to practical problems, however, some items had to be excluded from the test; this did not affect the reliability of the test (personal communication, van Rossum, 1989). This abbreviated form of the MOT '87 is called the MOT '87k and consists of the following items (descriptions of these items are given in appendix H):

item 1: jump in and out a hoop;
item 2: walk a straight line; the second time include standing on one leg for 10 seconds (including 5 seconds with the eyes closed);
item 3: put dots on a piece of paper with a pencil;
item 4: pick a handkerchief up off the ground with the toes;
item 5: jump sideways from one side of a line to the other;
item 6: run with tennis balls;
item 7: pick up matches;
item 8: hop in and out a hoop;
item 9: catch a ring;
item 10: 'Hampelmann' jump;
item 11: standing high jump;
item 12: roll around the long axis of the body;
item 13: jump in and out of a hoop while turning 180 degrees;
item 14: standing broad jump;
item 15: step over a stick;
item 16: clap the hands in front of and behind the body, while skipping.

The diversity of the items should give us an impression of the variety of motor performance. It was not our absolute goal to provide a representative and valid assessment of 'the' motor development of 'the' child.

The first item is a warming-up item and was not included in the calculation of the total score. The performance of each item was scored with 0, 1 or 2 points. In addition the time needed to perform the item or the distance –in centimetres– jumped was recorded.

The sequence of the items of the test was the same for all children. Children from the sample were measured in random order, one child at a time. In so far as possible no spectators were present during the test.

All children seemed to be very willing to participate in the test, because the measurements were taken during school hours and the children were allowed to miss their lessons. Testing of the children in the lowest classes took about 20 minutes, the eldest children performed the test in about 12 to 15 minutes.

Three observers were involved in this part of the investigation. They had been trained by the author of the test, both in the laboratory and at school. Two observers worked together –one child observed by just one observer– at the schools in the provinces of Groningen, Friesland, Drenthe, Gelderland, Utrecht, Noord- and Zuid-Holland, the third observer worked alone at schools in three other provinces (Overijssel, Noord-Brabant, Limburg). In Flevoland and Zeeland, however, the motor development of children was unfortunately not measured due to practical problems.

8.5 Calculation of the total score

Van Rossum calculated the total score, by combining the points and time or centimetres recorded for each item. In order to explain his method, an example will be given using item 4: pick a handkerchief up off the ground with your toes.This item is described as: a handkerchief must be picked up with the toes and lifted to knee height.

The points were awarded as follows:
2: the handkerchief is picked up with the toes and lifted to knee height;
1: the handkerchief is picked up with the toes, but dropped before it reached knee height;
0: the handkerchief could not be picked up with the toes.
In addition to the points (0, 1 or 2 points), the time required to perform this item was also recorded.

Only a performance of 2 points –meaning the item was performed according to the requirement– combined with a time that fell within the lowest 33% of the sample norm for the time needed by the entire group to perform the item resulted, according to the method of van Rossum, in a score of two. Therefore children meeting these two criteria had a score of two. When they had two points for performance and the time fell between 33% and 66%, they received a score of one. All other children did not receive any score for that item. The scores per item were added to get the total score of the entire test.

Examination of the data led to a method of calcultation of the total score which was not entirely identical to that of van Rossum. The reason was the fact that in our series some items exhibited a highly skewed distribution, which implied that either all or none of the children got points. The difference is that we also gave points to children who did not get 2 points for performance, by combining the points for performance with the time taken. We preferred this approach because we considered all items as behavioural variables with a range in level and time.

In the above-mentioned example of the handkerchief, the shortest time required to perform this item was equal to 2.00 points, the longest time needed was equal to 0.00 points. All the times in between were transformed into a point on the continuum between 2.00 and 0.00. In this way both time and level had a value between 0.00 and 2.00. The points for both parts (level and time) were added and divided by two, in order to keep the score between 0.00 and 2.00. The result is that, besides the fact that *all* children received points, the score received per item now lies on a scale between 0.00 and 2.00, instead of being a discrete score of 0, 1 or 2.

8.6 Analysis of the data

In total 552 children between 4 and 13 years of age participated in this part of the investigation.

First the general statistics of each item were studied to identify extreme values. The extreme values were then inspected and, when possible, corrected or recoded. If impossible, they had to be deleted. Fortunately, this was rare. Only the data for one child had to be deleted, because of the fact that too many items were missing.

Originally the MOT '87k consisted of two versions, one for the lower classes and one for the upper classes of primary school. The difference between the versions was that two items consisted of slightly different tasks for lower and upper classes; furthermore different norms were used to calculate a total score for each version. Due to the new way of calculating the total score used in this investigation, the second difference was no longer relevant. For this reason we combined the two versions, deleting the two items that were different in the two versions (item 8 and item 11). A third item (item 12) was discarded due to its substantial observer effect. This resulted in a test for motor performance consisting of 13 items with equal tasks for all children; one of them was a warming-up item, which was not included in the analyses.

The mean value and the standard deviation per item are given in table 8-1.

	$\bar{x}$	s
item 2	1.18	0.76
item 3	0.77	0.36
item 4	1.65	0.41
item 5	0.92	0.42
item 6	1.39	0.25
item 7	1.63	0.26
item 9	1.38	0.82
item 10	1.01	0.87
item 13	1.21	0.60
item 14	1.19	0.31
item 15	1.52	0.36
item 16	1.54	0.62

Table 8-1: Mean value and standard deviation per item.

factor loadings	factor scores
0.68170	0.10660
0.72382	0.11319
0.56748	0.08874
0.88410	0.13825
0.78697	0.12306
0.84981	0.13289
0.75987	0.11882
0.57154	0.08937
0.59839	0.09357
0.80951	0.12659
0.72242	0.11297
0.72235	0.11296

8-2 Factor loadings and factor scores resulting from the factor analysis

A Factor Analysis (Principal Components) yielded 1 factor, explaining 53.3% of the variance. Factor loadings ranged between 0.567 and 0.884 (table 8-2). The analysis of internal consistency yielded an alpha of 0.8795. The statistics are presented in table 8-3.

	scale mean if item deleted	corrected item-total correlation	α if item deleted
item 2	14.2110	0.6030	0.8707
item 3	14.6303	0.6373	0.8698
item 4	13.7435	0.4936	0.8746
item 5	14.4760	0.8344	0.8590
item 6	14.0017	0.6975	0.8719
item 7	13.7668	0.7835	0.8691
item 9	14.0117	0.6695	0.8671
item 10	14.3867	0.5172	0.8829
item 13	14.1893	0.5399	0.8723
item 14	14.2047	0.7284	0.8681
item 15	13.8805	0.6464	0.8694
item 16	13.8514	0.6587	0.8646

Table 8-3: Results of the reliability analysis.

The first column of table 8-3 shows what the average score for the scale were to be if the item were excluded from the scale. The second column is the Pearson correlation coefficient between the score on the individual item and the sum of scores on the remaining items. The last column shows the value for Cronbach's α if the item were to be deleted from the scale.

The statistics presented above gave no reason to use different weights per item when adding the results of the items to obtain a total score. Therefore the total score was determined by just adding the score received for each of the 12 items, the maximum total score being 24.00 points.

The resulting motor scores are presented in table 8-4 and figure 8-1.

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0 – 4.9	21	2.62	3.72	7.84	13.22	26	2.73	3.47	8.51	14.42	2.67	8.21
5.0 – 5.9	39	2.31	6.81	10.42	15.13	38	2.36	6.38	10.75	14.25	2.33	10.59
6.0 – 6.9	40	2.59	7.48	12.24	16.60	41	2.27	10.70	14.60	18.54	2.70	13.43
7.0 – 7.9	40	2.56	9.01	14.57	17.85	31	2.35	11.38	16.07	20.05	2.56	15.23
8.0 – 8.9	31	1.79	13.01	16.87	19.91	26	1.79	12.37	17.03	19.26	1.77	16.94
9.0 – 9.9	30	2.02	13.77	17.60	20.63	31	1.37	15.36	18.86	21.21	1.82	18.24
10.0 – 10.9	24	1.28	15.80	18.91	21.25	29	1.65	13.96	19.34	21.30	1.50	19.14
11.0 – 11.9	31	2.10	13.02	18.77	21.89	31	1.51	16.59	19.48	22.20	1.85	19.12
12.0 – 12.9	26	1.98	15.19	19.73	22.19	17	1.41	16.67	19.83	21.67	1.76	19.77

Table 8-4: Motor score for boys and girls between 4 and 13 years of age per age group.

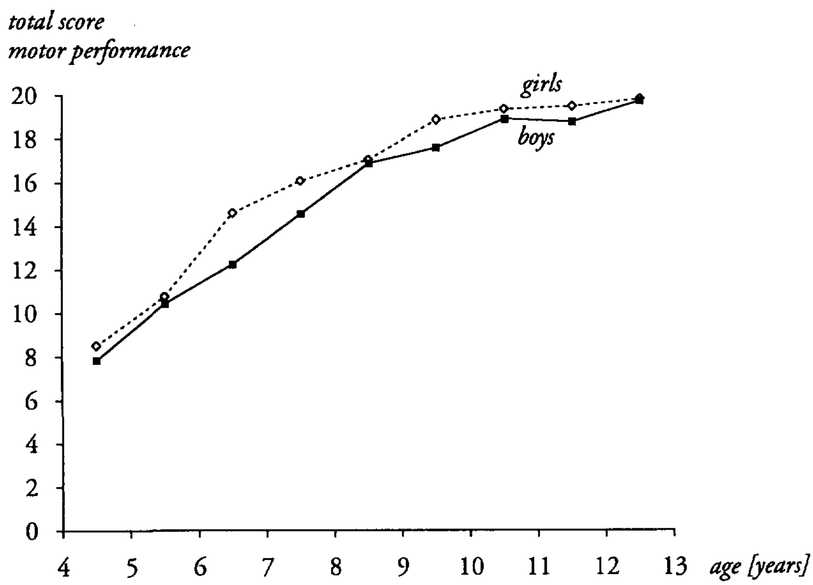


Figure 8-1: Mean score of motor performance according to age and sex.

The correlation coefficient between age and individual total score was 0.8342.

Regression analysis yielded the following equation as the best predictor of the motor score:

motor score = 2.02 + 1.45 · age + 0.90 · sex (r = 0.84)

An analysis of variance revealed main effects of age (F = 220.739, p = 0.000), sex (F = 26.469, p = 0.000) and observer (F = 6.8320, p = 0.001) and an interaction effect of age and sex (F = 2.243, p = 0.023). No interaction between observer and sex was found.

8.7 Results

8.7.1 Sex

The mean scores for boys and girls per age group were tested with the t-statistic. The MOT '87k was supposed to be equally difficult for boys and girls. The results of the t-test show, however, that the mean scores differ significantly between boys and girls at ages 6, 7 and 9. The statistics are presented in table 8-5.

age [years]	results t-test t	p
4.0 – 4.9	-0.85	0.398
5.0 – 5.9	-0.63	0.533
6.0 – 6.9	-4.35	0.000 *
7.0 – 7.9	-2.53	0.014 *
8.0 – 8.9	-0.34	0.733
9.0 – 9.9	-2.85	0.006 *
10.0 – 10.9	-1.04	0.304
11.0 – 11.9	-1.53	0.132
12.0 – 12.9	-0.18	0.860

Table 8-5: Results of the t-test, comparing mean values between boys and girls per age group.
** denotes significant difference ($p < 0.05$; two-sided).*

According to the author of the test there were not supposed to be any differences in mean score between boys and girls, because items testing balance and fine motor skills are offset by items measuring speed and strength. However, differences between boys and girls were found. Therefore all items were examined separately in order to find out whether the above-mentioned compensations are true.
An analysis of variance revealed significant differences in mean score per sex for the following items, when age and observer were used as covariates (table 8-6):

			mean score		significance	
			boys	girls	F-value	p
item	2	balance	1.13	1.24	5.72	0.017 *
item	3	dotting	0.80	0.73	8.32	0.004 *
item	4	pick up handkerchief	1.62	1.69	6.03	0.014 *
item	5	side jumps	0.89	0.95	17.27	0.000 *
item	6	run with ball	1.43	1.36	15.54	0.000 *
item	7	pick up matches	1.62	1.64	3.37	0.067
item	9	catch ring	1.45	1.32	3.45	0.064
item	10	Hampelmann	0.81	1.22	47.95	0.000 *
item	13	turn while jumping	1.14	1.27	12.73	0.000 *
item	14	broad jump	1.22	1.16	7.31	0.007 *
item	15	step over stick	1.48	1.56	14.13	0.000 *
item	16	skipping/clapping	1.46	1.63	19.65	0.000 *
		total score	15.05	15.76	19.21	0.000 *

Table 8-6: Mean scores per item for boys and girls and the results of the analysis of variance.
** = for these items a significant difference between boys and girls can be distinguished.*

Evaluation of all of the significant differences reveals that boys only performed item 3 (make dots with a pencil), 6 (run with tennis balls) and 14 (standing broad jump) better than girls. All other significantly different items were performed better by girls.

The fact that boys performed a fine motor task (item 3) better was at the least unexpected, because it is generally accepted that girls in this age range perform fine motor tasks better. The fact that boys had higher scores for items 6 and 14, which are items requiring speed and strength, was to be expected.

The statement of van Rossum that this test will not yield differences between boys and girls cannot be confirmed on the basis of these results. A possible explanation might be the deletion of three items, although generally speaking these items would presumably not have been performed better by boys than girls.

8.7.2 Age

The differences between successive age groups for boys and girls separately were also tested with t-tests. The results are presented in table 8-7 and figure 8-2. In table 8-7 it can be seen that, for example, the differences between boys aged 7 and 8 years of age are significantly different from zero. The differences between girls of the same ages are not significantly different from zero.

age	boys		girls	
[years]	t	p	t	p
4 – 5	-3.95	0.000 *	-3.51	0.001 *
5 – 6	-3.29	0.002 *	-7.36	0.000 *
6 – 7	-4.06	0.000 *	-2.68	0.009 *
7 – 8	-4.44	0.000 *	-1.71	0.093
8 – 9	-1.50	0.139	-4.37	0.000 *
9 – 10	-2.76	0.008 *	-1.22	0.227
10 – 11	0.28	0.778	-0.35	0.727
11 – 12	-1.76	0.084	-0.78	0.439

Table 8-7: Results of the t-test comparing group means of successive age groups of boys and girls.

boys										
mean	age	4	5	6	7	8	9	10	11	12
7.84	4									
10.42	5	•								
12.24	6	•	.							
14.57	7	•	•	•						
16.87	8	•	•	•	•					
17.60	9	•	•	•	•	.				
18.91	10	•	•	•	•	.	.			
18.77	11	•	•	•	•	.	.	.		
19.73	12	•	•	•	•	•	.	.	.	

girls										
mean	age	4	5	6	7	8	9	10	11	12
8.51	4									
10.75	5	•								
14.60	6	•	•							
16.07	7	•	•	.						
17.03	8	•	•	•	.					
18.86	9	•	•	•	•	.				
19.34	10	•	•	•	•	•	.			
19.48	11	•	•	•	•	•	.	.		
19.83	12	•	•	•	•	•	.	.	.	

Figure 8-2: Significant differences (•) between age groups per sex.

It can be concluded that the scores of the successive age groups of younger children differed, while the increase in scores for children over 9 was not large enough to be statistically significant, although the averages continued to increase slightly (figure 8-1). The test therefore seems to be less suitable for testing improvement in motor performance among older children, because the maximum scores were already achieved by quite a number of the younger children.

8.8 Conclusions

8.8.1 Mot '87k

It can be concluded that the suitability of the test used in this investigation for children above the age of 9 is not as high as expected. The discrimination within this group is small, probably because the items were too easy or there was not enough motivation for these children. For the younger children, however, this test gives a fair and varied impression of motor performance at different ages.

Although the observers received intensive training, the results show that some items are sensitive to observer effects. Therefore it is recommended that in the future the performance of the observers should be checked repeatedly during the period of measurement.

8.8.2 Motor development

Despite some imperfections in the test and its results, several conclusions on motor performance of children can be drawn. Because there is empirical evidence to assume that this test measures motor performance and that the score for successive age groups is a measure of the rate of development, the following general conclusions can be drawn:

- Motor skills increase with age: the older children perform better than the younger ones.
- Girls get –generally speaking– higher scores on the test, their motor skills being more advanced than the skills of boys.
- The differences between boys and girls become less outspoken with increasing age.
- Most development appears to occur during the ages 4 to 8 years (the difference between the lowest and highest mean score in this age group was 13.72). In later years the rate of development decreases (the maximum difference in mean score between the age groups 8 to 13 years was 5.94).

According to the author of the test, the items are not supposed to be examined separately. They cannot be divided, for example, into scores for gross motor performance and fine motor performance. It is, therefore, not possible to verify hypotheses or theories stating that girls are more advanced in fine motor performance and boys in motor behaviour requiring strength and speed, although the significant differences per item (see table 8-6) are plausible in this respect.

9 Physical flexibility

9.1 Introduction

Physical flexibility is a characteristic of children that may influence the occurrence of accidents. This influence may be two-fold: on the one hand it is assumed that children who are very lithe are able to move their body in such a way that they will manage to correct sudden movements which otherwise would have led to an accident. Awareness of this ability, however, may encourage these children to take more risks than children who are less flexible. Physical flexibility could also favour accidents since lithe children can reach farther while sitting or standing, which enables them to get at dangerous products or end up in a risky situation more easily than children who are not as lithe.
In this project an attempt was made to verify this possible relationship; in this chapter the assessment of physical flexibility is described.

Many different kinds of physical flexibility exist. This becomes clear when the definition has to be established.
Physical flexibility can be defined as the extent to which joints can reach extreme angles. Thus there are as many kinds of flexibility as there are types of joints (for example, hinge, pivot, saddle and ball-and-socket joints; flexion or rotation).
Physical flexibility is influenced by many different factors such as the natural ability of a joint to move, the length of muscles and tendons surrounding the joint, movement and position of the next joint, sex, conditions etc.

In literature on physical fitness tests (Kemper, 1981; Docherty et al., 1985) 'sit and reach' is accepted as a measurement of the general flexibility of the body. In addition to this measurement, we defined another kind of physical flexibility, i.e. rotation of the body around the z-axis while standing. These measurements are related to the range of forward and rotational movement of the body, respectively, both of which involve several joints.

9.2 Method

9.2.1 Measurement 1: Sit and reach

The child sits on the ground, the legs stretched and the feet flexed against a vertical board, the arms held about horizontally. The child is then asked to push a second board forward with the fingertips as far and as slowly as possible, without bending the knees and keeping the arms horizontal. This posture should be held for 3 seconds. The child was allowed to practice before the measurement was taken.

Figure 9-1: Measurement of sit and reach.

The distance reached was read from a measuring tape. This tape was attached to the horizontal part of the apparatus, in such a way that it showed 25 centimetres at the point where the feet were placed against the vertical board.

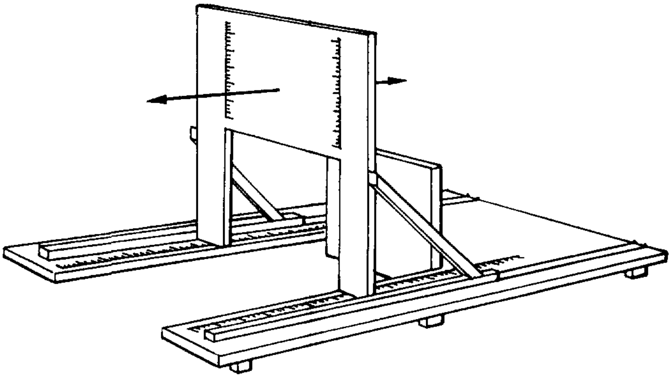


Figure 9-2 Apparatus to measure the distance reached.

9.2.2 Measurement 2: Rotation of the body around the z-axis

The child stands erect, with the feet placed together and the arms hanging down next to the body, the head in the Frankfurt Plane (see chapter 6). A 'Myrin Goniometer', which resembles a compass, was placed on top of the head in the horizontal plane. The child was asked to turn the head and body as far to the right as possible while remaining erect, without bending the knees, and keeping the feet in the same place and the arms hanging down next to the body.

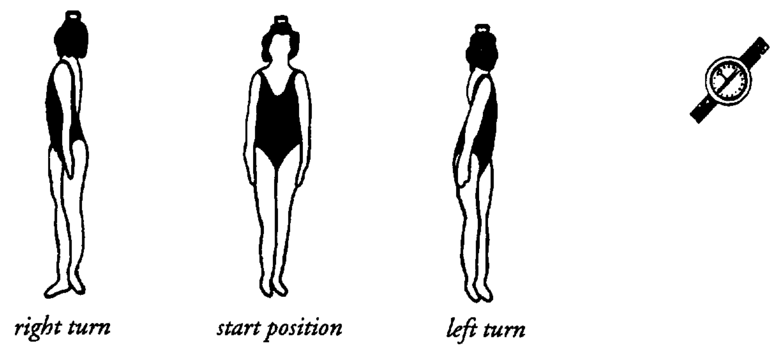


Figure 9-3: Rotation of the body.

Maximum rotation should be maintained for 3 seconds. During this time the position could be read from the compass, albeit with a rather low accuracy (± 5 degrees). Then the child had to turn to the left in the same way.
Practice was allowed in order to see whether or not the child understood what was expected.

Measurement of the two positions, sit and reach and rotation of the body to the right and to the left, was performed twice.

A total of 1151 children between 2 and 13 years participated in this part of the project. Repeated measurements of 106 children were taken within a week of the first session.

9.3 Analyses

9.3.1 Extremes and missing values

First the data were screened for extreme values, using histograms and scatter plots and comparing the values of the first and second measurements (taken during the same session). Extremes were judged 'by eye' and were deleted when the differences with respect to all other values were too big. Approximately 20 measurements were deleted.
In some cases not all measurements had been taken, mainly due to lack of cooperation of the child. The number of missing values was 19 for the sit and reach distance and 55 for rotation of the body. It was not possible to complete these data afterwards.

9.3.2 Presentation of the data

After screening the data, the best way to analyse and present the data was determined. For this purpose we checked which data resulted in the highest correlation with the repeated measurements: the minimum, mean or maximum scores of the first and the second measurement. The following correlations were found:

		correlation between first and second measurement with the repeated measurement when using:		
	n	minimum	mean	maximum
sit and reach	106	0.88	0.91	0.90
rotation of the body:				
to the right	103	0.56	0.57	0.52
to the left	103	0.62	0.64	0.59
irrespective of direction	103	0.69	0.70	0.57

Table 9-1: Correlation between first and second measurements and repeated measurements.

In all four cases the highest correlation coefficient was found for the means of the values. Therefore the results presented in the next paragraphs are based on the mean values of the first and second measurements. For measurement of the rotation of the body, the direction of movement was no longer taken into account.
The correlations shown above were significant, so, statistically speaking, it may be concluded that the test-retest reliability of the two measurements seems to be acceptable. But because of the fact that the values for rotation of the body were rather low, it is concluded that the test-retest reliability for this latter measurement is not acceptable.

9.3.3 Observer effects

One-way analysis of variance was applied to the measurements to analyse possible differences between the observers. It showed an observer effect for both positions

The results of this one-way analysis are presented below. For the reach distance $F = 40.57$; $p = 0$. The pairs of observers with significantly different mean values, according to the Scheffé Multiple Range test, are denoted with a • in the lower left-hand triangle:

mean	observer	1	5	9	8	2	6	7	3	4	12	10	11	15	19	17	13	16	20	21	18	14
23.5	1																					
23.9	5	·																				
24.1	9	·	·																			
25.3	8	·	·	·																		
25.5	2	·	·	·	·																	
26.2	6	·	·	·	·	·																
26.7	7	·	·	·	·	·	·															
27.6	3	·	·	·	·	·	·	·														
29.6	4	•	•	•	·	·	·	·	·													
32.1	12	·	·	·	·	·	·	·	·	·												
32.7	10	•	•	•	•	•	·	·	·	·	·											
32.8	11	·	·	·	·	·	·	·	·	·	·	·										
33.0	15	•	•	•	•	•	·	·	·	·	·	·	·									
33.3	19	•	•	•	•	•	·	·	·	·	·	·	·	·								
34.3	17	•	•	•	•	•	·	·	·	·	·	·	·	·	·							
34.7	13	•	•	•	•	•	·	·	·	·	·	·	·	·	·	·						
34.8	16	•	•	•	•	•	·	·	·	·	·	·	·	·	·	·	·					
35.5	20	•	•	•	•	•	•	•	•	•	·	·	·	·	·	·	·	·				
36.0	21	•	•	•	•	•	·	•	•	·	·	·	·	·	·	·	·	·	·			
36.4	18	•	•	•	•	•	·	•	•	·	·	·	·	·	·	·	·	·	·	·		
38.9	14	•	•	•	•	•	•	•	•	•	·	·	·	·	·	·	·	·	·	·	·	

Figure 9-4 Pairs of observers with significantly different mean values for the reach distance.

For rotation of the body F = 25.38; p = 0. The pairs of observers with significantly different mean values, according to the Scheffé Multiple Range test, are denoted with a • in the lower left-hand triangle:

mean	observer	9	14	18	6	17	2	13	1	11	19	16	20	21	8	12	15	5	4	3	10	7
134.4	9																					
140.8	14	·																				
144.3	18	·	·																			
146.9	6	·	·	·																		
146.9	17	·	·	·	·																	
148.4	2	•	·	·	·	·																
150.0	13	·	·	·	·	·	·															
151.2	1	•	·	·	·	·	·	·														
152.5	11	·	·	·	·	·	·	·	·													
153.3	19	·	·	·	·	·	·	·	·	·												
155.3	16	·	·	·	·	·	·	·	·	·	·											
155.6	20	•	·	·	·	·	·	·	·	·	·	·										
158.0	21	•	·	·	·	·	·	·	·	·	·	·	·									
159.6	8	•	·	·	·	·	•	·	·	·	·	·	·	·								
161.9	12	·	·	·	·	·	·	·	·	·	·	·	·	·	·							
162.4	15	•	·	·	·	·	·	·	·	·	·	·	·	·	·	·						
166.5	5	•	·	·	·	·	•	·	·	·	·	·	·	·	·	·	·					
168.8	4	•	•	·	·	·	·	·	·	·	·	·	·	·	·	·	·	·				
170.5	3	•	•	·	·	·	•	·	·	·	·	·	·	·	·	·	·	·	·			
174.8	10	•	•	•	·	•	•	·	•	·	·	·	·	·	·	·	·	·	·	·		
179.6	7	•	•	•	·	•	•	·	•	·	·	·	·	•	·	·	·	·	·	·	·	

Figure 9-5: Pairs of observers with significantly different mean values for rotation of the body.

These observer effects may be explained by the difficulty of taking the measurements. Some children, especially those who are not very lithe, may have found the tasks difficult because of the uncommon positions. This probably resulted in a performance which was not carried out exactly according to the definitions of the measurements. Some observers may have followed more accurately the definitions than others or may have applied them more strictly. There also might have been differences in exhortation or encouragement.

Another explanation for these observer effects might be the fact that age is an interfering variable, because not all observers assessed children of all ages. To see whether this is true, an analysis of variance with as the covariates age and sex was performed. This analysis again yielded a significant observer effect. This implies that the accuracy of the data is not as high as it was expected to be: in all cases a possible difference in values because of observer effects has to be kept in mind. In spite of these observer effects, some results will be given.

9.4 Results

9.4.1 Results of 'sit and reach' measurements

The results of the measurement of 'sit and reach' are presented in a histogram as the mean of the two measurements for boys and girls aged 2 to 13 years.

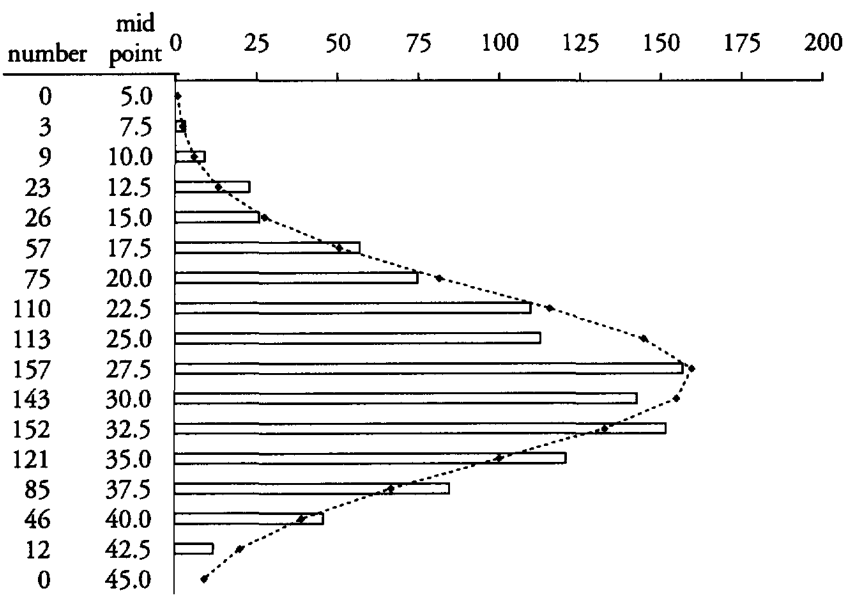


Figure 9-6: Histogram for reach distance (-•- indicates normal distribution).

The mean sit and reach distance per age group and sex is given in table 9-2.

age [years]	boys n	boys s	boys $\bar{x}$	girls n	girls s	girls $\bar{x}$
	reach distance [cm]					
2.0 – 2.9	81	3.3	34.9	92	3.2	35.2
3.0 – 3.9	97	4.3	34.1	86	3.6	34.6
4.0 – 4.9	49	5.9	27.4	48	5.3	27.8
5.0 – 5.9	53	5.6	24.5	59	4.6	27.3
6.0 – 6.9	60	5.1	24.2	57	6.1	25.7
7.0 – 7.9	51	5.5	25.0	42	4.8	27.1
8.0 – 8.9	41	6.5	23.8	40	5.7	25.4
9.0 – 9.9	41	5.9	22.9	42	5.5	27.5
10.0 – 10.9	36	6.2	22.6	39	6.1	26.3
11.0 – 11.9	40	5.8	20.6	44	7.7	25.4
12.0 – 12.9	30	5.5	22.1	23	7.0	25.0

Table 9-2: Reach distance per age group and sex.

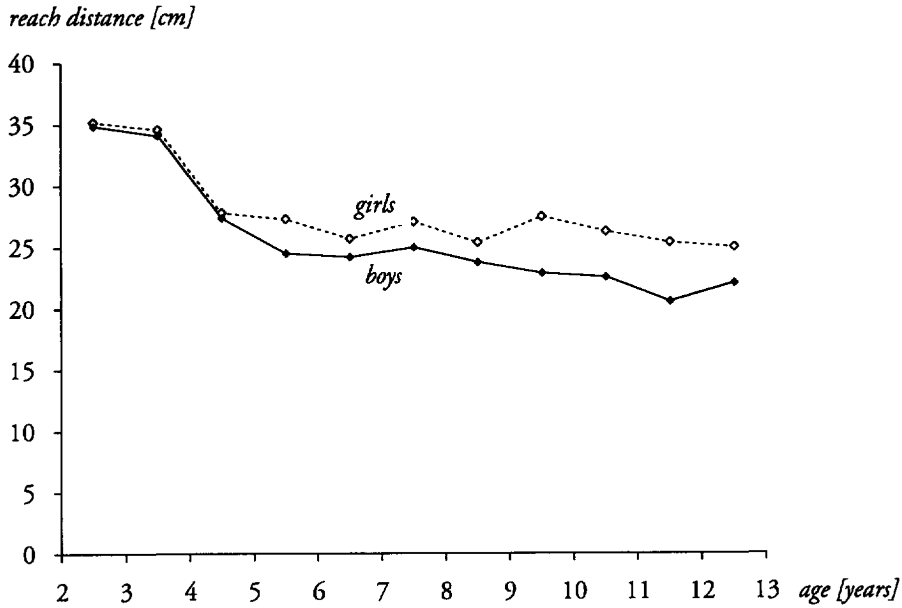


Figure 9-7: Mean values for reach distance per age group and sex.

An analysis of variance showed a main effect of both age and sex on the sit and reach distance (F = 5.04; p = 0 and F = 40.49; p = 0, respectively). The reach distance decreases with age, and girls are likely to be more flexible because their mean reach distance was longer than that of boys. A distance of more than 25 cm means the child reached beyond its toes.

Children below 4 years of age did not always understand what they were expected to do. They often pushed the board away instead of sliding it. It also appeared to be very difficult for them not to bend their knees during this task. Therefore the reach distance, as established here, may be somewhat longer than it would have been had the task been performed in the proper way.

9.4.2 Relationship of 'sit and reach' with body measurements

Although no agreement exists on this subject in literature (Erich, 1980), a relationship between body proportions and the sit and reach distance is expected, especially with respect to the length of arms and legs: the longer the legs, the farther the child has to reach in order to achieve a long distance; similarly the longer the arms the easier to reach a long distance.

In order to gain insight into flexibility (i.e. movement of the trunk) independent of limb length, the following mathematical approach was used:

Horizontal movement of the trunk in cm. can be defined as

$$x = (a + c) - (25 + b),$$

where
- a = distance buttock to foot
- b = arm length
- c = reach distance
- y' = shoulder height seated
- y = height of arms
- α = angle between trunk and legs
- β =angular displacement of straight trunk

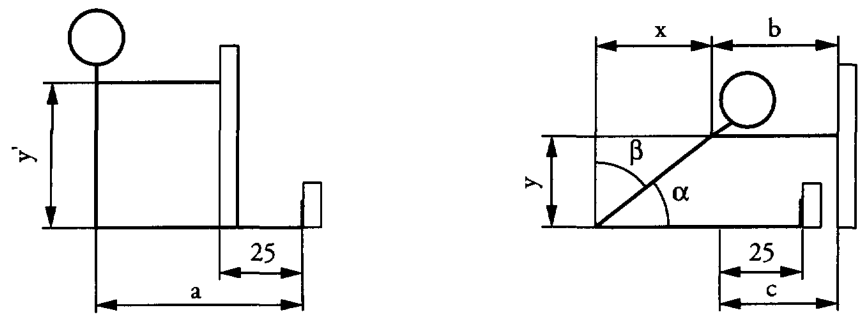


Figure 9-8: Schematic drawing of the variables.

The movement of the trunk, which determines the degree of flexibility, consists of two components:
1. angular displacement β of the straight trunk towards the legs;
2. degree of bending of the trunk itself (thoracic plus lumbar intervertebral angles).

It is obvious here that flexibility can be enhanced or partly compensated for by bending the trunk.

Flexibility is very large when the shoulder describes an imaginary circle (figure 9-9). Lower flexibility implies bending of the trunk and thus a shoulder height below the 'circle value'.

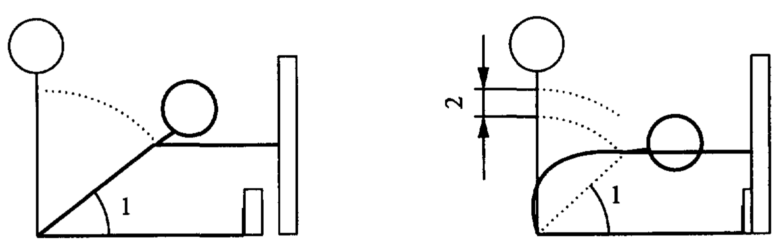


Figure 9-9: Schematic drawing of forward movement without and with trunk bending.

The angle between trunk and legs (1) and the degree of bending of the trunk (2) can be estimated by:

$$(1) = \arctan \frac{y}{x} \qquad (2) = 1 - \frac{\sqrt{x^2 + y^2}}{y'}$$

A low value of (1) combined with a value of (2) that approaches 0 implies a high degree of flexibility. The opposite means a low flexibility. The results of these two calculations are presented in figure 9-10.

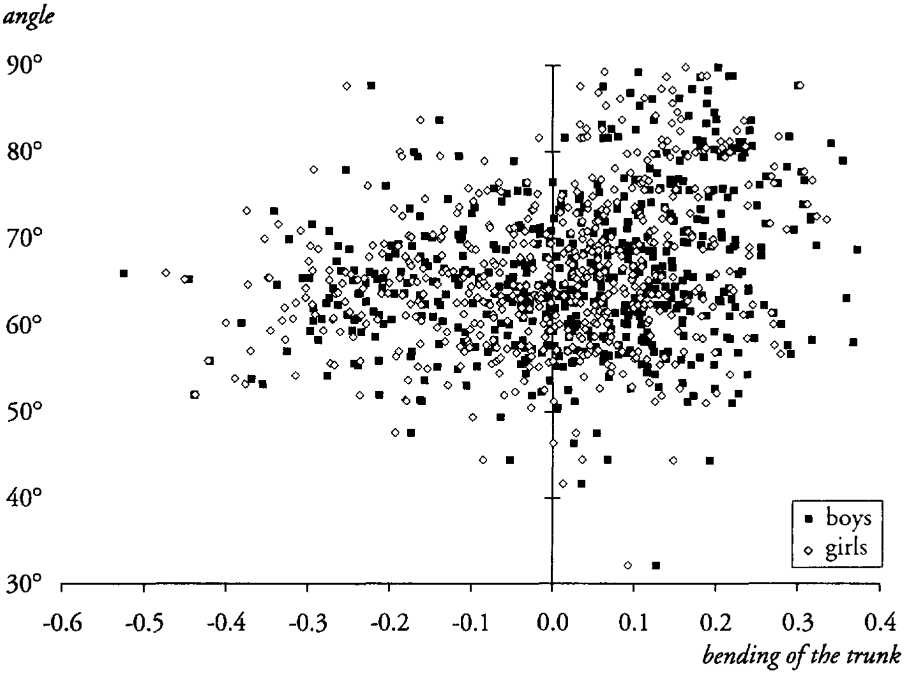


Figure 9-10: Scatter plot of angle and degree of bending of the trunk.

Children appearing in the lower right-hand part of the plot are flexible, while children in the upper left-hand part exhibit little flexibility.
Transformation of the data yields a 'score for flexibility' which lies between –2 and +2, ranging from not flexible to very flexible. These scores are presented in table 9-3 and fig. 9-11.

age [years]	boys n	boys s	boys P3	boys x̄	boys P97	girls n	girls s	girls P3	girls x̄	girls P97	boys + girls s	boys + girls x̄
2.0 – 2.9	81	.24	-1.08	-.59	-.16	92	.22	-1.06	-.61	-.21	.23	-.60
3.0 – 3.9	97	.23	-.97	-.48	-.09	86	.20	-.79	-.46	-.13	.22	-.47
4.0 – 4.9	49	.23	-.81	-.35	.05	48	.22	-.77	-.30	.12	.23	-.33
5.0 – 5.9	53	.23	-.76	-.34	.14	59	.20	-.59	-.22	.16	.22	-.28
6.0 – 6.9	60	.21	-.69	-.22	.08	57	.21	-.74	-.21	.10	.21	-.22
7.0 – 7.9	51	.26	-.69	-.15	.23	42	.19	-.52	-.08	.19	.23	-.12
8.0 – 8.9	41	.27	-.51	-.10	.31	40	.25	-.37	-.01	.47	.26	-.05
9.0 – 9.9	41	.24	-.66	-.08	.27	42	.32	-.47	.03	.61	.29	-.02
10.0 – 10.9	36	.25	-.46	-.05	.38	39	.23	-.31	.04	.58	.24	.00
11.0 – 11.9	40	.27	-.62	.01	.44	44	.26	-.44	.09	.62	.27	.05
12.0 – 12.9	30	.27	-.64	.01	.62	23	.33	-.41	.16	.97	.31	.08

Table 9-3: Scores for physical flexibility according to age and sex

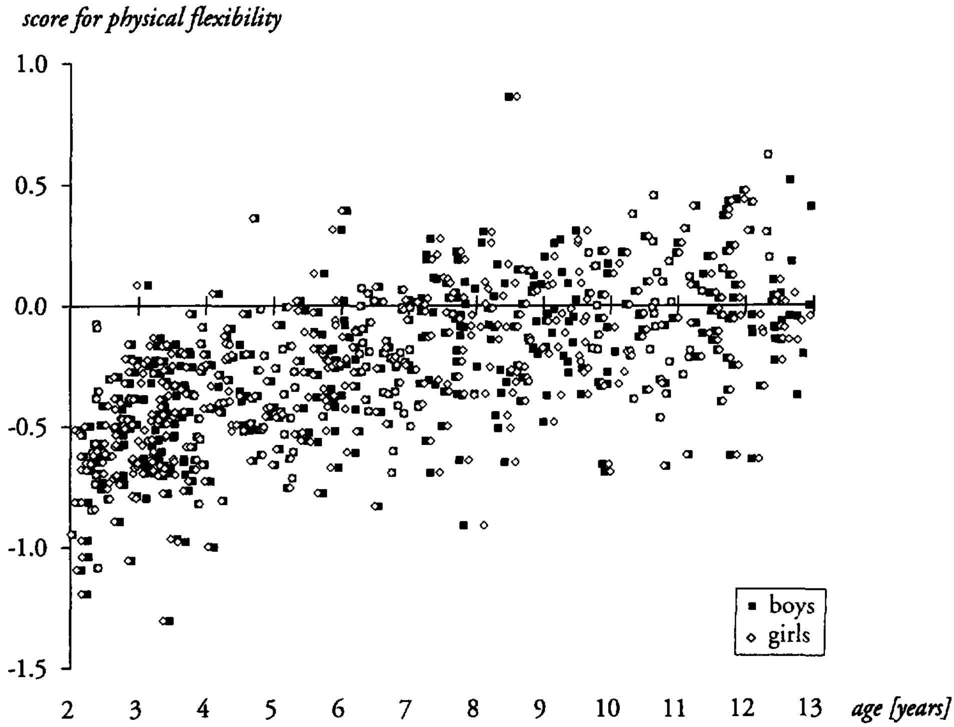


Figure 9-11: Scores for flexibility according to age and sex.

An analysis of variance, performed to assess the possible influences of age and sex on the physical flexibility, again showed main effects of age (F = 97.01; p = 0) and sex (F = 16.24; p = 0). Girls seem to be more flexible than boys.

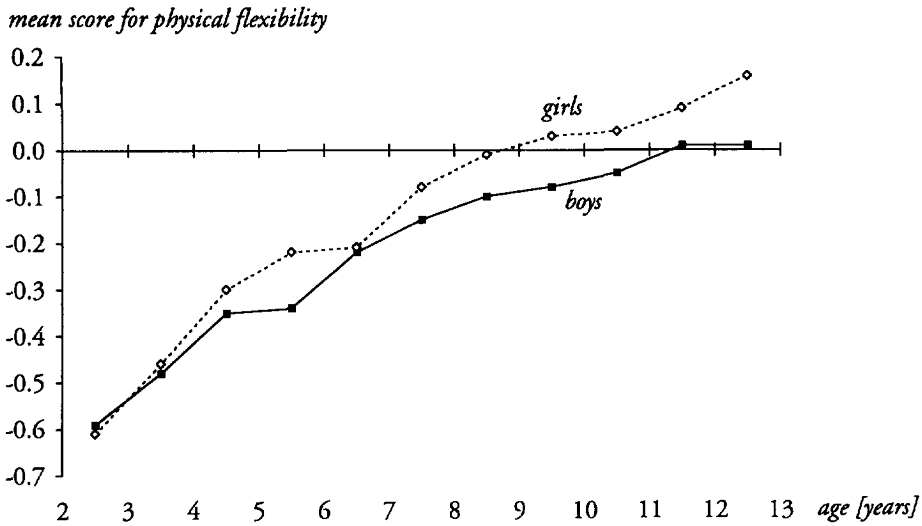


Figure 9-12: Mean scores for physical flexibility per age group and sex.

The significance of the differences between successive age groups per sex is presented in figure 9-13. It appears, for example, that the mean values for 2-year-old boys differ significantly from the mean values for boys aged 4 and older.

		boys													girls										
mean	age	2	3	4	5	6	7	8	9	10	11	12	mean	age	2	3	4	5	6	7	8	9	10	11	12
-.5941	2												-.6123	2											
-.4801	3	·											-.4595	3	·										
-.3514	4	•	·										-.2982	4	•	·									
-.3391	5	•	·	·									-.2215	5	•	•	·								
-.2239	6	•	•	·	·								-.2071	6	•	•	·	·							
-.1466	7	•	•	·	·	·							-.0838	7	•	•	·	·	·						
-.0978	8	•	•	•	•	·	·						-.0080	8	•	•	•	•	·	·					
-.0762	9	•	•	•	•	·	·	·					.0341	9	•	•	•	•	•	·	·				
-.0470	10	•	•	•	•	·	·	·	·				.0449	10	•	•	•	•	•	·	·	·			
.0065	11	•	•	•	•	•	·	·	·	·			.0899	11	•	•	•	•	•	·	·	·	·		
.0146	12	•	•	•	•	•	·	·	·	·	·		.1583	12	•	•	•	•	•	·	·	·	·	·	

Figure 9-13: Differences in mean scores per age group and sex (• = significantly different from zero).

9.4.3 Results of measurement of 'rotation of the body'

The histogram for rotation of the standing body around the z-axis is given in figure 9-14.

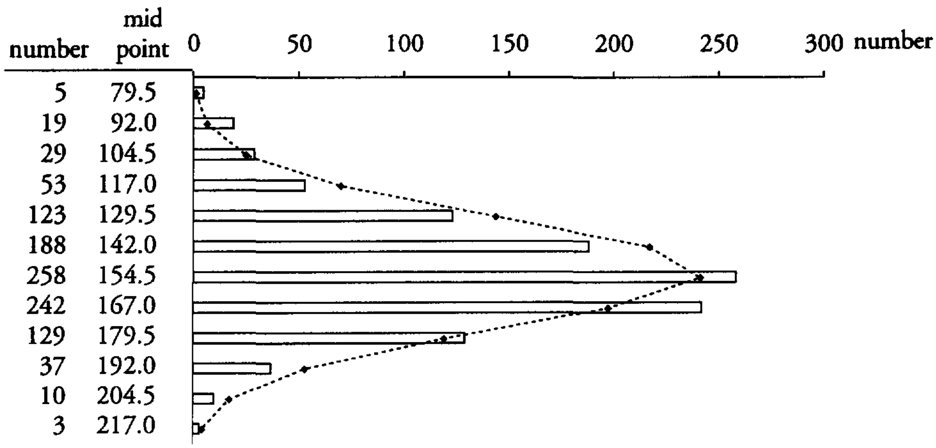


Figure 9-14: Histogram for rotation of the body around z-axis (-◆- indicates normal distribution).

The results per age group and sex are listed in table 9-4.

age [years]	boys n	boys s	boys x̄	girls n	girls s	girls x̄
	rotation of the body around the z-axis [°]					
2.0 – 2.9	81	16	154	92	17	157
3.0 – 3.9	97	16	156	86	17	162
4.0 – 4.9	49	26	138	48	22	138
5.0 – 5.9	53	26	143	59	24	147
6.0 – 6.9	60	22	143	57	30	150
7.0 – 7.9	51	23	154	42	17	153
8.0 – 8.9	41	21	157	40	17	157
9.0 – 9.9	41	23	156	42	19	157
10.0 – 10.9	36	21	159	39	25	155
11.0 – 11.9	40	26	156	44	23	158
12.0 – 12.9	30	21	158	23	20	166

Table 9-4: Rotation of the body per age group and sex in degrees.

For rotation of the body there was a main effect of age ($F = 9.27$; $p = 0$) but not sex. The large angles of rotation of the body before the age of 4 are partly due to misunderstanding of the instructions by the children and the complexity of the task. It appeared to be very difficult for these children not to bend their knees and to keep their feet on the floor while rotating.

This implies that the values are not very accurate for these age groups. After the age of 4 years, when the children were better able to understand the task, there appears to be a slight increase in the ability to rotate the body.

9.5 Conclusions

9.5.1 Method

The method used to measure 'sit and reach' is a generally accepted method. The scores, however, need correction for trunk-bending, which we applied. It has to be concluded, however, that this method is less accurate for younger children, because they do not really understand what is expected of them.

Operationalization of the measurement of rotation of the body around its z-axis was not successful, although the concept seemed to possess face validity. Especially for the younger children it appeared to be too difficult to concentrate on different aspects of one task at the same time. Another factor, related to the instrument used, should be mentioned here too. In order for it to function correctly, the compass had to remain horizontal. When rotating the body a child is very likely to bow its head, which implies that the compass will not remain in the horizontal plane. As a result the needle could no longer turn freely and therefore probably indicated a value that was lower than the real value.
This is likely to have occurred more often among younger children, because the older children could be told to keep their head up; for younger children this appeared to be far more difficult.
Because the measurement method for this position had a lower validity, these results were excluded from the calculation of a total score for physical flexibility.

In addition to the above-mentioned disadvantages, both methods appeared to be very sensitive to observer effects. Although all observers underwent a thorough training programme beforehand, there were clear differences in results.

9.5.2 Results

Despite the fact that the results were influenced by an observer effect, some conclusions on the physical flexibility of children aged 2 to 13 years can be drawn on the basis of the results of measurement of the 'sit and reach distance'.
It can be stated that the absolute values of the reach distance increase with age. This is in accordance with expectations, because of growth of the limbs. Therefore a mathematical model was designed such that the values could be compared, irrespective of limb length. This approach yields a score for flexibility. These values tended to increase during the period 2 to 8 years. For older children the differences were no longer statistically significant. This probably indicates that this aspect of development levels off after the age of 8 or even stops. Further and more detailed empirical confirmation of this conclusion is, however, necessary.

10 Technical comprehension

10.1 Introduction

Growing up implies acquiring some understanding of the mechanisms of equipment used in daily life, of 'how things work' and thus of the action required to achieve a specific effect through equipment. This understanding can be referred to as technical comprehension, which is indispensable to every participant in our modern techno-culture.

Technical comprehension has many aspects. One is knowledge of valid relationships between, on the one hand, the way to handle the control(s) of a product or system and, on the other, the effect this will have on the product. The preferable types of relationships are laid down in so-called rules of compatibility. Compatibility refers to the degree to which relationships between stimulus and response are consistent with human expectations. The expectations people have about relationships are based on stereotypes which, however, are not necessarily the same for all people. These stereotypes are determined:

- intrinsically: the operation or the movement of a control results in a similar, geometrical movement within the system; or a similarity in shape, colour or contrast provides a relationship between the control and display or system: a green button to light a green lamp.
- socio-culturally: these relationships are learned by trial and error, often unconsciously; for example, the control of the central heating system has to be turned to the left in order to get more heat although, according to the compatibility rule 'clockwise-for-more', it should have been turned to the right to reach this goal.

Generally speaking, different kinds of compatibility exist (mainly related to industrial products) (Sanders and McCormick, 1987):

- conceptual compatibility: the degree to which codes and symbols correspond to the conceptual associations of individuals (for example, a sign with an airplane on it to indicate an airport is clearer than a green square);
- spatial compatibility: the physical arrangement in space of controls and their associated displays (for example, a button placed on the right side of a control device in order to control a pointer on the right side of the display);
- movement compatibility: the relationship (direction, size, delay) between the movement of controls and the response of the system.

For man-product interactions the last form of compatibility is the most important. It refers to the dynamic relationship between stimulus and response because physical interaction is required, while conceptual and spacial compatibility refer to the configurations, being static aspects, of products.

In this investigation only compatibility with respect to the direction of movement was evaluated. The aim was to determine whether children at certain ages are already familiar with effective (re)action, which means acting according to compatibility rules. This was operationalized by a task, being the operation of certain controls to effectuate a predetermined direction of movement.

A second goal was to determine whether differences exist between boys and girls in the performance of this task.

10.2 Choices

A goal of this investigation was assessment of the influence on the operation of controls of:

- the type of control,
- the plane in which the control is placed,
- the direction of movement.

A test was developed in our laboratory, as a first trial to gain some insight into a child's knowledge of compatibility rules. As far as we know, this kind of investigation has never before been performed among children between 2 and 13 years of age.
Four types of controls, parts of products used in everyday life, were tested. This implies that the children may already have had experience in operating the types of controls chosen. These controls were a push button, a handle, a rotary knob and a joystick. They were placed in the horizontal or vertical plane and effectuated the movement of a 'pointer' in the horizontal or vertical direction.

The compatibility rules for the controls, used to effectuate horizontal movement of a 'pointer' on a display to the right, were:

- *pair of push buttons:* activation of the button placed on the right starts movement to the right;
- *handle:* clockwise for movement to the right;
- *rotary knob:* clockwise for movement to the right;
- *joystick:* movement of the joystick to the right effectuates movement to the right.

The compatibility rules for the controls, used to effectuate vertical movement of a 'pointer' on a display downward, were:

- *pair of push buttons:* activation of the lower or closer button starts movement downward;
- *handle:* counterclockwise for movement downward;
- *rotary knob:* counterclockwise for movement downward;
- *joystick:* pulling a joystick (when placed in the horizontal plane) or pushing it downward (when placed in the vertical plane) effectuates movement downward.

10.3 Instrument

The instrument used was a television-like box (figure 10-1), placed in front of the children. At the bottom of the 'screen' there was a dog in the left-hand corner and its kennel in the right-hand corner. On the left side of the screen there was a bird in the upper corner and a tree in the lower corner. The dog and the bird could be moved separately by activating a control. These controls were placed on yellow cubes, in either the horizontal or the vertical plane (figure 10-2). The cubes could be connected to the front of the 'television'. Those to be used for horizontal movement were placed below the middle of the screen, while the cubes for vertical movement were placed below the tree, on the left-hand side of the screen. Activating a control in the right way made the dog move toward its kennel and the bird towards the tree; otherwise they moved to the left and upwards, respectively.

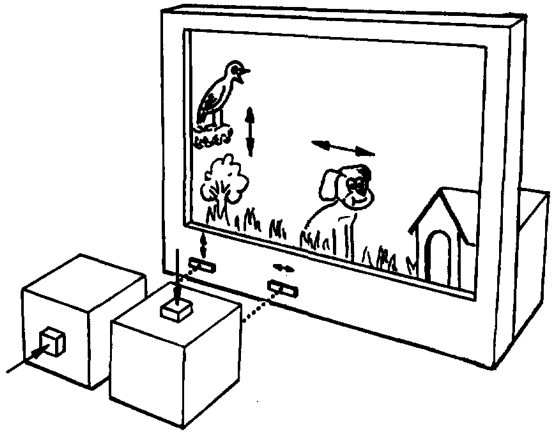


Figure 10-1: The screen with connections and two different controls (for the observer).

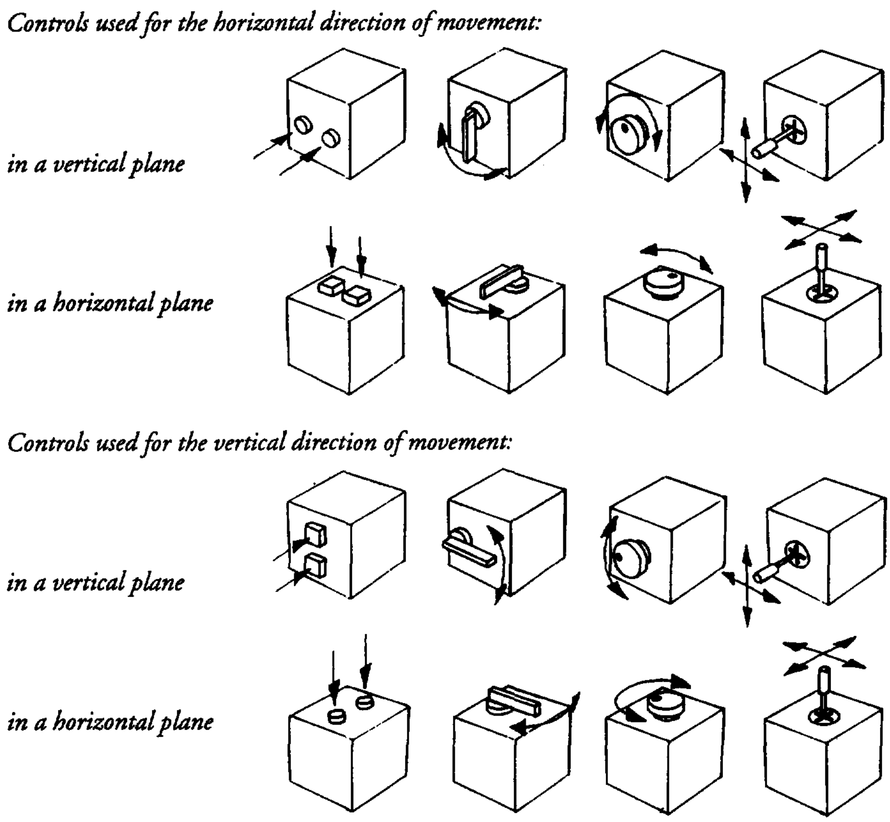


Figure 10-2: The controls used for the horizontal and vertical direction of movement, installed in a horizontal or vertical plane.
On cubes a, e, i, m were the push buttons, a different colour for each plane;
on cubes b, f, j, n was the handle;
on cubes c, g, k, o was the rotary knob;
on cubes d, h, l, p was the joystick, which could be moved along two axes.

10.4 Method

By operating a 'neutral' control (one single push button on a separate cube; see figure 10-1), the observer showed the child that the dog and the bird actually could be moved to the right or downwards, respectively. Then the child was asked to operate the experimental controls in such a way that the dog would move toward its kennel and the bird towards the tree. First the controls for horizontal movement (of the dog) had to be operated in random order, then the controls for vertical movement (of the bird). For each direction of movement 4 controls, each placed in two planes (which totals 8) were to be operated once.
The observers were not allowed to use words like 'push', 'pull', 'rotate', 'to the right' etc., because they could imply the way to operate a control or a certain direction of movement. The child had to sit in front of the screen in such a way that the control to be operated was at the sagittal midline of the child's body. The children were allowed to use either hand to operate a control. The hand choosen was recorded.

We expected that the operation of 16 controls would require too much of the attention and concentration of the younger children (up to grade 4 (grade 1 consists of 4-year-olds); being all children between 2 and approximately 9 years of age), partly because of the amount of time required to fulfil this task. Therefore children in grades 1 to 4 had to operate 8 controls: 4 for the horizontal direction of movement and 4 for the vertical direction of movement. The controls were divided in such a way that 2 types (each placed in the horizontal and vertical plane) were used for the horizontal task, while the remaining two were used for the vertical movement. The 4 controls per direction of movement were presented in random order (figure 10-3).

		direction of movement				
control:	plane:	horizontal	vertical		horizontal	vertical
push buttons	horizontal	•				•
	vertical	•				•
handle	horizontal		•		•	
	vertical		•	*or:*	•	
rotary knob	horizontal	•				•
	vertical	•				•
joystick	horizontal		•		•	
	vertical		•		•	
		↓	↓		↓	↓
		in random order			in random order	

Figure 10-3: Combinations of controls for children aged 2 to 9 years.

The children in grades 5 to 8 (8 to 13 years of age) had to operate 16 controls: all controls for both the horizontal and vertical direction of movement (figure 10-4)

control:	plane:	direction of movement horizontal	vertical
push buttons	horizontal	•	•
	vertical	•	•
handle	horizontal	•	•
	vertical	•	•
rotary knob	horizontal	•	•
	vertical	•	•
joystick	horizontal	•	•
	vertical	•	•
		↓	↓
		in random order	

Figure 10-4: Controls operated by children aged 8 to 13.

The age groups in the two groups of children overlap, because grade was the criterion for assignment of the children to the 'younger' or 'older' group and eight-years-olds were present in both grades 4 and 5. Because of the difference in the number of controls used by the younger and the older children, the results will be described for the two groups separately.

10.5 Results

10.5.1 Results for children aged 2 to 9 years

In total 715 children participated in this part of the investigation. The time required to perform the task was a maximum of 5 minutes.

It appeared that it was not always clear to a child how a certain control should be operated. They usually just gave it a try. The result was, by chance, either right or wrong. These results were recorded as 'right after try' and 'wrong after try'. In the analyses, however, both were counted as 'wrong'. The results are shown in table 10-1.

	right	wrong
push buttons	64%	36%
handle	29%	71%
rotary knob	55%	45%
joystick	34%	66%

Table 10-1: Overall results of the operation of the controls.

It is apparent that the handle and the joystick were too difficult for them. As far as the joystick is concerned, the children often did not know what they were supposed to do with it: they pushed it or turned it around; ultimately they just tried something, without knowing what would happen. This explains the large percentage of wrong results. The handle was even more difficult for these children. They often used the handle of the control as a means of operating the control, instead of applying the clockwise-for-more principle.

An attempt was made to analyse whether a learning effect occurred. It is to be expected that, if technical comprehension really does exist, a child who operates a control incorrectly the first time would apply this acquired knowledge when operating the same control –but in the other plane– a second time.

The results of the analysis to reveal a learning effect are shown in table 10-2.

	horizontal movement			vertical movement		
	wrong/ right [1]	equal [2]	right/ wrong [3]	wrong/ right [1]	equal [2]	right/ wrong [3]
push buttons	19.9 %	68.9 %	11.2 % *	32.8 %	41.3 %	25.9 %
handle	23.2 %	63.7 %	13.1 % *	16.1 %	71.1 %	12.8 %
rotary knob	21.9 %	58.7 %	19.4 %	22.4 %	56.9 %	20.7 %
joystick	21.4 %	71.7 %	6.9 % *	21.6 %	66.4 %	12.0 % *

Table 10-2: Analysis of learning effects.
** significant difference (p < 0.05)*

[1] *first trial wrong, second trial right*
[2] *both trials either right or wrong*
[3] *first trial right, second trial wrong*

If a learning effect does not exist, the percentages listed under 'wrong/right' and 'right/wrong' should be –almost– equal (25 %) per type of control, because the controls were operated in a random fashion. A learning effect is suggested when the percentages for 'wrong/right' are higher than those for 'right/wrong'. A χ^2-test (one-sided) was applied to the percentages 'wrong/right' versus the percentages 'right/wrong'. There appeared to be a statistically significant difference for the controls marked with an asterisk '*' ($p < 0.05$).

It is concluded that for horizontal movement the results obtained for all controls, except the rotary knob, were subject to a learning effect. For vertical movement a learning effect could only be demonstrated for the joystick. This confirms once again how difficult it was for these children to operate a joystick, although their performance improved after one trial.

In order to study the effect of the interaction of:
- the type of control,
- the plane in which the control was placed,
- the direction of movement and
- the hand used to operate the control

on the results obtained, analysis of variance was applied.

The type of control appears to have had a significant influence on the 3-way interaction between control, plane and movement ($F = 36.3$; $p = 0.00$) as well as the interaction between control, plane and hand ($F = 10.9$; $p = 0.00$).
In the first interaction push buttons placed in the vertical plane and used for movement in the vertical direction gave rise to the greatest differences (table 10-3). This one combination of control, plane and movement explains the 3-way interaction found in this analysis of variance.

control	movement	plane vertical	horizontal
push buttons	horizontal	28%	32%
	vertical	57%	25%
handle	horizontal	61%	72%
	vertical	75%	78%
rotary knob	horizontal	33%	51%
	vertical	52%	43%
joystick	horizontal	62%	67%
	vertical	69%	64%

Table 10-3. Percentage incorrectly performed operations per type of control according to plane and direction of movement; the group consisted of 715 children aged 2 to 9 years.

The second interaction is explained by the push buttons used for movement in the horizontal direction and operated with the left hand (table 10-4).

control	movement	hand right	left	both
push buttons	horizontal	10%	86%	62%
	vertical	39%	43%	48%
handle	horizontal	72%	46%	40%
	vertical	80%	63%	40%
rotary knob	horizontal	37%	57%	45%
	vertical	48%	44%	69%
joystick	horizontal	63%	70%	91%
	vertical	63%	72%	90%

Table 10-4. Percentage incorrectly performed operations per type of control according to hand and direction of movement; the group consisted of 715 children aged 2 to 9 years.

It can be concluded that only the type of control influences performance of the task. The other variables, i.e. plane and direction of movement, do not significantly affect performance.

To assess the reliability of the test, several analyses were performed. The reliability coefficient for internal consistency Cronbach's α, was 0.0761 when all operations were taken into account. When the results for the handle were deleted, α increased to 0.2265 but remained rather low. Factor analysis (Principal Components) of all controls yielded one factor, that explained 30.6% of the variance. In the factor matrix the handle had a negative factor loading. The following correlation matrix was computed for all types of controls.

	push buttons	handle	rotary knob
handle	-0.0376 (*p*=.070)		
rotary knob	0.0914 (*p*=.000)	-0.0172 (*p*=.250)	
joystick	0.0706 (*p*=.003)	-0.1109 (*p*=.000)	0.1063 (*p*=.000)

Table 10-5 Correlation coefficients between different types of controls.

The low correlation between the handle and all other types is, in addition to the results of the reliability and factor analyses, another reason for excluding the score for the handle from calculation of a total score for the concept of technical comprehension.
Because of the fact that the operating principle of the handle seemed to be ambiguous, it was expected that this control would have confused the children and that this in turn would have influenced operation of the other controls. Therefore a t-test was applied to determine whether children who had to operate the handle during the first four operations (horizontal movement) had lower scores for the second set of operations (vertical movement). This appeared to be true ($t = 4.79$; $p = 0.00$).

Despite this rather disappointing result, a total score was computed by adding the results for operating the pair of push buttons, the rotary knob and the joystick.
Factor analysis (Principal Components, one factor, explaining 39.3 % of the variance) revealed that the factor loadings were almost equal (0.59 – 0.67 – 0.63) which justifies the addition of the results without using different weights for each control.

The total score ranged between 0 (all wrong) and 6 (all right).
The frequencies of these scores are presented in table 10-6, the histogram in figure 10-5.

total score	frequency	percent	cumulative percent
0	21	2.9	2.9
1	75	10.5	13.4
2	169	23.6	37.1
3	185	25.9	62.9
4	147	20.6	83.5
5	78	10.9	94.4
6	40	5.6	100.0
total:	715	100.0	

Table 10-6: Frequency distribution of the total score for children aged 2 to 9.

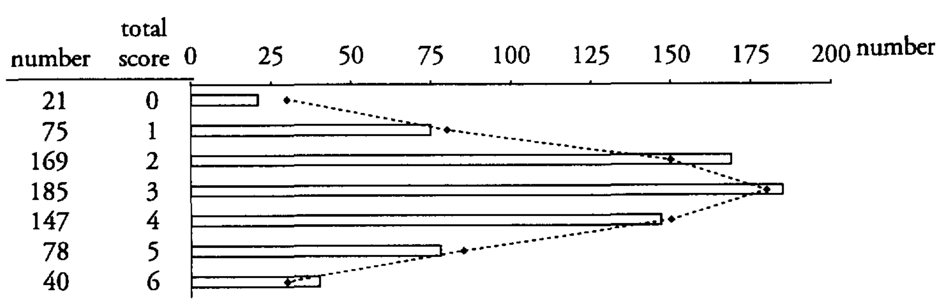


Figure 10-5: Histogram of the total scores.

The mean scores of the children between 2 and 9 years of age are presented in table 10-7.

age [years]	score for technical comprehension					
	boys			girls		
	n	s	$\bar{x}$	n	s	$\bar{x}$
2.0 – 2.5	44	1.26	2.59	40	1.44	2.65
2.5 – 3.0	36	1.19	2.19	51	1.20	2.29
3.0 – 3.5	52	1.04	2.69	47	1.19	2.74
3.5 – 4.0	45	1.36	2.80	39	1.10	2.56
4.0 – 4.5	17	1.36	2.88	18	1.29	2.83
4.5 – 5.0	20	1.32	2.95	16	1.41	3.00
5.0 – 5.5	18	1.27	2.72	25	1.53	3.00
5.5 – 6.0	26	1.66	3.88	21	1.63	3.38
6.0 – 6.5	27	1.15	3.63	22	1.47	3.36
6.5 – 7.0	27	1.41	3.93	22	1.52	3.27
7.0 – 7.5	14	1.16	4.43	13	1.26	3.92
7.5 – 8.0	20	1.21	3.90	19	1.38	4.37
8.0 – 8.5	11	1.90	4.00	7	1.81	4.57
8.5 – 9.0	8	1.36	3.88	10	0.74	4.10

Table 10-7. Mean total score and standard deviation for technical comprehension according to age and sex; results for 715 children.

By means of analysis of variance the influence of age and sex on the total score was determined. Only age appears to have influenced the score (F = 11.45; p = 0.00).

Comparison of all age groups (Scheffé's Multiple Range test) yielded the following figure. The '•' in the lower half of the matrix denotes significantly different pairs. Groups which did not differ are indicated by a point '·'.

mean	age	2	3	4	5	6	7	8
40.50	2							
44.86	3	·						
47.76	4	·	·					
54.67	5	•	•	·				
59.10	6	•	•	·	·			
68.99	7	•	•	•	•	·		
68.94	8	•	•	•	•	·	·	

Figure 10-6 Differences between the mean scores per age group.

There was no statistically significant difference between the mean scores per age group for children 2, 3 or 4 years old. Children aged 2 or 3 years had a lower score than children aged 5 years or older.
The 4 and 5-year-old children had a lower score than those aged 7 or 8 years.
There appears to be no significant difference between children in age groups 6, 7 and 8 years.

10.5.2 Results for children aged 8 to 13 years

In total 244 children participated in this part. They had to operate 16 controls, representing 4 types (push buttons, handle, rotary knob, joystick) placed in 2 planes (horizontal and vertical) for movement in 2 directions (horizontal and vertical). Per direction of movement the controls were operated in random order. All children started with the controls for the horizontal direction of movement. Analyses of the data were the same as those applied to the data for the younger children. The results per type of control were:

	right	wrong
push buttons	86%	14%
handle	36%	64%
rotary knob	83%	17%
joystick	79%	21%

Table 10-8: Overall results per control.

In order to test whether a leaning effect occurred, the results per type of control were compared.

	horizontal movement			vertical movement		
	wrong/ right [1]	equal [2]	right/ wrong [3]	wrong/ right [1]	equal [2]	right/ wrong [3]
push buttons	15.2 %	75.1 %	9.7 %	10.0 %	82.8 %	7.2 %
handle	43.8 %	47.9 %	8.3 % *	32.4 %	60.0 %	7.6 % *
rotary knob	14.2 %	77.5 %	8.3 % *	13.5 %	76.8 %	9.7 %
joystick	17.6 %	70.2 %	12.2 %	9.4 %	81.9 %	8.7 %

Table 10-9: Analysis of learning effects
** significant difference ($p < 0.005$)*

[1] *first trial wrong, second trial right*
[2] *both trials either right or wrong*
[3] *first trial right, second trial wrong*

The differences between 'wrong/right' and 'right/wrong' were tested with the χ^2-test and appeared to be statistically significant for those differences indicated by a '*', ($p < 0.05$). For the handle a learning effect was found for both directions of movement, which is remarkable. When 'comprehension' is defined as the ability to apply knowledge to a new situation, it must be concluded that technical comprehension of the operation of a handle was less than that of the other types. Once again the principles involved in the operation of a handle appear to be ambiguous.

Analysis of variance was performed to assess the influence of the type of control, the plane, the performing hand and the direction of movement on the operation of a specific control. Only the type of control appears to have had a significant influence on the 3-way interaction between control, plane and direction of movement ($F = 83$, $p < 0.005$) and the 3-way interaction between type, movement and hand ($F = 67$, $p < 0.005$).

The first interaction can be explained by the many failures to operate the handle in the horizontal plane such that a horizontal movement occurred (table 10-10).

control	movement	plane vertical	horizontal
push buttons	horizontal	14 %	19 %
	vertical	12 %	10 %
handle	horizontal	59 %	74 %
	vertical	62 %	60 %
rotary knob	horizontal	11 %	18 %
	vertical	22 %	16 %
joystick	horizontal	31 %	23 %
	vertical	17 %	15 %

Table 10-10. Percentage incorrectly performed opperations per type of control according to plane and direction of movement; results for 244 children aged 8 to 13 years.

The second interaction is explained by the many failures to operate the push buttons for the horizontal movement with the left hand (table 10-11).

control	movement	hand right	left
push buttons	horizontal	13%	46%
	vertical	10%	15%
handle	horizontal	66%	66%
	vertical	60%	65%
rotary knob	horizontal	14%	21%
	vertical	18%	24%
joystick	horizontal	26%	31%
	vertical	15%	20%

Table 10-11. Percentage incorrecly performed operations per type of control according to hand and direction of movement; results for 244 children aged 8 to 13 years.

The reliability of the test, given by Cronbach's α, was 0.2610 for all controls together. The value increased to 0.4019 when the handle was excluded. The correlation matrix for the types of control is given below:

	push buttons	handle	rotary knob
handle	0.0521 *(p=.038)*		
rotary knob	0.1476 *(p =.000)*	0.0100 *(p = .367)*	
joystick	0.2387 *(p = .000)*	-0.0424 *(p=.074)*	0.1655 *(p=.000)*

Table 10-12: Correlation coefficients between different types of controls.

These correlation coefficients are higher than those for the younger group, but they are still very low. Again the handle exhibits a low correlation with the other types. The correlation of the handle with the total results for the other controls is 0.0048 (p = 0.435): there is no relationship between the handle and the other controls.

An analysis was also performed to determine whether these children had become confused after having had to operate the handle within the first four operations. This appears to be true for the horizontal direction of movement; for the vertical direction of movement, however, there was no clear influence of the handle on performance.
The t-statistic for the horizontal direction of movement is: $t = -2.12$; $p = 0.035$. The t-statistic for the vertical direction of movement is: $t = 0.91$; $p = 0.365$.

These analyses all indicate that the handle should again be excluded. Therefore, the results of the other controls were added to obtain a total score. Factor analysis (Principal Component) again yielded one factor, which explained 45.7 % of the variance. The variables had almost the same factor loadings (0.70 - 0.60 - 0.72), which led us to decide to add the scores without weighting.

The total scores for technical comprehension ranged between 0 (all wrong) and 12 (all right). The frequency distribution of these scores is given in table 10-14, the histogram of the total scores in figure 10-7. As can be seen the frequency distribution is skewed towards the higher values. This points towards the fact that this testing method was (too) easy for a number children.

total score	frequency	percent	cumulative percent
2	2	0.8	0.8
3	1	0.4	1.2
4	3	1.2	2.5
5	10	4.1	6.6
6	11	4.5	11.1
7	16	6.6	17.6
8	9	3.7	21.3
9	26	10.7	32.0
10	33	13.5	45.5
11	55	22.5	68.0
12	78	32.0	100.0
total:	244	100.0	

Table 10-13: Frequency distribution of the total score for children aged 8 to 13.

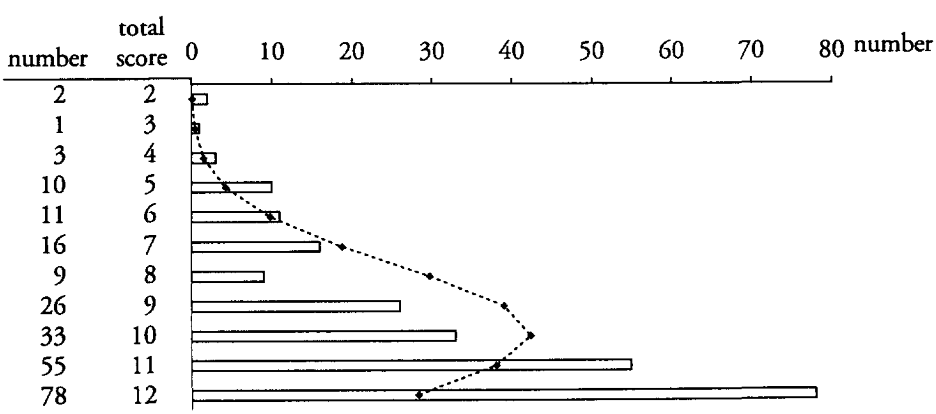


Figure 10-7: Histogram of the total scores.

The mean total scores for children between 8 and 13 years of age are summarized in table 10-14.

age [years]	boys n	boys s	boys x̄	girls n	girls s	girls x̄
	score for technical comprehension					
8.0 – 8.5	1	–	11.00	3	1.44	7.00
8.5 – 9.0	9	1.12	10.33	10	1.20	8.20
9.0 – 9.5	13	2.39	9.77	10	1.19	9.20
9.5 – 10.0	13	1.50	10.62	24	1.10	10.46
10.0 – 10.5	13	1.97	10.69	9	1.29	9.11
10.5 – 11.0	17	2.70	9.82	21	1.41	10.00
11.0 – 11.5	10	1.93	10.80	12	1.53	9.08
11.5 – 12.0	19	1.95	10.37	23	1.63	9.30
12.0 – 12.5	10	2.06	10.70	6	1.47	9.83
12.5 – 13.0	10	2.11	10.70	11	1.52	10.00

Table 10-14. Mean total score and standard deviation for technical comprehension according to age and sex; results for 244 children.

An analysis of variance showed that the only variable which influenced the total score was sex ($F = 7.945$; $p = 0.005$). Girls achieved significantly lower mean scores than boys.

10.5.3 Results of all children

In order to compare the results found for the younger and the older children, the results are presented as percentages of the maximum achievable socre. In this way the results can be combined in one table or figure.
The frequency distribution of this proportional score is presented in table 10-15, the histogram is figure 10-8.

proportional score	frequency	percent	cumulative percent
0.00	21	2.2	2.2
16.67	77	8.0	10.2
25.00	1	0.1	10.3
33.33	172	17.9	28.3
41.67	10	1.0	29.3
50.00	196	20.4	49.7
58.33	16	1.7	51.4
66.67	156	16.3	67.7
75.00	26	2.7	70.4
83.33	111	11.6	82.0
91.67	55	5.7	87.7
100.00	118	12.3	100.0
total:	959	100.0	

Table 10-15: Frequency distribution of the proportional score for technical comprehension for children aged 2 to 13.

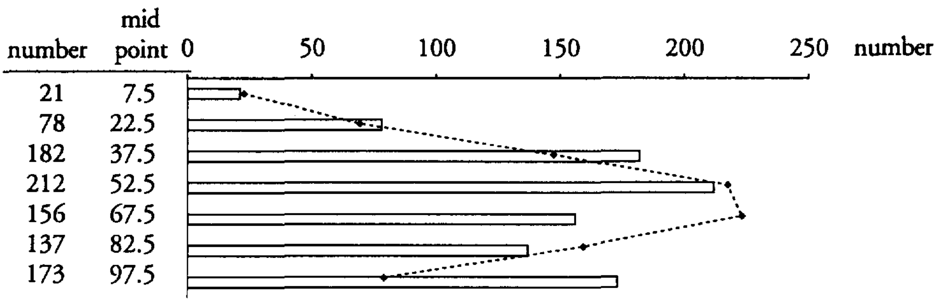


Figure 10-8: Histogram of the proportional score for technical comprehension.

The mean values of the proportional scores per age group and sex, for all children together, are presented in table 10-16

age [years]	boys n	boys s	boys x̄	girls n	girls s	girls x̄
	proportional score on technical comprehension					
2.0 – 2.9	80	20.66	40.21	91	21.98	40.84
3.0 – 3.9	97	19.88	45.70	86	19.06	44.38
4.0 – 4.9	37	22.01	48.65	34	22.24	48.53
5.0 – 5.9	44	26.73	56.82	46	26.13	52.90
6.0 – 6.9	54	21.39	62.96	44	24.58	55.30
7.0 – 7.9	34	20.00	68.63	32	22.17	69.79
8.0 – 8.9	29	24.77	72.99	30	21.01	69.17
9.0 – 9.9	26	16.67	84.94	34	16.84	84.07
10.0 – 10.9	30	20.11	85.00	30	16.80	81.11
11.0 – 11.9	29	16.00	87.64	35	25.25	76.90
12.0 – 12.9	20	16.91	89.17	17	18.51	82.84

Table 10-16: Proportional score for technical comprehension for all children; results for 480 boys and 479 girls.

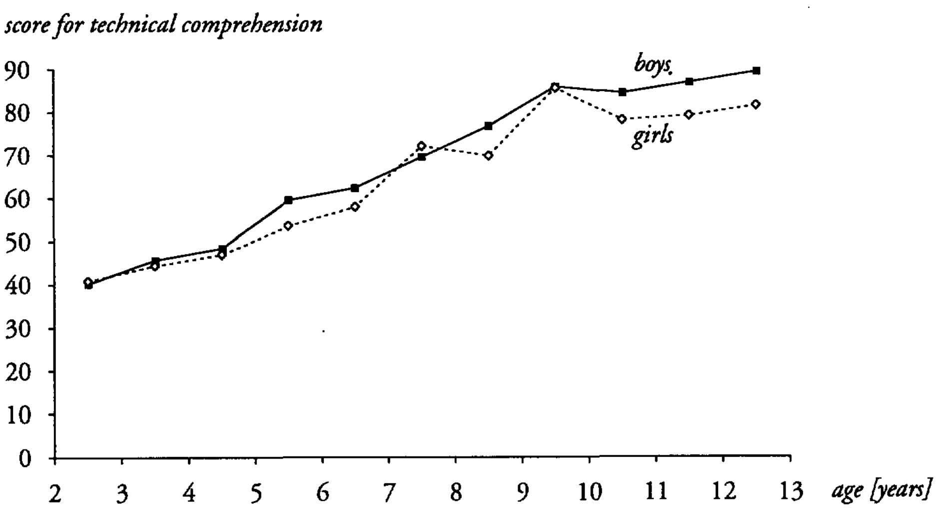


Figure 10-9: Mean scores for technical comprehension according to age and sex.

The only variable influencing the mean score was age (analysis of variance, $F = 27.2$; $p = 0.00$).

A multiple comparison test (Scheffé Multiple Range test) revealed significant differences between certain age groups; these groups are denoted by a '•'. The '·' indicates that these groups did not differ. Again this means, for example, that the mean score for technical comprehension of children aged 2 years is significantly different from the mean scores of children aged 5 or more.

mean	age	2	3	4	5	6	7	8	9	10	11	12
40.50	2											
44.86	3	·										
47.76	4	·	·									
54.67	5	•	·	·								
59.10	6	•	•	·	·							
68.99	7	•	•	•	•	·						
72.18	8	•	•	•	•	·	·					
83.48	9	•	•	•	•	•	·	·				
82.32	10	•	•	•	•	•	·	·	·			
82.35	11	•	•	•	•	•	·	·	·	·		
85.31	12	•	•	•	•	•	·	·	·	·	·	

Figure 10-10: Differences between the mean scores per age group (all children).

There appeared to be no differences in mean scores within two groups of children: those aged 2 to 4 years and children aged 7 to 12 years. Children in the age group 2 to 6 years differed at all ages from children aged 9 to 12 years and at some ages from the age group 5 to 8 years.

The overall correlation coefficient between total score and age was 0.6015. For boys it was 0.6355; for girls the correlation coefficient was 0.5696.
The correlation coefficients calculated for three age groups are given in table 10-17.

age [years]	correlation coefficient boys	girls	boys + girls
2.0 – 4.9	0.1029	0.0178	0.0609
5.0 – 8.9	0.3866	0.3352	0.3591
9.0 – 12.9	0.0954	-0.0242	0.0306

Table 10-17: Correlation coefficients between score for technical comprehension and age for three different age groups.

Although one should not forget the effects of the 'restriction of range', it can be concluded that the development of technical comprehension, according to the results of our investigation, is most apparent between ages 5 and 9.

10.6 Conclusions

10.6.1 Method

For some of the youngest children (2 - 4 years) this test was just a funny game with a dog and a bird. That they had to fulfil a specific task was of secondary importance. Other children in this age group, however, were very serious about performing the task.
For children aged 4 to 9 years the differentiation between scores is acceptable.
The older children (9 to 13 years of age) sometimes said that this test was childish and too easy for them. They performed all operations in the right way. Other children in this group reacted to this fact by being less motivated and less cooperative.

With respect to the controls it can be concluded that operation of the handle was not clear and that many children were confused by it. In this test the handle was seen as a sort of rotary knob and thus the clockwise-for-more principle was used. It would probably have been better to consider the handle grip as the most important part of the control and therefore to use the movement of this part of the handle to determine the direction of movement of the pointer.
The joystick seemed to be new, especially for younger children (aged 2 - 4); often they did not know how to operate it.

10.6.2 Technical comprehension

It appears that the plane in which the controls are placed and the direction of movement of the pointer have little influence on the results. Only the type of control influenced the way in which the operation was performed. The joystick and the handle were less likely to be operated correctly. This could imply a lower prevalence of these controls in everyday life, so that the children probably have not yet had the opportunity to learn the compatibility rules for these controls.

This test on technical comprehension revealed differences in scores between children of various ages, especially between 5 and 9 years of age.
The younger boys and girls did equally well, and their performance increased with age.
For the older children it can be concluded that the scores did not increase with age. The differences between boys and girls were, however, still striking.

10.7 Discussion

This test was a first attempt to measure development of one aspect of technical comprehension: knowledge of some of the more common compatibility rules, which are important in man-product interaction. This was operationalized by four types of controls, placed in two planes and used to effectuate a horizontal or vertical movement.
In this way an attempot was made to reveal a differentiation (regarded as an aspect of development) between children of different age groups. Cronbach's α, however, appeared to

be too low, and the scores for many age groups were quite similar. With respect to validation of the test it would be of interest to correlate these scores for technical comprehension with the results of the test on motor development as well as some body dimensions. Such an analysis, however, does not yet meet the normal test requirements and requires further development; this applied not only to the power of differentiation within the entire age group but also to reliability and validity.

Explanations for the differences found between children of different age groups and sex are not easily given. Some speculations can be made.

If this test is presumed to indicate technical comprehension to some extent, then our data suggest that there is a relatively rapid development in knowledge of compatibility rules after the age of 4. Before this age the children perform on an equal level. Probably because of the fact that after the age of 4 children become used to performing certain operations themselves, they have the opportunity to learn. And although in everyday life certain operations are not compatible, they learn (by trial and error) the general rules. One may also speculate that, as far as technical mechanisms are concerned, cognitive development only starts at the age of 4 years. Children then begin to understand what is happening; this awareness continues to develop throughout primary school, which is in accordance with the theory of Piaget (1930) on cognitive development in relation to physical causality.

The lower scores for girls aged 9 or more may confirm the stereotype: girls have less technical comprehension than boys. This in turn could point towards a continuing difference in the upbringing of boys and girls. Another explanation could be that the elder girls were less motivated to participate in such a 'childish' test.

11 Patterns of development as indicated by the groups of variables

11.1 Introduction

In the preceding chapters each of the different groups of variables was described and analysed according to age and sex. When necessary, a total score as representative value for each group of variables was computed. The way in which these total scores were calculated was also described in the previous chapters.
The representative variables are used in this chapter to acquire insight into the development of each group of variables and the relationships between these groups.
Despite the rather poor performance of the physical flexibility and technical comprehension tests they are nevertheless included in this chapter for the sake of completeness and because of curiosity on which relationships they appear to have in this project.
Development in the proper sense of the word requires longitudinal data. In this project however development is conceived as the change in characteristics of successive age groups. For a description of this pattern of development cross-sectional data can and must be used.

11.2 Predictability of a variable

For our attempt to find a dependable method for prediction of the physical variables at a certain age, the starting point was the assumption that the development of each of the physical characteristics can be described mathematically in a linear way, using age as the independent variable. In the development of several variables, sex also plays an important role, in these cases the equations will be different for boys and girls. With these expectations in mind regression equations can be calculated.

Of the anthropometric variables stature and body mass (being general measurements of the body) as well as popliteal height, head circumference and upper arm circumference were selected as being representative of the 40 body dimensions. The latter three variables had the highest factor loadings for the three factors that resulted from factor analysis: length, volume and head. For the psychomotor and temperamental variables, total scores were used in the regression analyses.

The regression equations which describe the development of these variables are given below. For the variables marked with '*' the differences between the equations for boys and girls were not statistically significant, but for the sake of completeness they are nevertheless given. For these variables the first equation can be considered as an acceptable description of the increase in value with age, regardless of sex. For the other variables cross-sectional development is better estimated by using separate equations for boys and girls. The equations proved to be as follows:

variable	regression equation	sex	fit
stature * [cm] =	80.18 + (6.27 · age)	♂ + ♀	r = 0.96
	81.09 + (6.19 · age)	♂	r = 0.96
	79.25 + (6.36 · age)	♀	r = 0.96
body mass * [kg] =	5.10 + (3.00 · age)	♂ + ♀	r = 0.88
	5.96 + (2.87 · age)	♂	r = 0.88
	4.26 + (3.13 · age)	♀	r = 0.88
popliteal height [cm] =	18.30 + (2.12 · age)	♂ + ♀	r = 0.95
	18.46 + (2.13 · age)	♂	r = 0.95
	18.13 + (2.11 · age)	♀	r = 0.95
head circumference [cm] =	49.46 + (0.42 · age)	♂ + ♀	r = 0.65
	50.07 + (0.40 · age)	♂	r = 0.65
	48.81 + (0.45 · age)	♀	r = 0.69
upper arm circumference [cm] =	14.83 + (0.57 · age)	♂ + ♀	r = 0.70
	15.06 + (0.53 · age)	♂	r = 0.67
	14.61 + (0.61 · age)	♀	r = 0.73
force exertion =	-1.07 + (2.29 · age)	♂ + ♀	r = 0.82
	-1.65 + (2.51 · age)	♂	r = 0.85
	-0.40 + (2.06 · age)	♀	r = 0.81
motor performance =	3.40 + (1.45 · age)	♂ + ♀	r = 0.83
	2.81 + (1.46 · age)	♂	r = 0.84
	3.93 + (1.44 · age)	♀	r = 0.84
distance reached =	36.12 - (1.24 · age)	♂ + ♀	r = 0.55
	36.49 - (1.43 · age)	♂	r = 0.62
	35.72 - (1.03 · age)	♀	r = 0.49
technical comprehension * =	27.58 + (5.17 · age)	♂ + ♀	r = 0.60
	26.91 + (5.49 · age)	♂	r = 0.63
	28.13 + (4.86 · age)	♀	r = 0.57

Table 11-1: Regression equations for the variables with age.

As expected, the development of temperamental characteristics does not parallel the development of physical characteristics; there appears to be very little correlation with age:

judgement by parents =	-3.82 + (0.44 · age)	♂ + ♀	r = 0.14
	-4.74 + (0.36 · age)	♂	r = 0.11
	-2.82 + (0.52 · age)	♀	r = 0.17

The corresponding teacher evaluation cannot be estimated with age as independent variable. The best predictor for this variable was judgement by the parents:

judgement by teachers =	1.89 + (0.64 · judgement by parents)	♂ + ♀	r = 0.56
	-0.07 + (0.63 · judgement by parents)	♂	r = 0.55
	4.78 + (0.48 · judgement by parents)	♀	r = 0.48

Several graphs (appendix J) show the mean observed values for the sample and the predicted values per age group, based on these linear regression equations. These graphs clearly illustrate that not all of the observed patterns were linear, although this does not imply that a curvilinear correlation is the better approximation in most cases. The tests performed to support this statement are described below.

All empirical mean values per age group of the variables were tested for (deviation from) linearity, using an analysis of variance. For this purpose the mean sum of squares between the age groups was divided into a linear component and a deviation from the linear component (Marascuilo et al., 1988). The fraction of these two values follows an F-distribution. The deviation from linearity was divided by the mean sum of squares within the groups; this fraction also follows an F-distribution. These tests show that all variables exhibited a significant deviation from linearity, except for force exertion and judgement of temperament by parents. The judgement by teachers cannot be estimated properly by a linear equation. The results of these tests for each of the variables were:

	linearity		deviation from linearity	
variable	F	p	F	p
stature	24,446.3	0.00	13.8	0.00
body mass	7,680.9	0.00	10.2	0.00
popliteal height	19,757.2	0.00	19.3	0.00
upper arm circumference	2,168.9	0.00	5.4	0.00
head circumference	1,625.8	0.00	6.2	0.00
force exertion	1,518.0	0.00	1.4	0.21
motor performance	1,444.3	0.00	18.9	0.00
distance reached	590.2	0.00	22.9	0.00
technical comprehension	539.9	0.00	2.0	0.01
judgement parents	42.2	0.00	1.1	0.39
judgement teachers	0.6	0.44	1.1	0.38

Table 11-2: Results of analysis of variance applied to linearity.

For most of the variables the magnitude of the F-value for linearity was much larger than that for the deviation from linearity, indicating that the linear equations are rather good estimations of the curves through the observed mean values. In spite of this, curvilinear equations were computed.

For the variables which exhibited a significant deviation from linearity, the difference between the residual sums of squares for the linear and the curvilinear equation was computed and divided by the mean square error of the curvilinear equation. This fraction follows an F-distribution.

variable	F	p	r^2linear	r^2curvilinear
stature	105.55	0.00	0.92113	0.92473
body mass	91.56	0.00	0.77653	0.78543
popliteal height	162.54	0.00	0.90111	0.90793
upper arm circumference	29.84	0.00	0.49630	0.50304
head circumference	26.57	0.00	0.42325	0.43013
motor performance	143.26	0.00	0.69590	0.75887
distance reached	119.66	0.00	0.30592	0.37232

Table 11-3: Differences between linear and curvilinear equation; results of analysis of variance.

The values for r^2 improved slightly when a curvilinear equation was computed. Therefore the above-mentioned variables can be described somewhat better with a curvilinear equation but because the improvement in the explained variance was minor, the linear equations will be used in further analyses. For technical comprehension the fit of the curvilinear equation was worse than that of the linear equation.

When comparing the graphical presentations (appendix J) of the observed (empirical) and predicted values –based on these linear equations– per age group, some deviations from linear development can be seen. An observed value larger than the predicted value might indicate some kind of growth spurt. If the observed value is smaller, then a lag compared to the average rate of development may have occurred. It should, however, be noted that the differences found might possibly be explained by the occurrence of cohort effects, attributable to the cross-sectional sampling.

The differences between the observed and predicted mean values per age group were tested with the t-test for paired (empirical and predicted) observations. The results of this t-test, together with the correlation between predicted and observed values, provide some insight into developmental patterns. Correlation coefficients which differ significantly from zero ($p < 0.05$) indicate that there is a positive relationship between the observed and predicted value. In such a case, the means of the observed and predicted values were tested to see whether a growth spurt or growth lag could be identified. A negative value for the t-statistic indicated growth lag and a positive value pointed towards a growth spurt.

Tables 11-4 and 11-5 give the significant results of the t-tests for boys and girls, respectively, provided that the correlation coefficient between the observed and predicted values per age group was significantly different from zero. The reason for this extra criterion is that only in the event of a significant correlation between observed and predicted values an average rate of development is a justifiable concept, which in turn allows comparison per age group between the predicted and the observed values. All results are presented in appendix K.

	boys											
age	stature				body mass				popliteal height			
[years]	r	p	t	p	r	p	t	p	r	p	t	p
2.0 – 2.9	.69	.000	-6.86	.000	.52	.000	7.36	.000	.70	.000	-8.05	.000
3.0 – 3.9	.45	.000			.22	.030	5.27	.000	.49	.000	-2.40	.018
4.0 – 4.9	.36	.001			.29	.010			.32	.005		
5.0 – 5.9	.34	.002	3.44	.001	.25	.023			.46	.000	3.91	.000
6.0 – 6.9	.35	.001	2.29	.024					.37	.000	3.25	.002
7.0 – 7.9	.22	.022	2.77	.007					.26	.007	3.07	.003
8.0 – 8.9	.27	.007			.22	.035	(3.63)	.000				
9.0 – 9.9												
10.0 – 10.9	.20	.021							.23	.007		
11.0 – 11.9	.17	.042	-2.02	.045	.17	.046						
12.0 – 12.9	.31	.006							.31	.006	-2.30	.024
	head circumference				**upper arm circumference**				**force exertion**			
2.0 – 2.9	.30	.011	-2.18	.032					no measurements			
3.0 – 3.9									no measurements			
4.0 – 4.9									.38	.014		
5.0 – 5.9												
6.0 – 6.9												
7.0 – 7.9									.30	.036		
8.0 – 8.9	.20	.049										
9.0 – 9.9												
10.0 – 10.9												
11.0 – 11.9												
12.0 – 12.9												
	motor performance				**distance reached**				**technical comprehension**			
2.0 – 2.9	no measurements											
3.0 – 3.9	no measurements											
4.0 – 4.9	.53	.014	-3.11	.006								
5.0 – 5.9	.48	.002							.30	.039		
6.0 – 6.9												
7.0 – 7.9												
8.0 – 8.9												
9.0 – 9.9												
10.0 – 10.9												
11.0 – 11.9												
12.0 – 12.9												
	judgement parents temperament				**judgement teachers temperament**							
2.0 – 2.9					no measurements							
3.0 – 3.9					no measurements							
4.0 – 4.9					.33	.038						
5.0 – 5.9					.49	.001						
6.0 – 6.9					.56	.000						
7.0 – 7.9					.66	.000						
8.0 – 8.9					.50	.005						
9.0 – 9.9					.54	.001						
10.0 – 10.9					.67	.000						
11.0 – 11.9					.67	.000						
12.0 – 12.9					.61	.001						

Table 11-4: Significant values of the correlation coefficients per age group between observed and predicted values, and the significant t-values for paired observations, testing the differences between mean predicted and mean observed values, for boys; $p < 0.05$.

girls

age [years]	stature				body mass				popliteal height			
	r	p	t	p	r	p	t	p	r	p	t	p
2.0 – 2.9	.67	.000	-6.52	.000	.44	.000	11.52	.000	.55	.000	-8.50	.000
3.0 – 3.9	.52	.000	-2.35	.021	.37	.001	4.53	.000	.46	.000	-2.43	.017
4.0 – 4.9	.44	.000							.40	.001		
5.0 – 5.9	.30	.004	3.03	.003					.26	.014	3.71	.000
6.0 – 6.9	.32	.002	4.28	.000	.25	.010	-3.78	.000	.25	.019	3.86	.000
7.0 – 7.9	.42	.000	2.76	.007	.28	.007	-2.09	.039	.34	.001	3.10	.003
8.0 – 8.9					.23	.027	-4.00	.000				
9.0 – 9.9	.27	.003							.24	.009		
10.0 – 10.9	.34	.000	1.99	.049	.20	.023	2.51	.013	.32	.000		
11.0 – 11.9	.35	.000	-2.62	.010	.36	.000			.25	.002	-3.19	.002
12.0 – 12.9												

age [years]	head cirumference				upper arm circumference				force exertion			
2.0 – 2.9	.40	.000	-4.15	.000	.40	.000	-4.15	.000	no measurements			
3.0 – 3.9									no measurements			
4.0 – 4.9									.32	.028		
5.0 – 5.9									.27	.037		
6.0 – 6.9												
7.0 – 7.9					.23	.031						
8.0 – 8.9					.21	.037						
9.0 – 9.9												
10.0 – 10.9	.22	.006										
11.0 – 11.9	.18	.025			.22	.006						
12.0 – 12.9												

age [years]	motor performance				distance reached				technical comprehension			
2.0 – 2.9	no measurements											
3.0 – 3.9	no measurements											
4.0 – 4.9	.58	.002	-3.84	.001								
5.0 – 5.9	.34	.038	-3.07	.004								
6.0 – 6.9					-.28	.037	-4.15	.000				
7.0 – 7.9												
8.0 – 8.9												
9.0 – 9.9									.46	.008	4.24	.000
10.0 – 10.9												
11.0 – 11.9												
12.0 – 12.9												

age [years]	judgement parents temperament		judgement teachers temperament	
2.0 – 2.9			no measurements	
3.0 – 3.9			no measurements	
4.0 – 4.9	.39	.000	.41	.010
5.0 – 5.9			.49	.000
6.0 – 6.9			.35	.022
7.0 – 7.9			.61	.000
8.0 – 8.9				
9.0 – 9.9			.61	.000
10.0 – 10.9			.49	.004
11.0 – 11.9			.45	.010
12.0 – 12.9			.70	.000

Table 11-5. Significant values of the correlation coefficients per age group between observed and predicted values, and the significant t-values for paired observations, testing the differences between mean predicted and mean observed values, for girls; $p < 0.05$.

The results lead to three preliminary conclusions:

- Only stature, body mass and popliteal height can be predicted fairly accurately by a linear regression equation with age as independent variable, because for most age groups the correlation coefficients for these variables were significantly different from zero. Furthermore the explained variance does not improve dramatically when a curvilinear equation is used to describe the data.

- Only for stature, body mass and popliteal height were more or less systematic differences between observed and predicted values present.

  For the length-related variables (stature and popliteal height) there appeared to be differences between mean attained height and mean predicted height, especially for girls. For the first two years (2 to 4 years of age) the observed values were smaller than expected, indicating some retardation with respect to the average rate of development throughout the entire age range under study. This turns into an opposite difference during the period from 5 to 7 years. In this period of life a kind of growth spurt seems to take place. With respect to body mass, the pattern seems to be just the opposite. For the first two years the mean values for body mass were larger than expected, but they were lower than expected during the period 6 to 8 years. Therefore there seems to be a decrease in rate of weight gain during the period 2 to 8 years of age, compared to the estimated linear pattern. This cannot be explained by a similar pattern in breadth or depth measurements, because the differences seem to be more coincidental for these measurements. Again, differences between cohorts of birth cannot be excluded as an explanation.

- The mean values for motor performance by girls were lower than expected in the age range 4 to 5 years, whereas this measurement was only lower for boys four years of age.

- The differences found for the other variables cannot be seen as systematic differences; they appear to be just coincidental.

In addition to the above-mentioned results some data on changes in proportions of the body between the ages of 2 and 13 years can be given. The mean values and percentiles for the dimensions of the head, trunk and legs, relative to stature, are presented in table 11-6. These values can be used to visualize changes in proportions during the ages under study. This is illustrated in figure 11-1.

head length as percentage of stature

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	1.23	16.81	18.77	21.09	92	1.39	16.06	18.52	21.35	1.32	18.64
3.0 – 3.9	97	1.13	15.89	18.11	20.29	86	1.02	15.99	17.75	19.99	1.09	17.94
4.0 – 4.9	85	1.04	15.94	17.55	19.36	79	.92	15.65	17.15	18.63	1.00	17.36
5.0 – 5.9	86	.97	15.10	16.93	18.87	94	.96	14.93	16.64	18.73	.97	16.78
6.0 – 6.9	98	.83	14.47	16.29	17.74	92	.88	14.24	15.72	17.26	.90	16.02
7.0 – 7.9	106	.90	14.28	15.84	17.41	93	.83	13.63	15.28	16.88	.91	15.58
8.0 – 8.9	96	.80	13.91	15.34	17.19	95	.80	13.35	14.91	16.39	.83	15.13
9.0 – 9.9	122	.76	13.35	14.68	16.07	122	.78	12.95	14.43	16.10	.78	14.55
10.0 – 10.9	134	.74	13.11	14.53	16.05	136	.75	12.68	14.00	15.34	.79	14.26
11.0 – 11.9	143	.68	13.17	14.25	15.47	151	.70	12.43	13.77	15.18	.73	14.00
12.0 – 12.9	78	.71	12.84	13.84	15.30	79	.64	12.20	13.37	14.41	.71	13.61

trunk length as percentage of stature

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	1.46	33.41	35.82	38.57	92	1.71	32.65	35.76	38.57	1.59	35.79
3.0 – 3.9	97	1.36	32.58	34.74	37.63	86	1.38	31.71	34.67	37.04	1.37	34.71
4.0 – 4.9	85	1.51	30.99	33.36	35.89	79	1.22	31.23	33.59	35.73	1.38	33.47
5.0 – 5.9	86	1.38	30.22	32.73	35.04	94	1.40	30.59	32.97	35.97	1.40	32.85
6.0 – 6.9	98	1.39	30.31	33.01	35.92	92	1.16	30.50	32.81	34.94	1.29	32.91
7.0 – 7.9	106	1.43	29.82	32.80	35.24	93	1.30	29.95	32.99	35.30	1.37	32.89
8.0 – 8.9	96	1.18	30.03	32.45	34.86	95	1.37	30.24	32.98	35.50	1.30	32.72
9.0 – 9.9	122	1.29	29.65	32.33	34.79	122	1.23	30.28	32.57	34.85	1.26	32.45
10.0 – 10.9	134	1.31	30.03	32.41	34.63	136	1.25	30.49	32.60	34.85	1.28	32.51
11.0 – 11.9	143	1.20	29.82	32.23	34.42	151	1.16	30.72	32.74	34.90	1.20	32.49
12.0 – 12.9	78	1.22	30.21	32.41	35.04	79	1.31	30.55	32.64	35.14	1.27	32.53

leg length as percentage of stature

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	1.41	38.27	41.09	43.36	92	1.44	38.58	41.37	44.22	1.43	41.24
3.0 – 3.9	97	1.46	40.14	43.14	45.71	86	1.29	41.19	43.51	46.06	1.39	43.31
4.0 – 4.9	85	1.28	41.72	43.96	46.20	79	1.33	42.05	44.45	46.95	1.33	44.20
5.0 – 5.9	86	1.35	43.24	45.38	48.26	94	1.36	43.25	45.52	48.30	1.36	45.45
6.0 – 6.9	98	1.30	43.34	45.73	48.67	92	1.29	43.56	45.92	48.47	1.30	45.82
7.0 – 7.9	106	1.19	44.26	46.35	48.33	93	1.20	43.83	46.56	48.56	1.20	46.44
8.0 – 8.9	96	1.35	44.37	47.08	49.50	95	1.18	44.86	46.97	49.39	1.27	47.02
9.0 – 9.9	122	1.23	44.97	47.67	49.77	122	1.25	45.21	47.58	50.38	1.24	47.62
10.0 – 10.9	134	1.27	45.79	48.08	50.65	136	1.22	45.64	48.17	50.41	1.24	48.13
11.0 – 11.9	143	1.26	46.25	48.51	51.07	151	1.14	46.25	48.37	50.43	1.20	48.44
12.0 – 12.9	78	1.18	46.34	48.78	50.80	79	1.24	46.60	48.74	51.31	1.20	48.76

Table 11-6. Relative dimensions of head, trunk and legs per age group and sex.

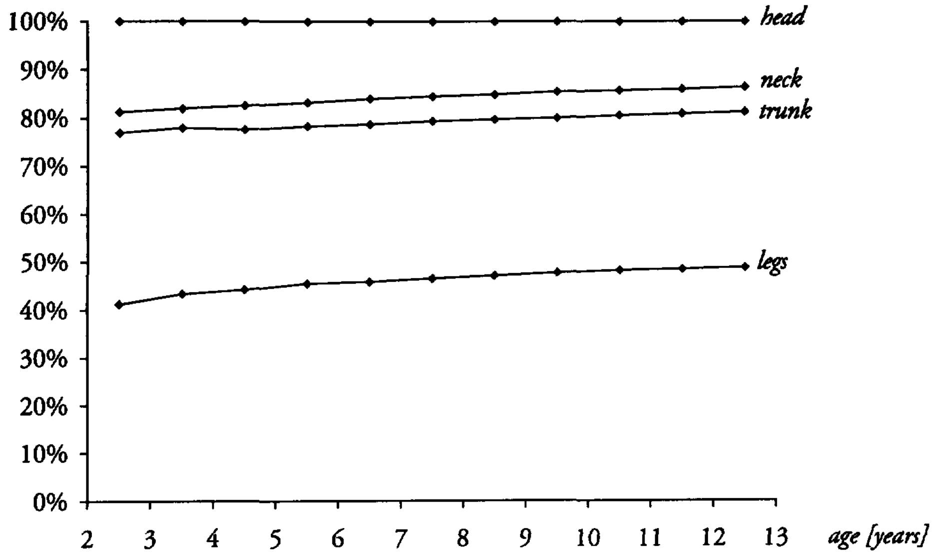


Figure 11-1. Mean relative values of the dimensions of head, trunk and legs for different age groups.

The relative dimensions of the head decrease, while the relative dimensions of the legs increase in length with age. The relative dimensions of the trunk remain more or less constant after the age of 5 years; before this age they decrease slightly.
The differences in mean relative dimensions between boys and girls were tested with t-tests, and the results lead to the conclusion that for all ages only differences in the dimensions of the head exist. There is little difference in the length of the trunk and legs between boys and girls. In appendix L the results of the t-tests are given.
There seems to be no evidence for the expectation that girls are always proportioned in a more 'childlike' way, because the only difference found (head length as percentage of stature) was already present at birth and this persisted during the period of time under study in this project.

Comparison of the mean values for successive age groups leads to another conclusion. The mean relative dimensions of the head and legs appear to differ systematically in successive age groups. The relative dimensions of the head decrease with age, whereas the relative dimensions of the legs increase. The differences between the mean values for the trunk differ significantly only between the ages of 2 and 5 years.

An analysis of variance (table 11-7) revealed main effects of age on the three variables and sex on the variables head and trunk. No interaction effects could be demonstrated, meaning that the differences found between boys and girls did not alter with age. They remained in the same direction.

	main effects			
	age		sex	
	F	p	F	p
head	692.59	0	127.23	0
trunk	116.23	0	13.35	0
legs	623.05	0	3.25	0.071

Table 11-7: Results of analysis of variance.

11.3 Predictability of age in relation to the groups of variables

Step-wise regression analysis including all variables was performed to find the best predictors for age, meaning the variables most dependent on age. A linear equation with popliteal height, motor performance and force exertion appeared to be the best predictor of the age of children between 4 and 13 years. The equation is:

$$\text{age} = -4.78 + 0.26 \cdot \text{popliteal height} + 0.15 \cdot \text{motor performance} + 0.05 \cdot \text{force exertion} \qquad (r = 0.94)$$

The most important variable in the equation is popliteal height ($\beta = 0.58$), second is motor performance ($\beta = 0.27$) and third force exertion ($\beta = 0.15$). These variables can thus be seen as core characteristics for (physical) development and the anthropometric variable seems to be the most important of the three.

11.4 Relations between variables

The correlations between the variables for all children together provide a picture of development during the period 2 to 13 years. The higher the correlation coefficients, the more the variables develop simultaneously. Low coefficients point towards relatively sequential, a-synchronous development. The term 'relatively' is used because all characteristics develop during the period of life studied in this project, but there seems to be a kind of periodicity: for example, during a period of rapid increase in body height, the increase in body mass slows down, whereas during a period of increased weight gain, increase in height diminishes (see paragraph 11.2).

For comparison of the correlation coefficients the variables were grouped into three categories:

1. *anthropometric variables:* stature, body mass, popliteal height, head circumference, upper arm circumference;
2. *psychomotor variables:* force exertion, motor performance, distance reached, technical comprehension;
3. *temperamental variables:* judgement by the parents and judgement by the teachers.

Correlation coefficients were calculated for the variables within and between these groups, for all children together as well as for three age groups.

In table 11-8 the lowest and highest significant correlation coefficients are given per group of variables. A matrix of all correlation coefficients is presented in appendix M.

This table shows that, for example, within the group of anthropometric variables 10 correlation coefficients were computed, and they all appeared to be significantly different from zero, both for the sample as a whole and for each age group. For the total sample the values ranged from 0.6321 to 0.9850. In another example 20 correlation coefficients between the anthropometric and psychomotor variables were computed. For children between 2 and 6 years of age, 17 of these coefficients were significantly different from zero, ranging from 0.1353 to 0.5985.

within:	k	age [years]	lowest and highest correlation coefficient	#
anthropometric variables	10	2.0 – 12.9	0.6321 ... 0.9850	10
		2.0 – 5.9	0.3830 ... 0.9550	10
		6.0 – 8.9	0.2763 ... 0.8993	10
		9.0 – 12.9	0.3697 ... 0.9045	10
psychomotor variables	6	2.0 – 12.9	0.0962 ... 0.6954	5
		2.0 – 5.9	0.2400 ... 0.5002	3
		6.0 – 8.9	0.1488 ... 0.2645	3
		9.0 – 12.9	0.1537 ... 0.2371	2
temperamental variables	1	2.0 – 12.9	0.5558	1
		2.0 – 5.9	0.4915	1
		6.0 – 8.9	0.5297	1
		9.0 – 12.9	0.6337	1
between:				
anthropometric - psychomotor	20	2.0 – 12.9	0.3855 ... 0.8267	20
		2.0 – 5.9	0.1353 ... 0.5985	17
		6.0 – 8.9	0.1704 ... 0.4867	12
		9.0 – 12.9	0.1586 ... 0.5580	8
psychomotor - temperamental	8	2.0 – 12.9	0.1093 ... 0.1762	3
		2.0 – 5.9	0.0897 ... 0.2353	3
		6.0 – 8.9	0.1466 ... 0.1896	2
		9.0 – 12.9	0.1493 ... 0.2533	3
temperamental - anthropometric	10	2.0 – 12.9	0.0757 ... 0.1257	5
		2.0 – 5.9	0.0788 ... 0.1947	4
		6.0 – 8.9	-	0
		9.0 – 12.9	-	0

Table 11-8: Lowest and highest correlation coefficients (significantly different; $p < 0.05$, 2-tailed) within and between the three groups of variables.
k = number of correlation coefficients computed
 # = number of correlation coefficients significantly different from zero.

11.4.1 Correlations within the groups of variables.

For all children together the correlation coefficients between most of the variables were significantly different from zero, although the values decreased from the more anthropometric variables towards the more temperamental variables (hypothesis 2, chapters 4 and 12). Therefore, development of physical characteristics exhibits a closer relationship with age than the development of a personality trait, such as temperament.
In the successive age groups the values of most of the correlation coefficients decreased, pointing towards an increasing differentiation of characteristics and thus individualization of the children.

11.4.2 Correlations between the groups of variables

There appears to be a clear relationship between the anthropometric variables and the psychomotor variables, especially when all ages are taken into account. In each of the three different age groups the relationships were less marked but still present.

Some of the correlation coefficients between the physical characteristics (anthropometric and psychomotor variables) and the temperamental variables were significantly different from zero, but the values were very low, irrespective of age. This again shows the minor importance of age in the development of the temperamental aspects of personality, as judged by parents and/or teachers.

Partial correlation coefficients were computed to correct for the influence of age and age plus sex on the correlation coefficients. The values of these coefficients are, as expected, lower than the values given in table 11-8. Part of this decrease in value can be explained by the phenomenon'restriction of range'. In table 11-9 the partial correlations, corrected for age and corrected for age and sex, are presented. Matrices with all partial correlation coefficients are given in appendix N.

	k	correlations for all ages	#	partial correlation controlling for age	#	partial correlations for age and sex	#
within:							
anthropometric variables	10	0.6321 ... 0.9850	10	0.2029 ... 0.8368	10	0.2115 ... 0.8393	10
psychomotor variables	6	0.0962 ... 0.6954	5	0.1315 ... 0.8498	3	0.0938 ... 0.8485	5
temperamental variables	1	0.5558	1	0.5568	1	0.5405	1
between:							
anthropometric – psychomotor	20	0.3855 ... 0.8267	20	0.1281 ... 0.2759	10	0.0834 ... 0.3051	11
psychomotor – temperamental	8	0.1093 ... 0.1762	3	0.1036 ... 0.2380	6	0.0877 ... 0.1528	5
temperamental – anthropometric	10	0.0757 ... 0.1257	5	0.0476 ... 0.0889	2	0.0384 ... 0.1044	4

Table 11-9. Correlation coefficients and partial correlation coefficients within and between groups of variables.
k = number of correlation coefficients computed
 # = number of correlation coefficients significantly different from zero.

The lower values for the correlation coefficients may reflect the form and functional patterns of the body, which could be present in adults. It can be assumed that the process of individualization, which takes place during the ages under study, does not stop at the age of 13 but continues until adulthood (or even beyond). This implies that the correlation coefficients for an adult population can be expected to be even smaller that those for children. In order to verify this, the correlation coefficients were compared with those based on anthropometric measurements of adults. Often these samples are, however, drawn from selective populations, for example, the military. Hardly any data on random samples of civilians are available. The lowest and highest correlation coefficients between the –previously mentioned– five anthropometric variables, based on the data of Dutchmil '85 (Brekelmans et al., 1986) and Churchill et al. (1978), are presented in table 11-10.

source	k	range of correlation coefficients
Dutchmil '85	10	-0.0200 ... 0.8500
Air force women '68	10	0.0582 ... 0.8026
USAF flying personnel '67	10	-0.0168 ... 0.8406
Health examination survey 1960-1962, females 25-40	6 *	0.0035 ... 0.9024
Health examination survey 1960-1962, males 25-40	6 *	-0.0333 ... 0.8540

Table 11-10. Correlation coefficients between anthropometric measurements of adults.

** Since head circumference was not measured in this survey, only 6 correlation coefficients could be computed.*

Comparison of the partial correlation coefficients with the correlation coefficients for adults –as far as body dimensions are concerned– shows that the values for children are larger than those for adults, which leads to the conclusion that the process of individualization is indeed not yet completed at the age of twelve but continues for many years. Data for adults on variables other than the anthropometric parameters and comparable to the data of this project are not available.

11.4.3 Grouping of variables by means of factor analysis

Factor analysis (Principal Component) was performed to be able to group the different kinds of variables on the basis of covariance or intrinsic similarity. This resulted in two factors which explained 66.2% of the variance. A varimax rotation did not alter the arrangement of the variables.

The first factor can be described as the 'developmental factor' and explains 51.9% of the variance. It consists of the following variables:

	factor loadings
stature	0.967
popliteal height	0.951
age	0.936
body mass	0.929
force exertion	0.867
motor performance	0.833
upper arm circumference	0.783
head circumference	0.674
technical comprehension	0.579
physical flexibility	0.527

The second factor is the temperamental or accident liability factor; it explains 14.3% of the variance and consists of:

	factor loadings
score by teachers	0.845
score by parents	0.808
liability to have accidents	-0.672

This suggests a different way of grouping the variables than that chosen in the previous paragraphs. Here a division can be made between the more or less objectively measurable variables of the first factor and the subjectively assessed variables of the second. As can be seen all previous analyses involved mainly aspects of the developmental factor.

12 Accident liability

Tables:

Appendices:

The fact that some people have accidents more often than others is sometimes believed to have a predictive value for the future. This observation is called 'accident-proneness', which is supposed to be a kind of personality trait and is therefore expected to be present over longer periods of time. In contrast in this study this higher frequency of accidents is considered a temporary characteristic or a statistical concept which might be due to chance. No predictive value is attached to this frequency. This concept is called 'accident liability'.

The concept of accident-proneness is highly controversial, and this seems to originate from the way it is defined and investigated. Many people seem to accept the (implicit) theory that there are certain individuals who have an accident significantly more often (more than chance variation!) than others. Whether this is caused by personality traits, rates of exposure or other reasons is not a matter of further thought.

Many scientists have tried to assess the concept of accident-proneness. In her thesis on the concept of accident-proneness Houghton (1986) gives an overview of the history of this concept, relevant theories and the results of investigations; her findings are summarized below.

In the past two different approaches to research on accident-proneness have been used: the statistical and the psycho-physiological approach.

The statistical approach

Two methods have been applied: the curve fitting technique and the correlation technique. Greenwood and Woods (1919) and Greenwoods and Yule (1920) developed both techniques.

For the curve fitting technique the frequency distribution of individuals with a certain number of accidents was compared with the number of subjects with that number of accidents in a theoretical distribution (Porter, 1988). The three distributions used were:

1. chance distribution: the occurrence of accidents is random, resulting in a Poisson distribution;
2. biased distribution: it was assumed that after one accident an individual becomes either more or less likely to incur another accident;
3. unequal liability distribution: it was assumed that a propensity towards accidents does exist among some members of a population and not others, resulting in a negative binomial distribution.

This third distribution fitted their data best. They believed accident-proneness to be a permanent and stable trait which was unitary (as a consequence of one single and identical characteristic in each individual) in nature. The authors concluded that varying individual susceptibilities to accidents might be an important factor in determining the distribution of the number of accidents over the number of persons. They acknowledged, however, that other factors such as the inequality of risks, sample selectivity, unequal exposure to accidents, errors in the ascertainment of accidents, a difference between actual and reported accidents, length of the observation period, etc. may have influenced the results of their study. They therefore advised that the results should be considered with caution.

More recent research (Cresswell and Froggatt, 1963) with the curve fitting approach was based on an alternative hypothesis for the occurrence of accidents. In this hypothesis a 'spell' is the main concept. A spell is defined as a period of time during which an individual's

performance of a complex task is substandard. During such a spell accidents are more likely to happen.
Houghton (1986) assumed that the trait of accident-proneness (or the characteristic(s) which constitute(s) the trait) is normally distributed and proposed to look for the extremes of this distribution. Accidents caused by personal 'malfunctioning' may be a part of the expected range of human behaviour.

The correlation technique was also developed by Greenwood and Woods (1919). They argued that if accident-proneness is a viable concept, those involved in an accident in one period of time should also be involved in accidents in a subsequent period of time. The correlation coefficients subsequently found by different researchers were, however, not always very large. The results did not provide unambiguous evidence for the existence of something like accident-proneness.

The psycho-physiological approach
This approach can be seen as complementary to the statistical approach. It was developed by Farmer and Chambers (1926). Assuming that the statistical methods used proved the existence of accident-proneness, it was still not clear what caused this trait. Many tests have been used to prove differences in a variety of psycho-physical characteristics between those who are accident-prone and those who are not accident-prone. Aspects that were studied included: psychomotor performance, vision, perception and attention, balance, intelligence, life events and personality.
The relationship between these variables and accident-proneness was not always very clear. However, it seemed likely that the more complex tasks, requiring attention, had the best differentiating power between the two groups of individuals. A related disadvantage of investigations using these variables to explain accident-proneness was the inappropriateness of the methods chosen to operationalize and assess accident-proneness itself.

In her study on accident-proneness, Houghton (1986) used a questionnaire to identify accident-prone and non-accident-prone individuals by asking about the occurrence of minor accidents or near-accidents, such as stumbling, knocking things over, dropping, bouncing, etc. Different kinds of psycho-physical tests were then administered to the subjects. She concluded that poor skills or abilities with respect to various psychological and physiological variables did not contribute to accident-proneness, as measured by the accident-proneness questionnaire.

These individuals did, however, mention that certain 'moods' such as being preoccupied, distracted, hurried or stressed, influenced the occurrence of accidents. Therefore Houghton concluded that 'inattention' seemed to contribute to the occurrence of (minor) accidents, such as stumbling, knocking things over, falling, etc. This result might, however, have been a subject's rationalization afterwards, because he/she may have thought it hard to believe that someone just stumbles, etc. without some reason.

To investigate this aspect more thoroughly, a complex visual-motor task was defined (Houghton, 1986). Those who were accident-prone performed significantly worse on this task than those who were not accident-prone. This resulted in the assumption that accident-proneness might be related to attention and the prediction of movements, although the precise nature of the differences between the two groups was not shown. Other explanations could be differences in skills or willingness and motivation of the subjects.

All of these investigations were performed using a more or less select sample of adults, often from specific professions. Whether or not these results can be applied to children is not clear.

In this project we assumed that it would not be possible to ask the children themselves about accidents or certain characteristics related to accidents. We therefore chose to ask relatives of the children to complete a questionnaire in which we asked whether a child was often the victim of major or minor accidents. This method of assessment does not necessarily imply the possibility of predicting future accidents; instead it should be considered primarily as a frequency count of accidents in the previous year. A prediction of accidents in the future cannot be given on the basis of this concept. We therefore prefer to use the term accident liability instead of accident-proneness, because this latter term implies the possibility of being able to predict future accidents.

In addition to a judgement of accident liability the parents and teachers were also asked to score various temperamental characteristics. Temperament was considered to be a personality trait which plays a role in the occurrence of accidents. The question was raised whether differences in patterns of development of the various variables exist between children who were judged liable to have accidents and those who were not. This was tested with a t-test, comparing group means per age group. The mean values for children who –according to parents and teachers– are certainly (group C) or probably (group B) liable to have accidents were compared with the mean values for children who were judged absolutely not liable to have accidents (group A). Tables of the mean and standard deviations per age group and per accident liability group for all variables are given in appendix P.

The main result of table 12-1 is that only the scores of parents and teachers for the temperamental characteristics of the children yielded differences between the various accident liability groups of children. This was consistent across all age groups. When the anthropometric and psychomotor variables were used hardly any differences were found between children who are liable to have accidents and those who are not, at least no systematic differences between group A and B+C.

These results indicate that the influence of judged personality traits on the occurrence of accidents is greater than the influence of physical and psychomotor variables. Unfortunately the relevance of this conclusion to product design is that, should this judged liability also be predictive, little can be done to prevent accidents except behavioural training because physical adjustment of hardware to this liability group as such is impossible.
Another conclusion is that the differences between children who are liable to have accidents according to both parents and teachers and those who were judged liable to have accidents by only one of them (B versus C) are not very large. Evaluation of the temperamental characteristics did not really differ between parents and teachers. The only relationships between accident liability and physical variables which differed between groups B and C were related to stature and some of the psychomotor variables, but there was not a systematic difference across the age groups.

age [years]		A↔B+C t	p	A↔C t	p	A↔B t	p	B↔C t	p
4.0 – 4.9	score parents	5.28	.000	4.90	.000	3.41	.001		
	score teachers	4.76	.000	4.00	.000	3.43	.001		
	popliteal height	-2.67	.009						
	distance reached			-2.37	.021			-2.97	.008
5.0 – 5.9	score parents	5.42	.000	3.04	.003	4.88	.000		
	score teachers	3.39	.000	2.41	.018	2.82	.006		
6.0 – 6.9	score parents	5.33	.000	3.25	.025	4.51	.000		
	score teachers	5.13	.000	4.35	.000	3.76	.000		
	stature			-2.70	.008			-3.76	.010
7.0 – 7.9	score parents	5.21	.000	4.70	.000	3.48	.038		
	score teachers	5.48	.000	3.48	.001	4.69	.000		
	body mass	2.08	.040	2.30	.025				
	upper arm circumference	2.27	.026	2.32	.023				
	head circumferenc	2.04	.045	2.24	.028				
	distance reached					2.11	.038		
	force exertion							2.07	.048
	technical comprehension							2.51	.021
8.0 – 8.9	score parents	2.55	.013			2.34	.022		
	technical comprehension	2.08	.042			2.66	.010		
	motor performance			3.32	.002				
9.0 – 9.9	score parents	2.89	.005			2.99	.004		
	score teachers	4.93	.000	2.70	.009	4.49	.000		
	technical comprehension	2.17	.033						
	motor performance							2.82	.011
10.0 – 10.9	score parents	4.79	.000	2.34	.022	4.49	.000		
	score teachers	4.74	.000	3.23	.002	4.05	.000		
11.0 – 11.9	score parents	2.37	.020			2.38	.020		
	score teachers	2.67	.009			2.33	.023		
12.0 – 12.9 *	score teachers					2.31	.026		
	force exertion					-2.22	.033		

Table 12-1: The significant results ($p < 0.05$) of t-tests applied to groups with different accident liability as judged by parents and teachers.
** no children in category C.*
A = not liable to have accidents
B = liable to have accidents according to parents or teachers
C = liable to have accidents according to parents and teachers

It would go too far to assume on this empirical basis that some of these physical or psychomotor variables do play a role in specific age groups only. The table shows that the diffenences appear somewhat haphazardly and are not being confirmed by shifting the ABC-definitions.

Accident liability was expected to be a –possibly past– characteristic of an individual, which could be related to the development of physical and psychomotor variables. During a period of development the body has to adapt itself to a new situation. It might take some time before a state of renewed equilibrium is reached. During such a period of time a person might be more susceptible to accidents than in other periods; this was our theory.
We tried to investigate whether an 'advanced' or 'retarded' development, compared with age peers, could be shown to be related to accident liability in this sample. For this purpose deviations from the mean, based on regression analysis, were computed for all children. If our theory is true, children who are liable to have accidents should exhibit larger deviations from the mean pattern than children who are not liable to have accidents. Because of the fact that this deviation can be in both the positive and the negative direction, absolute standardised z-scores were computed. The mean absolute values for these z-scores per accident liability group were calculated and t-tests were applied to see whether statistically significant differences from zero existed. The results of these t-tests are given in table 12-2.

	A↔C		A↔B		B↔C	
	t	p	t	p	t	p
stature	-2.35	0.019 *	-0.29	0.774	-1.95	0.053
body mass	-0.51	0.608	-0.20	0.843	-0.35	0.723
popliteal height	-1.37	0.172	-0.40	0.687	-0.98	0.330
head circumference	0.59	0.557	1.26	0.208	-0.19	0.850
upper arm circumference	-0.65	0.519	-0.39	0.689	-0.34	0.734
force exertion	0.02	0.986	-0.55	0.585	0.28	0.783
motor performance	-0.86	0.388	-1.07	0.284	-0.10	0.921
technical comprehension	0.54	0.924	1.29	0.197	-0.33	0.743
distance reached	-0.10	0.586	1.81	0.071	-1.03	0.305
judgement parents	-4.16	0.000 *	-6.03	0.000 *	-0.41	0.680
judgement teachers	-2.00	0.046 *	-1.55	0.123	-0.73	0.468

Table 12-2: Results of t-tests applied to differences in mean values between the accident liability groups.
** = significant ($p < 0.05$)*

Again, hardly any differences in the physical and psychomotor variables appeared between the different accident liability groups. Only temperamental characteristics as judged by parents yielded a more or less systematic difference between the various groups.

The results of the questionnaire on temperament were used to calculate total scores (see chapter 5). These total scores and those for the other groups of variables were correlated with the degree of accident liability to identify a possible relationship with the developmental phase of physical and psychomotor variables. These correlations, however, showed that hardly any relationship between the variables exists, which seems to be in accordance with results described in the overview of literature by Houghton (1986), namely that hardly any relationship can be found between accident-proneness and psychological and physical variables.

variable	liability to have accidents 2.0 - 12.9 years	2.0 - 5.9 years	6.0 - 8.9 years	9.0 - 12.9 years
stature	.0105	.0607	.0357	–.1142
	n = 721	n = 178	n = 267	n = 276
	p = .779	p = .421	p = .562	p = .058
body mass	–.0037	.0729	–.0355	–.0584
	n = 721	n = 178	n = 267	n = 276
	p = .922	p = .333	p = .564	p = .334
popliteal height	.0150	.1095	.0213	–.0978
	n = 721	n = 178	n = 267	n = 276
	p = .687	p = .146	p = .728	p = .105
upper arm circumference	–.0002	.0716	–.0970	.0114
	n = 721	n = 178	n = 267	n = 276
	p = .996	p = .342	p = .114	p = .851
head circumference	–.0116	.1365	**–.1358**	–.0193
	n = 721	n = 178	n = 267	n = 276
	p = .755	p = .069	p = .027	p = .749
force exertion	.0400	.1062	.0228	.0168
	n = 668	n = 174	n = 250	n = 244
	p = .302	p = .163	p = .720	p = .794
motor performance	-.0069	–.0917	–.0992	–.0640
	n = 416	n = 93	n = 161	n = 162
	p = .889	p = .382	p = .211	p = .418
distance reached	.0055	.1303	.0067	–.0409
	n = 669	n = 173	n = 251	n = 245
	p = .888	p = .087	p = .915	p = .524
technical comprehension	–.0037	.0330	–.0261	–.0644
	n = 604	n = 166	n = 228	n = 210
	p = .927	p = .673	p = .695	p = .353
judgement parents	**–.3809**	**–.4804**	**–.4054**	**–.3006**
	n = 737	n = 190	n = 270	n = 277
	p = .000	p= .000	p= .000	p= .000
judgement teachers	**–.3932**	**–.3904**	**–.3793**	**–.4130**
	n = 723	n = 189	n = 263	n = 271
	p = .000	p = .000	p = .000	p = .000

Table 12-3: Correlation coefficients between anthropometric and psychomotor variables and the judged accident liability in different age groups.
*The correlation coefficients in **bold** type are significant at the 0.05 level.*

Discussion

Various statistical analyses were performed to ensure that every chance of revealing possible differences in physical or psychomotor variables between accident liability groups was covered. Hardly any systematic differences, however, were found. This seems to be in accordance with the results of many other studies on this subject, in which it appeared difficult to demonstrate (physical and psychomotor) differences between various groups of subjects. Still the 'accident-prone myth' does exist. An explanation might be the difficulty of assessing accidents and/or near-accidents objectively. In the first place the accident frequencies used in several investigations might have been biased by such aspects as the availability of and distance to a first aid centre or hospital, severity of the injury or, in the case of children, the anxiety of parents, guardians or teachers. This might have led to the conclusion that certain persons had more accidents. Another explanation might be rationalization by the subjects, because they found it hard to believe that accidents occur for no reason at all, and therefore a reason had to be given.

Of course judged accident liability, as applied in this study, might be biased and based on prejudice too, but the definition used and the way it was operationalized make this less likely, because the judges stated their opinion independently of one another.

Conclusions

Different statistical procedures have been used to test whether physical and developmental differences exist between children grouped according to judged accident liability. The results of these tests show that only the judged temperamental characteristics differ. Assuming that the evaluation of accident liability by parents and teachers is more than a prejudice, it can only be explained by the above-mentioned differences in temperament between the children. The development of physical and psychomotor variables appears to have little or no influence on the occurrence of accidents. There seems, therefore, to be no need to design special products with extra requirements for safety for children who often have accidents.

13 Hypotheses testing

In chapter 4 several expectations were described on basis of theoretical considerations and subsequently formulated as hypotheses. In the preceding chapters most of the data relevant to these hypotheses have been presented. In this chapter each of the hypotheses will be tested explicitly according to the preconditions. Confirmation may then add to theory on child development (hypotheses 1 to 4) or accident causation (hypotheses 5 to 7).

Hypothesis 1: *There is a positive correlation between the diverse developmental aspects (variables of type 2 to 7); ($p < 0.05$).*

For all children together this hypothesis is confirmed. The correlations between the variables were positive and the values were rather high. The mean correlation between all variables was 0.5345. The conclusion, based on cross-sectional data, must be that an increase in each of the physical, psychomotor and temperamental variables coincides with an increase in each of the others. In other words, each of the variables develops during the period from 2 to 13 years and a more or less balanced, internally controlled pattern of capacities and characteristics along the trajectory towards adulthood is likely.

Differences between the sexes in mean correlation coefficients were minimal: 0.5344 for boys versus 0.5512 for girls. Therefore the developmental pattern, as operationalized and assessed in this study, can be assumed to be equal for both sexes.

Within age groups covering three or four years (2 - 6, 6 - 9, 9 - 13 years), the correlation coefficients remained positive, but the values were below the values for all age groups together. The mean correlation coefficients were 0.2501, 0.2280 and 0.1907, respectively, for the three age groups. Therefore within age groups relatively large differences in the pattern of development seem to be present, resulting in lower correlation coefficients.

The mean correlations between the three groups of judged accident liability barely differed. For the children who were judged not liable to have accidents the mean correlation was 0.4029, for the group labelled 'doubtful' 0.4001, and for children who are judged liable to have accidents 0.4310.

It can be concluded that there is no significant difference in the development of the various groups of variables between boys and girls in different age groups and between children in different accident liability groups.

Hypothesis 2: $\bar{r}_{(group\,1\,+\,group\,2)} > \bar{r}_{(group\,3\,+\,group\,4)}$

The variables in these groups are:

- group 1: *static anthropometric variables:* static body dimensions and force exertion;
- group 2: *dynamic anthropometric variables:* functional body measurements and flexibility;
- group 3: *psychomotor variables:* motor performance and technical comprehension;
- group 4: *personality variables:* temperament as judged by parents and teachers.

This hypothesis is confirmed. The mean correlation coefficient for all children together between static and dynamic anthropometric variables was larger than the mean correlation between psychomotor and personality variables: 0.6870 versus 0.0776 (see appendix M). This points towards a more stringent –and for all children more or less equal– pattern of development for the physical variables and a somewhat less stringent pattern for the psychomotor and personality variables (given the measurement methods used). This can be explained as increasing individualization for all variables; initially it is small for the physical variables. The psychomotor and personality variables however differ from the beginning and only become more diverse (see figure 4-1).

Sub-hypothesis 2a: $\bar{r}_{group\,1} > \bar{r}_{group\,2} > \bar{r}_{group\,3} > \bar{r}_{group\,4}$

The mean correlations for these groups were: 0.7694 > 0.6831 > 0.5364 < 0.5584.

This sub-hypothesis is not confirmed, although the differences between the coefficients for groups 3 and 4 are not very large.

The correlations within the group of static anthropometric variables were the largest of the four groups. The association between the variables in this group is obvious, being less outspoken in the other groups. This again seems to confirm the theory of change towards a less stringent pattern of development from the physical towards the more personality-related variables.

Sub-hypothesis 2b: $\bar{r}_{((group\,1+\,group\,2)\,\times\,group3)} > \bar{r}_{(group\,3\,\times\,group\,4)}$

This sub-hypothesis is confirmed, given the values of the mean correlation coefficients: 0.5716 versus 0.0776.

The values for the psychomotor variables are more closely related to -and probably influenced by- the physical variables than the personality variables.

Hypothesis 3: *The mean scores per age group of each of the variables physical flexibility, motor performance and temperamental characteristics* are larger for girls than for boys; for the variables body dimensions (until 10 years of age), force exertion and technical comprehension the mean values for girls per age group will be smaller than those for boys; ($p < 0.05$).*

* The scoring of this variable is such that a negative score indicates a more temperamental child and a positive score is a less temperamental child.

Statistically speaking this hypothesis is confirmed for all groups of variables, except for body dimensions. In these groups, however, there are incidental deviations from the rule stated in this hypothesis. For instance, for physical flexibility the mean values for 2-year-old boys were larger than those for girls of the same age; in the other age groups the tendency stated in this hypothesis is supported by the data. Likewise for technical comprehension deviations from the rule were found for the ages 2 and 7. At these ages girls had a higher mean score for technical comprehension than boys. For the variables motor performance, temperamental characteristics and force exertion the data show that this hypothesis is confirmed.

The data on body dimensions exhibit too many deviations to be able to accept this hypothesis. For most of the variables there are some age groups in which the values for boys are significantly different from those for girls, but this is not true for all age groups and in all variables (see appendix D).

Generally speaking the conclusion can be drawn that the development of force exertion and technical comprehension is more advanced in boys, whereas the development of motor performance and physical flexibility is more advanced in girls.

Hypothesis 4: *Socioeconomic class of the parents influences the physical development of children as well as their technical comprehension; ($p < 0.05$).*

This hypothesis is not confirmed because the correlation coefficients between what the parents said was their educational level and the total scores for the variables were only sometimes related (see appendix R).

A low but significant negative correlation was found between this educational level and body mass as well as upper arm circumference. This suggests that those with a lower educational level tend to have somewhat heavier children. The relationship between educational level and force exertion also exhibited a low but significant positive correlation, i.e. those with a higher educational level tend to have somewhat stronger children.

Per combined age group (three or four years), only a few variables were significantly correlated with the educational level of the parents. These correlations seem to be fairly coincidental and a satisfying explanation cannot be given, except for the fact that nutritional status in the higher socioeconomic classes might be better. However, this cannot be regarded as having been proven here.

A surprising detail is the fact that when all children were combined (including the extra added sample which consisted mainly of children who are liable to have accidents), the correlations between head circumference and parental educational level were significantly positive in all three age groups (2-6, 6-9, 9-13 years). No other variable in the total sample exhibited correlation coefficients that were significant in all three age groups. This would almost seem to suggest an amazing relationship between accident liability and head circumference, a highly unlikely phenomenon.

All in all it can be said that no convincing evidence was found for an influence of parental socioeconomic class on either the physical development of children or their technical comprehension.

Hypothesis 5: *The correlations between (absolute) deviations from the age group norm for each of the developmental aspects (variables 2 to 7), on the one hand, and the judged liability to have accidents (variable 1), on the other hand, are systematically and significantly different from zero; ($p < 0.05$).*

This hypothesis is not confirmed. Although the correlation coefficients were very low, they were significantly different from zero for some variables (appendix Q). This is especially true for the temperamental variables. The children who were judged to be liable to have accidents had a lower score (i.e. were more temperamental, impetuous, etc.) for the questionnaire –completed independently by the same judges– on temperamental characteristics than children who are not liable to have accidents. This was true for all children grouped together as well as the children in the three age groups. Thus children considered liable to have accidents often have temperamental characteristics that are generally considered to be related to the occurrence of accidents. For the physical and psychomotor variables the correlations, in general, were not significantly different from zero. It therefore must be concluded that physical and psychomotor variables do not differ between children in the various accident liability groups. This implies that, generally speaking, designers need not and may not use data on specific groups of accident-liable children when designing products. Data on 'normal' Dutch children apply to 'all' Dutch children, including those considered liable to have accidents.

Sub-hypothesis 5a: *The predictive value of the variables for the liability to have accidents decreases from group 4 to group 1, meaning that personality factors (i.e. temperament) are more likely to predict the occurrence of accidents than physical variables.*

This sub-hypothesis is not confirmed. The correlations between the different groups of variables and accident liability were, generally speaking, very low. Only the judgement by parents and teachers of temperament correlated significantly with the judged accident liability. Whether this can be assumed to be 'predictive' for future accidents is not known, given the method of measurement used. Judged temperament according to parents and teachers can only be considered to be related to the occurrence of accidents.

Hypothesis 6: *Retarded motor development will be compensated, to some extent, by a more careful attitude.*

Contrary to expectations, the correlations between motor performance and the judgement of temperament by parents (0.1762) and by teachers (0.1347) were positive. Although the values were low, they were significantly different from zero. Therefore a somewhat less advanced motor performance is, generally speaking, not compensated by more careful behaviour. This means that the hypothesis is not confirmed, perhaps even that the opposite is true: less advanced motor development is accompanied by less careful behaviour.
When the hypothesis was tested in separate age groups (of one year each) and per sex, the correlation coefficients were never significantly different from zero; therefore no clear relationship between these two variables was found.

Hypothesis 7: *A negative relationship exists between degree of urbanization and the estimated occurrence of accidents.*

This hypothesis is not confirmed, because the correlation between degree of urbanization and accident liability was significantly positive for all ages (see appendix R). Therefore children who are liable to have accidents seem to live in urban regions more often than in rural areas.

When the three different age groups were analysed, it was is only significantly positive for children over 6 years of age. The correlations between urbanization and judgement by parents of their children's temperamental characteristics were, however, not significantly different from zero.

Generally speaking our theory on the development of the various kinds of variables, as described in paragraph 4.1, is confirmed by the results of this project. The hypotheses for accident liability were, in contrast, not confirmed; this means that the developmental aspects investigated in this project do not seem to play an important role in the occurrence of accidents.

14 Applications for design and safety

The growth and development of children are, in general, very clear and highly varied, also during the period of 2 to 13 years. At the age of two children are dependent on the care of parents or guardians. When they are 13 years old, the children are able to act independently in many respects, although some supervision is still needed for other activities.
In previous chapters descriptions of and the intercorrelations found for various physical and psychomotor variables were presented. Some aspects of development of these variables have to be kept in mind when designing products for children.

- First of all the data collected during this project are not required in many designs. Often more specific data on the physical characteristics of children are needed when designing a product for children. Furthermore, the availability and use of data on all types of characteristics do not guarantee a good design. The data of this project have to be considered as a general background source, which can and should be used often.
- The mean values as well as the standard deviations of all kinds of variables increase with age, which implies absolute growth and development as well as an increase in differentiation among successive age groups. The differences in body form and capacities between children of the same age become larger and larger.
- This differentiation also implies an increase in overlap between age groups. A tall 4-year-old child might be taller than a small child 7 years old. This is also true for almost all of the other anthropometric variables. It might therefore be more desirable from the viewpoint of physical child-product interaction to design products for children grouped according to (physical) variables other than age, for example stature or build.
- This does not, however, necessarily hold for all variables. A child who, for example, is the 95th percentile for stature for its age might be 5th percentile for force exertion compared to its peers. The older the child, the larger the age range in which the same value for a particular variable appears. It will, therefore, be even more difficult to design a product suitable for use by children in an older age group, because the differences in capacities and dimensions are large; this means products of various sizes or highly adjustable products (for example, school furniture) have to be available.
- A related difficulty is that a designer usually has in mind a profile of capacities which should be present in the user of his products. However these capacities often are not completely age-dependent. This became clear during the measurement of technical comprehension in this project. Assuming that the test indeed measures some kind and aspect of technical comprehension, then it is very clear that the differences in capacities can be greater within an age group than between age groups. A curious and smart four-year-old child might have a better comprehension of (or experience in) how to control a certain product than a ten-year-old child who is not at all interested in such matters. This principle should be kept in mind when products are designed for use by individuals in a restricted age range.

- Another aspect that should be recognized and is relevant for adults, but especially children because of their growth and development, is the fact that an industrial product will never be 'maximal' for all users. This can be explained by the large differences in dimensions and capacities of the individuals of a target group. The 'optimum' product should be the goal. Therefore specific characteristics of the future users might be important and should be decisive when designing a product, in order to get an optimal result. When safety is the most important aspect, for example the prevention of jamming accidents, a minimum or maximum value for a certain characteristic within a group of users is often required, because the negative effect for the user of an unsafe product might far exceed the effect of a less comfortable design. One example is finger breadth of children, which is used as a relevant dimension when trying to prevent jamming accidents involving the fingers. The smallest value for the little finger breadth and the largest value for the thumb breadth should be used. For children between 2 and 5 years, for example, this range will be 0.7 to 1.6 cm. The distance between, for example, the hinged parts of a product should therefore be less than 0.7 cm or more than 1.6 cm. When comfort or usability is decisive, a mean value or less extreme percentiles will usually give optimal results. And remember that an –in all *respects*– average user does not exist!

- As far as the anthropometric data in the tables are concerned, several remarks should be made. The subjects in the sample were lightly clad and not shod during the measurements. This is often not the case when a product is being used, so corrections have to be made for clothing and shoes. Generally speaking clothing adds an additional 10 to 40 mm, depending on the measurement to be corrected and the kind of clothes worn. Shoes add approximately 25 mm to a child's height (Pheasant, 1986, p. 70).

- Sometimes the results of anthropometric measurements along a continuous line have to be added or subtracted in order to get the desired dimension. In DINED (1986) Molenbroek and Dirken give the formulas to be used for this purpose. The formulas for calculation of the resulting mean and standard deviation are:

$$\bar{x}_3 = \bar{x}_1 \pm \bar{x}_2$$

$$s_3^{\,2} = s_1^{\,2} + s_2^{\,2} \pm r_{(1,2)} \cdot s_1 \cdot s_2$$

with $r_{(1,2)}$ = correlation coefficient between variable x_1 and x_2 (see appendix E).

Assuming a normal distribution of the variable (which is not always true!), other percentile values than P3 and P97, which are given in the tables in appendix B, might be computed. The formulas are:

$$P_1 = \bar{x} - 2.33s \qquad P_{99} = \bar{x} + 2.33s$$

$$P_3 = \bar{x} - 1.88s \qquad P_{97} = \bar{x} + 1.88s$$

$$P_5 = \bar{x} - 1.65s \qquad P_{95} = \bar{x} + 1.65s$$

$$P_{10} = \bar{x} - 1.28s \qquad P_{90} = \bar{x} + 1.28s$$

$$P_{20} = \bar{x} - 0.84s \qquad P_{80} = \bar{x} + 0.84s$$

$$P_{25} = \bar{x} - 0.67s \qquad P_{75} = \bar{x} + 0.67s$$

- The tables of data on –mainly static– anthropometric dimensions and force exertion (appendices B and G) only provide some basic information on the physical aspects of children between 2 and 13 years of age. It was not our intention to provide complete information, because this is hardly possible. Every design requires the specific use of all kinds of specific data. It is the designer's task and responsibility to translate the basic data or interpret a special investigation correctly such that the suitable or necessary application is obtained. This has to be done during several phases of the design process, which are described by Roozenburg and Eekels (1991)

Some examples of the implications for design and safety will be given below using the daily-life activities of and commonly used products for children in two age groups: the two-year-olds and the eight-year-olds.

A two-year-old child

At this age (psychomotor) capacities and abilities differ markedly. Some children have for example been able to walk for some time, while others have mastered this skill only recently. A two-year-old child is in all respects dependent on others but tries hard to be independent and to show his/her desires and will.

This starts in the morning when a child wakes up and wants to get out of bed. A child of this age is able to climb, but its capacities are not yet sufficiently developed and the possibility of falling still exists. It is therefore advisable to give a child the opportunity to get in and out of bed easily by removing some of the bars of the bed, so that the child can crawl through the opening. At the same time this opening should be small enough that the child will not fall through it during the night when asleep. The head may not get stuck between the bars when the child crawls out of bed. Since the chin-to-crown length is the largest head measurement (and is larger than, for example, breast depth), this dimension should be kept in mind. The P97-value of chin-to-crown length for two-year-old children is 22 cm, which implies that the opening should at least be larger than this value.

In the bedroom all requisites for climbing on furniture etc. should be removed. Despite this minimized opportunity to climb, window bolts should be installed to keep the child from opening the window and possibly falling out it. Since a child should not be able to open these bolts some amount of force should be needed to open them and, if possible, this should be combined with the requirement of fine-motor skills. This is also true for a stair gate placed at the foot and the head of the stairs. The height of the stair gate should at least equal shoulder height standing, so that the child cannot topple over it. This implies that the height of the stair gate, from its lowest to its highest point, should be at least 80 cm (P97, 2-year-old girls). It should be impossible for children to climb on a stair gate. The distance between bars should be less than the breadth of the head to keep the child from getting his head stuck between the bars. This distance should therefore be less than 11 cm (minimum value for 1-year-old children). When a child attempts to climb on the stair gate, it should not be possible for him to stand on it. The minimum foot breadth (5 cm, P3 2-year-old boys) is decisive in this case.

Along the stairs a child's banister is recommended, because a two-year-old child will not be able to reach the 'adult banister' yet. Of course parents are not likely to adapt the height of a banister, say, at 6-month intervals to ensure the optimal height for their child (or even place several banisters for other children). It is therefore best to use the optimum distance from the floor. This can be determined by using the lowest reaching height standing of a two-year-old child and the mean elbow height standing of a 7-year-old child as the critical measurements.

The estimated lowest value for the reaching height standing is 87 cm (mean – 3 · standard deviation for two-year-old children; 105.9 – 3 · 6.3). To obtain elbow height standing some calculations have to be made, because this measurement was not included in this project. The mean value can be computed from: stature - sitting height + elbow height sitting (128.7 – 68.9 + 17.4 = 77.2 cm, standard deviation 4.0 cm). Therefore a height between 77 and 87 cm would be suitable. The circumference of the banister should be such that the 2-year-old child can grip it easily. It is, however, not necessary to be able to enclose the banister with thumb and forefinger (grip circumference was measured in this way in this project), so the mean value for two-year-old children will result in a suitable dimension. The mean grip circumference (6.8 cm) for two-year-old children determines the required diameter: 6.8/3.14 ≈ 2.0 cm. The maximum value of the grip circumference (10.6 cm) for a 7-year-old child yields a diameter of 3.3 cm. The optimum diameter lies between these two values. An oval-shaped banister should be considered. The ends of the banister should be rounded off. It goes without saying that the banister should be firmly attached to the wall, and it should be made of inflexible material (so a rope is not an acceptable alternative). The distance between banister and wall should be sufficient for the hand to grip the banister and should therefore at least exceed the maximum hand thickness of the users (2.3 cm, P97 7-year-old child) plus about 3 cm of space for maneuvering.

A changing table is convenient for the person who helps the child to get dressed. It is of course possible that the child will fall off this table. It is quite difficult to prevent this by adapting the product. Therefore the child has to be watched continuously when put on such a table. An alternative is to dress the child on the floor.

Children two years old will be bathed in a baby-bath or the bathtub. In both cases the child should not be left alone, because when a baby slips he will not be able to push himself up out of the water and the possibility of drowning is not imaginary, as statistics show.

During meals a two-year-old child usually sits in a high-chair. This chair should be stable and the centre of gravity should be low so that the chair will not tilt over backwards when the child braces himself. Of course, the dimensions of the chair should be adapted or be adaptable to the dimensions of the child. Sharp edges should be avoided as well as small openings into which little fingers can be jammed. It should be noted that these children are able to reach rather far, so that dangerous items should be kept beyond this distance. The largest forward distance reached by a two-year-old child was 85.7 cm. This was measured from the back of the seat to the fist of the extended arm, the feet unsupported so the child could not lean on the foot-rest. The tray in front of the child will keep it from reaching this far; however most high-chairs rightly have a foot-rest for support, thus enabling the child to brace itself. The maximum reaching distance might therefore better be considered the minimum distance that the child can reach under 'optimal' circumstances.
For very small children a safety-harness is recommended to prevent the child from slipping or climbing out of the chair. This is also true for the baby carriage. For the latter additional measures are required to safeguard against accidents with moving parts. It should also be impossible for the child to fold the carriage when he/she sits in it or even stands next to it.

Toys for these children should not consist of small parts which can be removed and swallowed. Because the fine-motor skills of these children are not yet fully developed, toys should not be too tiny; otherwise the child cannot handle them. Of course the toys should

satisfy the regulations of the (Dutch) safe toy act (Warenwet, 1985).
Many children of this age are not able to ride a tricycle, because they have not yet mastered the skill of turning the pedals. A 'walking cart' without pedals, already known during the Middle Ages (Lindström, 1979), will usually satisfy them.

The transportation of these children by bicycle or car requires solid seats for them. A seat placed on a bicycle should support the child sufficiently. The child should not be able to get its feet stuck between the spokes of the wheel or its fingers jammed between the springs of the saddle. The foot-rest has to be adjustable in height. Assuming that such a seat is used for children up to 5 years of age, the adjustable range of the foot-rest should be at least 12.5 cm, because the popliteal height of the smallest 2-year-old child is 19 cm and that of the tallest 4-year-old child is 31.5 cm. The latter two dimensions determine the minimum and maximum distance from the foot-rest to the seat.
A car seat should be easy to handle and comfortable installation of the child should be simple in order to guarantee that the driver will use it for transportation of the child every time, even when the distance to be covered is very short. It should of course be safe –therefore some kind of safety-belt is required– and comfortable.

Children of this age are very curious and anxious to know everything. They will therefore be interested in something new, even when it is dangerous. It is obvious that it is hard, even impossible, for these children to judge danger and risks. Therefore they should not be able to reach a dangerous situation or product. If this cannot be avoided in advance, measures should be taken to reduce the danger. Examples of measures to be taken are child-resistant products and a guard for electric sockets. A child-resistant product should be based on one of two principles: a required amount of force combined with fine motor skills or anthropometric criteria. For example, a package that can be opened with one hand at two distances that cannot be bridged by a baby's hand. Such a product should be designed 'un-ergonomically' for these children but should remain sufficiently easy for (elderly) adults.

An eight-year-old child
At this age children can act independently in many respects but need to be supervised in others. A major difference between 2 and 8-year-old children is the fact that the latter understand more, so that a verbal explanation or warning might be enough to reach a certain goal. This is far more difficult with two-year-olds.

Many 'adult' products in the home can be used by 8-year-old children without any problem, because the use is incidental or for a relatively short period of time. During meals these children need not sit on special chairs. A 'normal' chair, when necessary with an extra pillow, can be used. For situations in which the child has to stand in front of a product, such as a kitchen counter or a sink, a platform might be required. Of course the platform should be stable and the surface should be large enough that the child will not easily miss its footing. Because of the possibility that adults will also use the platform in certain situations, anthropometric data on adults should be used to determine the dimensions and solidity of the platform. The height should be 23 cm, so that the elbow height standing of a small eight-year-old child will, for example, equal the height of the counter. The mean elbow height standing for an 8-year-old child can be calculated as follows:

stature - sitting height + elbow height seated

134.0 - 71.0 + 17.8 = 80.0 cm;

the standard deviation is 4.7 cm. The smallest eight-year-old child, with an elbow height standing of $80 - (3 \cdot 4.7) = 66.7$ cm, therefore needs a platform of approximately 23 cm to achieve a 'comfortable' height while standing in front of a counter.

Use of a toilet implies that it has to be flushed. Knobs that have to be pushed should not need much force. Eight-year-old children should be able to use them without difficulty. This implies a method of control, which requires a maximum force of 25 N (third percentile of maximum pushing force of the hand, girls); a lower value will, however, be much more comfortable. For buttons that have to be operated by pushing with a finger, the maximum required force should be less than 18 N. Again, this amount of force is not comfortable.

At school the children use the furniture for prolonged periods of time during the day. School furniture should therefore be adjusted to the dimensions of the users. Different standards have been set up, but at the European level agreement has not yet been reached on the exact dimensions of the furniture, so studies are still being carried out. General principles should, however, be applied. When seated the child must be able to reach the floor with both feet, at least when the angle between upper and lower leg is 90 degrees and preferably when this angle is between 110 and 125 degrees. The upper legs (partly) and buttocks have to be supported and a backrest should give support in the lumbar region. When the child is seated on a correct chair, the table top should equal elbow-height seated.
Because the difference in stature between 8-year-old children is rather large (between 123 and 145 cm) it is best to use popliteal height as classification criterion instead of age for the correct set of school furniture to be used by a child. For practical reasons, however, stature can also be used as the criterion, because stature can be measured more easily at school (although probably not more accurately) than popliteal height, with less advanced equipment. Calculation of the differences between measured popliteal height and estimated popliteal height, based on the ratio of stature to popliteal height per 5-cm increments of stature, revealed that the mean inaccuracy of the estimation lies between -0.45 cm and +0.81 cm. The maximum difference between the estimated and empirical value for popliteal height lies between -7.8% and 6.4%. This difference tends to decrease with the increase in stature. The differences are of such a magnitude that the conclusion can be drawn that stature is a good criterion for the classification of children and, in this example, estimation of the required size of a chair.

The children may go to school on their bicycles. Again the dimensions of these bicycles should be based on anthropometric data on the children. Because of the diversity of dimensions within an age group, it is better to take one body dimension (for example stature) as classification variable for bicycles of different sizes.
But again within a stature group all other dimensions of the children will vary too, so it should be possible to adjust the bicycle. Saddle and handlebar heights, relative to the axle, and the distance between saddle and handlebar are the main criteria.

During sport activities, in which the possibility of injury is present, protective gear is required. Examples are a helmet for use during horseback riding, cycling or skate-boarding and knee-guards and elbow-guards for the latter. Depending on the accuracy of the fit required, it will be almost impossible to design just one model for one age group. Highly accurate data are needed to design optimal, adjustable protective 'equipment'.

15 Discussion, conclusions and suggestions for further study

15.1 Project

In this project nationwide information on three groups of characteristics of children between the ages of 2 and 13 years was collected. Two of these groups, i.e. the anthropometric and psychomotor variables, are hypothesized to play a role in the accident liability of children. The third group, the variables of temperament, supposedly influence the use and control of physical characteristics. The choice of the variables was based on both their usefulness in the design of products for children and their influence on the occurrence of accidents involving daily-life products. In figure 4-2 of chapter 4 the relationships of the variables are depicted. A more important goal than establishing a databank of body dimensions was to obtain segment measurements and evaluate other physical and functional characteristics of children in order to gain more insight into the interrelationships between the different kinds of variables and thus the patterns of development. Research on development usually requires longitudinal data, because the change in variables over time is studied. In this project development was defined as changes in the characteristics between successive age groups. Therefore cross-sectional data were gathered. This means, however, that the possibility of 'cohort' effects cannot be excluded and this might have influenced (some of) the results.

15.2 Sample

In order to achieve the objectives of this study, a representative sample of children living in the Netherlands was required. The goal was regional representation with respect to the number of children, degree of urbanization and occupational status of the adults per region. A total of 100 children per age group and sex was large enough for statistical analyses of the anthropometric measurements. For the psychomotor measurements it was estimated that at least 20 children per age group and sex were needed. For evaluation of accident liability it was assumed that 10 children per 2-year age group could be obtained (no demographic statistics were available).

The way the children were recruited might give rise to questions, because there was no insight into the non-response group. Privacy regulations were the main reason for not being able to assess this group. Therefore a-selectivity of the total sample cannot be completely guaranteed. Despite the lack of insight into the non-response group, the representativeness of the sample appeared to be sufficient, because the frequency distributions of the variables were Gaussian and the distributions of the stratification variables within the sample and in the Dutch population were more or less comparable.
The numbers of children per age group and sex in the anthropometric and psychomotor samples were not always exactly equal to the required number, but the data collected within the sub-groups were sufficient to allow statistical analyses.
It has to be concluded, however, that the accident-sample was rather small, at least for the purpose of comparing different liability groups. Especially the group of elder children was small. Therefore caution is recommended when interpreting the data on accident liability. An extra disadvantage of this part of the project was that the accident liability of children under 4 years of age could not be judged according to the operational definition used,

because they do not yet attend school; teacher evaluation of the accident liability of these children was therefore lacking.
The distribution of children between 4 and 13 years of age in the anthropometric and psychomotor samples over the regions, as far as the number of children and degree of urbanization were concerned, was almost equal to that found for the Dutch population. For the younger children (2-4 years) the distribution across the country was not optimal; because a relatively small number of children under 4 was required, we decided to recruit them in only one municipality per region. This implies that this sub-sample does not represent all degrees of urbanization present at the regional level, but urbanization was sufficiently stratified within the sample as a whole.
The self-assessed educational level of the parents, used as an indication of socioeconomic and/or occupational status of the adults, appeared to be somewhat higher than expected when compared with population data. This could indicate a socioeconomic level above that of the normal population, which might influence the results. But it could also result from the parents' tendency to place themselves, when answering, a bit higher on the socioeconomic ladder. Another explanation might be that the willingness of 'educated parent' to participate was higher than that of 'less educated parents'.

Another aspect of the sample is ethnicity. This was operationalized by assessing the country where the parents were born. When either or both parents were not born in the Netherlands, the child was considered to be of 'non-Dutch origin'. In this connection two remarks have to be made. The first is that even if the parents were born in the Netherlands, the children might have been second or third-generation immigrants. This could influence the growth pattern of these children. A second interesting and perhaps relevant fact is that the question on ethnicity often (5.7%) was not answered. The reason for this is not clear. Sometimes the parents wrote in the margin that in his/her opinion such a question was not relevant to the subject under study.
It has to be concluded that both ethnic groups (Dutch-born and non Dutch-born parents) were heterogeneous, the second more than the first. This implies that a comparison of variables between the two groups should be regarded with caution; moreover, these groups cannot be considered as two families with different genetic endowments as far as the physical characteristics studied in this project are concerned. In physical anthropology it is well known that intra-group variance is larger than inter-group variance. On the other hand, the influx of, for instance, people of Mediterranean origin could influence the values of the lower percentiles for several physical variables, such as the length of body segments. Nevertheless, all of these children live in the Netherlands and use products, so that the data collected on immigrants and autochthones have to be and were combined whenever the results of the measurements are presented.

15.3 Measurements

The variables to be measured varied in objectivity and scale of measurement. The anthropometric variables were all concrete and measurable in a more or less objective way. For the psychomotor and temperamental variables, however, the possibility and capability of measuring in a valid and reliable way decrease rapidly. The scales used to measure the variables varied from nominal scales (technical comprehension, motor performance) to ordinal scales (items of the questionnaire) and metric scales (anthropometric and force measurements).

For most of the anthropometric variables and some of the psychomotor and temperamental variables a measurement method existed or could be adapted, but for others a method had to be invented, either because no methods existed or because the existing methods could not be adapted to the goal of the project or the target group under study.

These new methods differed in terms of reliability, differentiating power and operational feasibility. For some of the methods suitability appeared to be restricted to a limited age range, because of the decreased differentiation at certain ages (motor performance, technical comprehension). In other cases the measurement method itself appeared to be less suitable (rotation of the body along its z-axis), as indicated, for example, by the reproducibility of the test. Nevertheless, the results of the newly invented tests proved to be fairly useful.

15.3.1 Temperament

One variable possibly related to the occurrence of accidents is the temperament of a child, operationalized by a questionnaire in which some facets of the total concept of temperament were assessed.
This questionnaire, used to evaluate both temperament and the accident liability of children, was not the same for all parents. This was due to the fact that the questionnaire had to be developed during the course of the project because of the limited amount of time available. As a result the three versions of the questionnaire did not contain exactly the same items. But because of the fact that the range of the total scores (between -30 and +30) and the distribution over the age groups were equal for all versions, we assumed that the total scores as such were comparable. Interpretation at the item level may, however, be more difficult. The results can only be judged in terms of more or less temperamental. The lower the value of the total score the more temperamental the child.
The fact that the same parent had to answer questions on both the temperament and accident liability of his/her child may have resulted in contamination of or spurious correlations between the answers. The teachers, however, did not answer the two sets of questions at the same time, so that the effect on teacher evaluation was probably minimal. Because of the relatively high correlation between the scores of parents and teachers, we assume that the effect of contamination on the answers of the parents was not sufficient to necessitate rejection of the data.
A significant correlation exists between total score for the questionnaire and the judgement of accident liability. This can be considered as a validation of the questionnaire: it seems to measure characteristics which contribute to the occurrence of accidents.
Total scores for the temperamental characteristics of children who, according to parents and teachers, are liable to have accidents were lower (meaning: more temperamental) than those for the other children. This points towards a relationship between accident liability and temperamental characteristics, as hypothesized.

15.3.2 Body dimensions

Body dimensions were chosen mainly on the basis of their suitability for the design process. They should also give an impression of the changes in body shape in successive age groups, in boys and girls. The dimensions were measured, insofar as possible, according to generally accepted measurement definitions to allow comparison of our data with different (foreign) sources of anthropometric data.

The results of these measurements showed that the mean values and standard deviations of all dimensions increase with age and that differences exist between boys and girls. Some of the proportions between measurements also appeared to change with age.

Whereas at birth the trunk is relatively large compared to the total body length, this changes into longer legs relative to stature. The proportion of trunk to stature changes only slightly during the successive ages under study among both boys and girls. Therefore the change in body shape during this period is mainly due to the fact that the increase in leg length is larger than that in trunk length. The proportion of head height to stature in all age groups was larger for boys than for girls and decreased with age for both sexes. It is also remarkable that there is a difference in leg dimensions between boys and girls. When the mean proportion of buttock-knee depth to popliteal height is calculated, girls of all ages, except the 12-year-olds, have proportionally longer upper legs than boys. This might be caused by a larger amount of 'soft tissue' around the buttocks. This result is confirmed by data on adults (Pheasant, 1986). The mean proportional popliteal height for boys of all ages was larger than that for girls.

The ratio between shoulder breadth and hip breadth changed in the expected direction: shoulder breadth of boys increased relatively more than that for girls, whereas hip breadth for girls was larger than that for boys and the differences increased with age. Although the ratio between these measurements already differed among the younger age groups, it decreased mainly after the age of eight years, implying an increase in hip breadth after that age.

Factor analysis of the anthropometric variables revealed a length and a volume factor, in accordance with other studies, and a head factor. Of course, the resulting factors partly depend on the initial variables inserted into the analysis. Therefore the occurrence of the head factor can be explained by the large number of head dimensions in the analysis, although the 8 hand dimensions did not result in a 'hand factor'. It is, however, striking that sex appears in this head factor when included in the analysis. It may, therefore, be said that of the anthropometric dimensions assessed in this study, the head measurements yielded the most striking differences between boys and girls. These differences probably already exist at birth. The fact that one recognizes a clothed baby as being a boy or girl might be explained by these differences in head dimensions and therefore the shape of the head.

Thus some of the observed differences between boys and girls appear to be present from birth onwards. This seems to point towards genetically based differences between the sexes. Within certain age groups differences were also observed between children from different regions of the Netherlands and different degrees of urbanization. These differences were, however, not systematic throughout all age groups nor for the three degrees of urbanization. Furthermore the absolute differences were small and of little relevance to design. Environmentally based differences seem, therefore, to be less obvious and of little importance. This might be explained by the greater mobility of the population nowadays. The socioeconomic class of the parents was not an explanatory variable for differences in body dimensions, which might be due to the way in which this variable was operationalized, namely by asking the parents themselves about their level of education.

15.3.3 Force exertion

Some hand and arm forces were measured to get an impression of the increase between the ages of 4 and 13 years and to gain insight into differences between boys and girls.
The results of these measurements showed an increase with age, as expected, in both the mean values and the standard deviations per age group for all forces. Differences between boys and girls were present and seemed to be rather constant (for most of the finger forces in absolute values and for the hand forces mainly as percentages, see figures 1 to 4, appendix s) during the period under study in this project. This might be explained by a difference in body composition, i.e. a difference in muscle mass between boys and girls. These differences probably already existed at birth, but this cannot be proven here.
The fact that no systematic differences in forces were found between the preferred and non-preferred hand and between the right and left hand might indicate that the muscle tissue was not yet fully lateralized or differentiated, for instance due to ambidextrous training of the muscles. At least the extent of these effects was not yet significantly measurable.
Another goal was to be able to predict one kind of force from other forces. This, however, did not seem to result in reliable predictions: the correlations between the different kinds of forces were not very large. It is likely that different muscle groups or mechanisms are used to exert the different kinds of force, which prevents reliable prediction.

15.3.4 Motor performance

Motor development is seen as one of four aspects of general development. It has been studied and described by many scientists. Most of them conclude that development is the result of both nature and nurture: both innate and environmental factors influence development. The extent to which this influence exists differs according to the authors. Many tests have been designed to assess the degree of (motor) development at a certain age, but most of them appeared to have one or more disadvantages in terms of items, age range or time required for assessment. In our investigation we tried to assess the motor performance of children between 4 and 13 years of age. To reach this goal an adaptation of the MOT '87, developed by van Rossum (Free University of Amsterdam), was used. The test consisted of a number of items that measured different aspects of motor performance, such as gross and fine motor skills, balance, strength and speed. Advantages of this test, in addition to assessment of different aspects of motor performance, were that it could be used for children between 4 and 13 years of age; it took relatively little time to test a child and expensive instruments were not required.

As far as the items of the test are concerned it seems to have 'face validity': the test apparently measures motor performance. The positive correlations between the score for this test and both the physical flexibility measurements and the force exerted lead to the conclusion that a positive relationship between these variables seems to exist.
The results showed that the discriminating power for children over 9 years of age was lower

than expected. For the younger children, however, this test provided a fair impression of motor performance. At all ages girls had higher mean values for motor performance than boys. On the one hand this can be explained by the generally accepted rule that a difference in rate of motor development exists between boys and girls. The latter are ahead of the former. This tendency seems to be present from birth onwards. Another explanation might be insufficient content validity for the items of the test since it contained more items requiring balance, in which girls are known to be better performers. This was due to the necessary deletion of some items with an obvious observer effect, despite the fact that the observers received intensive training beforehand.
The items are not supposed to be regarded separately, so no conclusions can be drawn on single aspects of motor performance such as strength, balance, speed, etc.

15.3.5 Physical flexibility

Physical flexibility is presumed to play a role in the occurrence (or in some instances prevention) of accidents. It is expected that the more flexible a child is, the better it can react to unexpected circumstances or situations (for example, recovering its balance when it stumbles). On the other hand the possibility also exists of getting into dangerous situations more easily. The goal was to assess changes in physical flexibility in successive age groups and to see whether differences between boys and girls could be found.
Physical flexibility might be defined as the extent to which joints can reach extreme angles (also called the excursion of one or more joints). This implies that different kinds of flexibility exist, as many as there are joints. In this project two measurements were chosen: 'sit and reach' and 'rotation of the body along its z-axis'. In literature, the first is accepted as a measurement of general flexibility of the body. The second was defined by us, mainly because of a presumed relationship with accident liability (for example, the ability to look over the shoulder when bicycling).
Analysis of the data led to the conclusion that this second measurement was not reliable enough. The reproducibility was low and an observer effect appeared to be present. Although the concept of combined rotation of several body parts seems to possess face validity, operationalization proved to be unfortunate; namely, the measurement was poorly defined or too difficult to perform. Younger children in particular do not yet possess sufficient limb control and coordination to be able to concentrate on more than one aspect of a task at a time. The measuring device may have contributed to this outcome too.
The measurements of the 'sit and reach' distance were suitable for use. The distance reached was corrected for limb length, because of the conviction that this influences the results. The measured distance decreases with age, whereas the absolute distance increases due to the increase in leg length with age which means that the starting point is farther removed from the zero point of the apparatus. When the data were transformed, relative to limb length and trunk-bending, an increase in flexibility was shown. This is in accordance with results in literature on children between 12 and 18 years old, for whom increasing sit and reach distances were found (Kemper, 1985). This may point towards a continuous increase in flexibility.

15.3.6 Technical comprehension

When handling products some insight into the operation of a product is necessary in order to be able to use and control it. This might be called technical comprehension. This is, however, a very broad concept; therefore in this project measurement of this factor was restricted to testing some commonly used compatibility rules.
The attempt to measure technical comprehension in this way was not fully successful. The usual requirements of reliability and differentiating power were not completely satisfied. With respect to the validity of the test, it can be concluded that there was some face validity: the test measured some generally accepted rules for movement compatibility. A difficulty in this respect is, however, the fact that a compatibility rule is not absolute. It is a culturally determined and defined way of controlling or handling a product, as accepted by the majority of a population. This implies that a minor part of a population uses other rules, and that these other rules may be applied to products too. Experience with these products may lead to a discrepancy between the rules learned by the child and the rules commonly used in the design of products. This might have influenced the results of the test.
Despite these disadvantages some preliminary conclusions can be drawn. Insight into these compatibility rules increases with age and differences exist between boys and girls. Insofar as the test indeed measured some kind of technical comprehension, it can be concluded that this asset develops when the children are still young. The differences in scores per age group first appeared at the age of 4 years, which may be explained by the fact that more or less specific 'reasoning' starts to develop at that age. The differences between boys and girls can be explained by either a difference in upbringing –or even to some extent in hormones– which is expressed as less interest in 'technical matters' among girls, or by the test used, which might have been too childish for the older girls.

15.4 Pattern of development

The variables in this project can be divided into three groups: physical variables (anthropometric measurements), psychomotor variables (force exertion, motor performance, physical flexibility, technical comprehension) and temperamental characteristics.
The correlations between the variables within each of these groups decreased from the physical towards the temperamental variables. This points towards a more stringent, internal pattern of development for the group of physical characteristics and a more diffuse and less stringent pattern for the group of temperamental variables.
Among the groups of variables the relationships between the physical and psychomotor variables were more obvious than those between these two groups and the temperamental variables. This leads to the conclusion that 'temperament', as assessed in this project, is not as closely related to or specific for age as the other variables. Temperamental traits are indeed presumed to be long-lasting personality characteristics, with at least some genetic basis.

Within the group of physical variables there also appeared to be a developmental pattern during the period of life under study in this project. There seemed to be a periodicity in the development of height and width. In those periods of life when stature is larger than would be expected on the basis of a linear development, body mass is smaller than expected.

During phases in which body mass is larger than expected, stature is smaller. This pattern in the cross-sectional data was found for boys and girls up to approximately 8 or 9 years of age. This may be generalized as a prepubertal development in height followed by development in width and mass.
After the age of 8 years, these variables seem to develop more or less simultaneously. This is probably due to the start of puberty in some of the children while others lag behind in the prepubertal phase, which implies a larger variance in the patterns of growth.

Within the group of psychomotor variables the above-mentioned pattern of development, being more internally structured or more environmentally determined, can also be seen. Here a distinction can be made between more physical and more temperamental variables. Again the correlation between the more physical variables in this group (for example, force exertion) and the anthropometric variables of the first group was higher than that between the physical and the more psychological variables of the second group. For example, the correlation between stature and force exertion was higher than that between stature and motor performance. This confirms the above-mentioned pattern.

The temperamental characteristics of the children were judged by their parents and teachers by means of a questionnaire, which covered temperamental characteristics and character features that might influence the incidence of accidents. The results of this part of the test did not correlate closely with those for the other groups of variables. This variable appears to be totally different, when compared with the others.

15.5 Accident liability

We tried to assess differences in the groups of variables measured in this project between children who were judged liable to have accidents and those who were not. This judgement was made by the parents and teachers of the children, because they were presumed able to give the most reliable judgement of this characteristic: a relative frequency count of past accidents. As far as the physical and psychomotor variables are concerned, it has to be concluded that these two groups of variables are not of demonstrable influence on the occurrence of accidents. These variables did not differ significantly between children who are said to be liable to have accidents and those who are not. Temperamental and character features, however, did differ between the three liability groups.

For designers of durable products for children this means that, generally speaking, differences in the design of products for children who are liable to have accidents and those who are not will not help to prevent accidents. It is even possible that this liability is a prejudice rather than a predictable temperament trait. The specific physical aspects of development within a certain age group are, however, very important and remain highly relevant to design. This means that products have to fit –in some cases even the extreme percentiles of– the mental capacities and physical characteristics of the children in the target group, and these characteristics diverge increasingly in successive age groups.

It has to be concluded that it appears impossible to prevent accidents by focusing on the physical dimensions of products, but this might be achieved by choosing better concepts, mechanisms, materials, instructions, etc.

15.6 Growth and development

Physical growth and development are very complex and all-embracing processes, consisting of many aspects which affect all parts of the body to some extent. It is well known that growth and development take place continuously during various phases of life. During infancy physical growth is very prominent: the increase in body size is marked. Motor development is at that time restricted mainly to movements of whole limbs.
In the phase usually called childhood (2-4 years), the increase in body dimensions is less rapid than during infancy, but the development of motor performance and strength are very clear. Motor performance shifts towards and becomes prominent in the extremities during this period of life (proximo-distal development).
In the prepubertal phase growth stabilizes at a more or less constant rate until the growth spurt of puberty. In the former phase motor performance reaches the stage of maturity in which the basic conditions for training of specialized motor skills have been created, while strength continues to increase.
These phases were demonstrated in this project too. Almost all body dimensions increased with age, while motor development increased rapidly in the first years and levelled off in later years. This might, however, have been due to the variables or methods of measurement chosen. The amount of force exerted continued to increase during the whole period and the differences between boys and girls persisted; for the other groups of variables (such as anthropometric measurements) differences between boys and girls were not all that clear.

It is obvious that different kinds of factors interact with growth, which also might be deduced from the increase in variance of physical characteristics in successive age groups. The differences between individuals, both physical and mental, become greater (individualization). Factors influencing growth and development are both genetically and environmentally determined, and many studies have been performed to prove the influence of either or both principles. The conclusion can almost always be drawn that both nature and nurture have an influence on growth and development.
On the other hand growth and development can also constrain the possibilities and capacities of the body itself. Rapid growth could be expected to hamper the ability to move in a fluid, gentle and coordinated way, because of changes in body proportions and a temporary lack of ability of the nervous system to react adequately to a new body scheme (Tanner, 1990). Time is needed for adaptation to the new dimensions and proportions of the body.

The observed diversities in body shape and mental capacities can influence interactions with products and material environments. This demands either a wide range of adapted products or the possibility to adjust a product, in order to make all products suitable for use by a large percentage of the members of the target group. When trying to achieve this, designers and manufacturers must at least be familiar with these differences between children. It is obvious that in many cases the data were either lacking or ignored (see chapter 14), which unfortunately suggests that product designs are not optimal.
With the availability of the data of this project, some progress has been made towards acquiring more knowledge of the –variance in– physical characteristics of children and the interrelationships between several aspects of physical development.

15.7 Choice of the variables in this project

The main goal of this project was assessment of the growth and development of physical and psychomotor variables, as they relate to the handling and use of products. This was to result in norms or standards as well as a profile of development by means of intercorrelation of all of these variables.
In addition we tried to find differences in the capacities of children within the three groups of accident liability.
The variables measured in this project can all be grouped into the categories mentioned above and the results give a reasonable insight into developmental characteristics. This, however, does not imply that these variables are the only ones that can be measured. Within the group of anthropometric measurements, for example, the dimensions of the arm segments are the most important variables missing. With respect to the handling of products it might have been valuable to assess more 'functional' psychomotor capacities of the children, for example, 'visuo-motor coordination' and the range of motion of limbs (zones of convenient reach). Other suggestions for further study are given in the next paragraph.

15.8 Suggestions for further study

Of course, many aspects of the physical capacities of 2 to 13-year-old children as well as their knowledge and ability to cope in daily-life situations need to be studied.
Generally speaking, a study on growth and development requires a longitudinal design. However, in most instances this is almost impossible, due to limitations of time or finance. A semi-longitudinal study might be the optimum alternative between the two extremes: cross-sectional and longitudinal.

Another subject of interest is, for instance, the ability to predict other anthropometric dimensions from the data published in this study, on the basis of foreign data. Therefore a comparison of foreign data is needed to determine how to make them suitable for the Dutch population. On the other hand, insight into the diversity of different populations is essential since many products are not designed merely for the Dutch population but often for an European or even a worldwide market. This means an European database.
Translation from anthropometric dimensions, measured in static postures, towards those in functional postures is often needed by designers too; therefore conversion factors are required. An example might be the difference in posture (and thus the space required) between sitting in the standard measurement posture and the normal, relaxed sitting posture. Or reaching height when standing erect in the measurement posture compared with the usual situation in which a person stands on his/her toes to reach something.

Concerning the measurement of strength, additional data are required on the maximum forces exerted by the legs or the whole body in standard postures, for example cycling, or –even more important– in functional postures. For this purpose a first step would be to determine the best method for the measurement of functional or dynamic forces in order to get results that are more in accordance with real-life situations. One requirement in this

respect is the observation of children during interaction with different kinds of products, especially when they try to take a product apart or unfasten small parts. This is important because children are less likely to follow standard procedures.
Further study of the combined exertion of force is also required. For example, force exertion while turning and pulling a control or squeezing combined with pulling force.

It would be useful to obtain data on different aspects of motor performance (for example, gross and fine motor performance) in order to be able to differentiate between them when describing various types of motor development per age group.
As far as motor performance is concerned more attention should be directed to fine motor skills, especially among older children, because this facet of motor performance received little attention during this study. The previously mentioned characteristic 'visuo-motor coordination' can be grouped into this category too.

Another element of this project that needs further research is the technical comprehension of children. A broader definition than knowledge of some commonly used compatibility rules should then be established; for instance, it might be extended to include knowledge of physics and/or the mechanisms of various products as well as ways of handling or interacting with them.

During design processes specific questions are often asked concerning the capacities or dimensions of future users, data which more often than not are lacking. It often seems to be almost impossible to give direct and correct answers to these questions. Therefore some standard measurement and/or calculation methods, that give the answers to all sorts of questions on data, posture and capacities, are greatly needed, because it is impossible to establish a database that will provide the answer to every detailed question.
Data which is already known and applicable should be assimilated into standards or regulations in such a way that general principles are laid down and the designers and manufacturers can use these general rules for their specific product.

The concept of accident liability should also be studied in more detail. Different facets of temperament and personality, which may seem to contribute to the occurrence of accidents, have to be analysed further. This implies a follow-up of risky behaviour. Attention should be directed, for example, toward motorial speed of improvisation and the capability of risk judgement, possibly by further development and elaboration of the questionnaire on temperamental aspects used here. These data may be less applicable to product design but are relevant to accident theory.

Looking beyond our target group, comparable data on the physical characteristics (including forces and functional capabilities) of other age groups are needed by designers, i.e. data on children from 0 to 2 years of age (unless already measured in the pilot study of this project), 13 years to adulthood and the elderly.

Summary

This national cross-sectional study focused on the development of physical and psychomotor variables among children between 2 and 13 years of age. In this case the concept of development was formulated as changes in characteristics between successive age groups.

The first reason for starting this project was the fact that data on the development of children provided, for example, by human biological sciences often are not suitable for use in the design of daily-life products. A second reason was the fact that many accidents occur while children are handling durable products, such as toys, furniture, household tools, packaging, etc. Reasons for the occurrence of accidents may possibly be retarded development or a change in the rate of development of a child. Another reason could possibly be that the product is not adapted or adjustable to the dimensions and capacities of its intended users. In addition attention ought to be directed toward the risks for children using adult products. It was therefore considered worthwhile to investigate whether the physical characteristics of children play a role in the occurrence of accidents. The expectation was that children whose rate of development deviated from the mean pattern of development found for children of the same age are more susceptible to accidents than those who approximated the mean rate of development.
A pilot study (Steenbekkers, 1989a) analysing descriptions of accidents involving children and daily-life products gave insight into the general nature of the physical and psychomotor characteristics that possibly influence the occurrence of accidents.

Six groups of variables were chosen to be measured cross-sectionally in a representative sample of children between 2 and 13 years of age and living in the Netherlands.
The groups of variables can be characterized as:

- temperamental characteristics,
- body dimensions and proportions,
- force exertion,
- motor performance,
- physical flexibility,
- technical comprehension.

For some of these variables measurement methods already existed. When such methods were not available or were not suitable for children in the age group under study, a measurement method was developed. This project, together with the pilot study, took 6 years. Every effort was made to obtain valid and reproducible measurement methods.

The measurements had to serve three goals. The first was to obtain a database of physical and psychomotor variables suitable for use during a process of product design. A second goal was to study relationships within and between the different groups of variables, in order to gain insight into the patterns of development of children. A third goal was to study differences in characteristics between children who appear to be liable to have accidents and those who are not and thus to present recommendations for safer daily-life products.

The measurements were taken by teams of trained observers, usually consisting of 5 persons. In total, 42 observers took the measurements. Subjects between 2 and 4 years of age were measured at health care centres, measurements of the older children (4 - 13 years of age) took place at primary schools all over the country. For the choice of municipalities the degree of urbanization and the occupational status of the inhabitants were decisive, in order to have a representative sample at the regional level. The results of the measurements were described in the relevant chapters. The main results are summarized below.

Temperamental characteristics

In this project temperament was seen as a personality trait, possibly related to the occurrence of accidents.

The questionnaire used to assess temperamental characteristics of children consisted of a number of 5-point scales with opposite characteristics at the ends: for example, 'impulsive versus prudent', self-confident versus uncertain' and 'able to concentrate versus easily distracted'. Parents and teachers of the children were asked to complete this form. The results were analysed and a total score, which can be considered as a numerical judgement of the temperamental characteristics of the child, was calculated.

In general the total scores increased slightly with age, indicating 'development' of behaviour towards less risky patterns. It appeared that the older children are more aware of dangerous situations and the way in which they can be avoided. Another result was that at all ages boys attained lower mean values than girls, confirming the statement that boys in general behave in a 'more temperamental' way.

Body dimensions and proportions

Forty dimensions of the body, both static and functional, were measured. The choice was based on several criteria, design-relevance being the most important. The measurement definitions were mainly those used in other anthropometric studies, in order to make comparison with other data possible. A total of 2245 children were selected for this anthropometric part of the project; 206 children were measured twice in order to check reproducibility.

The obvious expectation that the mean values (and standard deviations) per age group would increase with age, thus reflecting body growth, was true. Furthermore there was a systematic augmentation of variance, which implies an increase in individualization. For some of the measurements differences between boys and girls could be proven, but not for others. The most striking –rather constant– difference was found for the dimensions of the head. On average the head of boys of all ages was larger than that of girls. Other dimensions which differed in all age groups were knee breadth and thumb breadth, which also can be considered as skeletal measurements. These results point towards a heavier skeleton in boys. As far as bodily proportions were concerned, the ratio between upper leg and lower leg was larger for girls than boys, which can be explained by the longer upper legs of girls (and not by shorter lower legs!). The ratio shoulder breadth/hip breadth was larger for boys than girls and decreased in girls with age, confirming the well-known increase in the difference in the shape of the trunk between boys and girls.

Factor analysis, applied to the forty variables, resulted in three factors: the length, volume and head factors. The variables with the highest factor loadings per factor can be considered as the best predictors for or representatives of these factors. The variables for each of the respective factors were: popliteal height, upper arm circumference and head circumference. Some differences in anthropometric dimensions between children from the various regions of the Netherlands and from municipalities with different degrees of urbanization were present, but there were no systematic and consistent differences per variable and per age group. Ethnic differences, however, did influence the anthropometric dimensions.

Force exertion

For this group of variables we decided to measure several types of hand/arm forces, because they might be relevant to the safety aspect of product design, especially child-proof packaging. The measurement methods were designed on the basis of literature on force exertion by adults, due to a lack of data for children. The amount of force that could be exerted was assessed in 785 children, aged between 4 and 13 years.

A remarkable result was the fact that hardly any systematic differences seem to exist between forces exerted with the right and left hand or between those exerted with the preferred and the non-preferred hand. Differentiation of muscle tissue in the right or left hand and arm due to consistent use or training has probably not yet occurred or at least has not yet resulted in a significant difference.
The mean values of the forces exerted increased with age, as did the standard deviations. Here again, individualization seems to take place.
Differences in mean values between boys and girls are rather constant. In literature these differences are often explained by a difference in the amount of muscle tissue. In this study, however, a positive relationship was found between the amount of force and the Quetelet index, used in human nutrition sciences as an indication of the amount of fat tissue in the body; this points towards the opposite. Differences in motivation, however, might be another explanation for these findings.
Because of the fact that the partial correlation coefficients, controlling for age and sex, between the different forces were not very high, it has to be concluded that it is not possible to predict one kind of force from another.

Motor performance

Motor development is very clear during the phases of life studied in this project. It was hypothesized that retarded or advanced motor development would influence the occurrence of accidents. Therefore relevant measurements were taken and deviations from average development calculated. Many different tests are used to assess motor performance, but there are also many disadvantages: the limited number of motor skills covered, suitability for only a limited age range, time and/or equipment needed to test a child. The MOT '87, chosen for this project, did not have these disadvantages. Two versions, one for the younger children and one for the older, were used. The abbreviated form consisted of 16 items all of which required different motor abilities. For each item a score could be obtained, and the score for all items resulted in a total score for motor performance. The first item was not be taken into account, because it was a warming-up. Because only two items differed in the

abbreviated versions of the test for younger and older children, they were omitted in order to have comparable results for all children. A third item was deleted because of the large observer effect noted after analysis. A total score on motor performance, based on 12 items, was available for 552 children between 4 and 13 years of age. No repeated measurements were taken, because a learning effect might have occurred.
The total scores for this test increased with age, while the standard deviations diminished. This suggests that the differentiating power of the test of motor performance decreases for the older children. From age 9 onwards no differences in mean values between age groups could be demonstrated.
Generally speaking girls had higher scores for this test, although it was presumed to be equally difficult for boys and girls and no differences between boys and girls should have been present. A possible explanation might be deletion of the three items, although these particular tests are not known to be performed better by boys than girls.
Assuming that this test measures what it is supposed to measure, motor performance develops predominantly between the ages of 4 and 8 years. The motor skills of girls are more advanced than those of boys, and this applies throughout the entire age range.

Physical flexibility

To assess physical flexibility two measurements were taken using 1151 children between 2 and 13 years of age. 'Sit and reach' was chosen as a generally accepted method for assessment of general flexibility. 'Rotation of the body along the z-axis' was used in this project to assess the ranges of movements of a series of adjacent joints. Although the concept of this latter measurement is correct, operationalization yielded barely reproducible and far from accurate data. This measurement was therefore excluded from subsequent analyses.
In contrast, the sit and reach distance yielded reproducible measurements. The absolute values of this measurement decreased with age, but this can be explained by an increase in limb length which implies a larger distance to be covered in order to achieve the same absolute distance. When the distance reached is adjusted for limb length, physical flexibility increased with age although the mean results for children above 7 years of age did not reveal statistically significant annual differences. Girls of all ages exhibited larger mean values than boys; they can therefore be regarded as being physically more flexible than boys.

Technical comprehension

This variable was meant to clarify some of the cognitive aspects of a child's understanding of how to handle products. This was operationalized by checking whether they followed some commonly used compatibility rules applicable to movement, which can be considered a part of technical comprehension. For example, turning a knob clockwise should result in a movement to the right of the object to be controlled. Therefore a measurement method consisting of the movement of an object to be accomplished by operating different kinds of controls was developed. The variables were the type of control, direction of movement and orientation of the control.

In total 959 children between 2 and 13 years old participated in this part of the project.

For some of the younger children (2 and 3 years old) this test appeared to be just a funny game, while others performed the task very seriously. For children between 4 and 9 years of age the differentiating power of the test was acceptable, whereas it diminished for the older children. For them the test was too easy and/or too childish. The scores on the test increased with age and, generally speaking, boys attained higher scores than girls.

Assuming that this test measured insight into compatibility rules, it has to be concluded that this insight develops between the ages of 2 and 13 years, and that this development is very rapid after the age of 4. This might be explained by the fact that in daily life children of this age are allowed to operate certain controls themselves and thus acquire experience in the general principles of these compatibility rules.

The lower scores for girls aged 9 and over may support the general stereotype that girls have less technical comprehension than boys. However it could also point towards a difference in the way in which boys and girls are raised. Another explanation might be that the difference is not so much a question of skills but motivation and that the test was, for example, too childish for these girls.

Pattern of development

A pattern of development can be defined as a similarity in the rate and type of growth of several variables. Correlations across successive age groups form the empirical basis.
It was hypothesized that within the different groups of variables different patterns of development would occur. The similarity between the groups of variables was expected to be less than within each group.
For the anthropometric variables the relationships between the variables was expected to be very clear, since the body shape can be assumed to follow a natural, inborn pattern which is less likely to be influenced by 'nurture', e.g. external factors. The groups of variables can be distinguished in terms of this nature-nurture axis, reflecting the change from structural-static towards behavioural-dynamic: from anthropometric dimensions to forces and flexibility, psychomotor skills, technical comprehension and, finally, personality traits such as temperament. In the progression towards the more behavioural variables, the pattern was expected to become less clear as well as more divergent among children. This would become manifest as differences in the magnitude of correlation coefficients within and between groups of variables.

The data of this project confirmed the above mentioned hypotheses. The correlations within the group of anthropometric variables appeared to be larger than within the other groups of variables, even when the correlation coefficients were controlled for age. It has to be concluded that the anthropometric variables exhibited a more or less congruent pattern, whereas the psychomotor and temperamental variables were already divergent at birth and this divergence increased during the successive phases of development.

It should be noted that these results are based on cross-sectional data, which implies that some of the results might have been caused by cohort effects. A corresponding systematic change in culture or nature in the eighties in the Netherlands seems, however, rather unlikely. If development is defined as a change between successive age groups, as in this project, the above pattern of development was present in our series of subjects.

Accident liability

Accident liability is defined here as a temporary, historic, characteristic of children and does not imply the possibility of predicting future accidents.

It was assessed by asking parents and teachers whether a child had had more accidents than age peers in the preceding year. If both assessments were positive, the child was 'labelled' as absolutely liable to have accidents. When only one of them was of the opinion that the child suffered more accidents, the classification was 'doubtful'. All other children were defined as not liable to have accidents. It was hypothesized that children who are liable to have accidents differ in physical, psychomotor and temperamental characteristics from children who are not liable to have accidents. The absolute scores were expressed as deviations from the norm for the age group and were related to accident liability. Analyses of the data showed, however, that these children only differed in their temperamental characteristics, as judged by parents and teachers.

This implies that since typical values of the determinants of physical, motor and cognitive interaction between these children and their daily-life products could not be demonstrated, it is neither possible nor necessary to design products especially for these children. Of course, the relevant requirements for safe design must be satisfied completely for all (childhood)users.

Conclusions and recommendations for further study

This project resulted in a representative database of anthropometric and psychomotor variables for children living in the Netherlands. In particular the body dimensions of 2 to 13-year-old children, supplemented with the data of 0 to 1.5-year-old children from our regional pilot project, can serve as useful background information and guidelines during the design process, when a designer establishes the dimensions of a product for children. These data are presented in the appendices.

Of course, many questions remain to be studied. With respect to the anthropometric measurements, for example, the transformation of data measured in static postures into dimensions of the body in functional postures must be investigated. Another subject, related to the psychomotor variables, is the exertion of combined forces, forces of other parts of the body and even whole-body forces. An interesting problem is technical comprehension in a broader sense than insight into some commonly used compatibility rules.

As far as safety and accident liability are concerned, the factors assessed in this project do not lead to recommendations for special designs. Not 'accident-proneness' but the preceding history of accidents was judged by parents and teachers; this yielded a degree of accident liability. All sorts of analyses were applied to the groups of variables to differentiate between the degrees of accident liability. A correlation was found only for the judged personality trait 'temperament'. Between groups of differing degrees of accident liability no differences in either the anthropometric or the psychomotor variables were found. It is therefore concluded that children liable to have accidents are not different and cannot be identified by means of the physical variables in this project.

Samenvatting

Omgang met gebruiksgoederen is een activiteit die dagelijks vele malen plaats vindt, bewust dan wel onbewust. De wijze van omgang wordt onder andere bepaald door een aantal antropometrische en psychomotorische kenmerken, die elk gedurende de jeugdjaren een zekere ontwikkeling doormaken. Dit betekent dat het produktgebruik gedurende die ontwikkelingsperiode, maar ook daarna, mogelijk niet altijd optimaal zal verlopen en dat de (jonge) gebruiker derhalve in risicovolle situaties kan terecht komen. Echter, hiervan zal deze zich misschien niet altijd bewust zijn, omdat het inschatten van risico geleerd moet worden. Het leren veilig om te gaan met technische hulpmiddelen en leefomgevingen is waarschijnlijk een langdurig en breed proces, dat door vele factoren wordt bepaald en op vele aspecten van gedrag betrekking zal hebben. Daarnaar is echter zo goed als geen onderzoek gedaan.
Het is bekend dat kinderen vaak slachtoffer zijn van ongevallen in de privé-sfeer (PORS, 1990). De oorzaken van die ongevallen kunnen velerlei zijn en op allerlei gebied liggen. Eén ervan is de gebruiker zelf: zowel zijn motorische en cognitieve ontwikkeling en vaardigheden als zijn lichaamsdimensionering impliceren een bepaalde handelwijze c.q. produkthantering, die risicovol zou kunnen zijn. Hoe deze ontwikkelingsprocessen doorlopen worden en welke invloed deze hebben op de omgang met produkten, is echter niet geheel duidelijk. Dit betekent voor een (produkt)ontwerper dat het niet goed mogelijk is hierop systematisch te anticiperen in zijn ontwerp. Vandaar dat het zinvol is de ontwikkeling van een aantal psychomotorische en antropometrische variabelen in relatie tot produktgebruik in de loop van de jeugdjaren na te gaan, teneinde met de daaruit verkregen nieuwe inzichten een beter en veiliger produktontwerpen mogelijk te maken.

In een vooronderzoek (Steenbekkers, 1989a) zijn ongevallen geanalyseerd waarbij produkten betrokken waren. Op basis daarvan is een aantal fysieke en psychomotorische variabelen onderscheiden, die mogelijk van invloed zijn op het ontstaan van de ongevallen, of het ontstaan van letsel. Over deze variabelen zou meer bekend moeten zijn, om in de toekomst een bijdrage te kunnen leveren aan de preventie van dergelijke ongevallen.

In dit onderzoek zijn 6 groepen van variabelen bij een landelijke steekproef van kinderen tussen 2 en 13 jaar gemeten. Deze groepen zijn:

- lichaamsmaten en lichaamsproportionering,
- krachtuitoefening,
- motorische vaardigheden,
- lenigheid,
- technisch inzicht,
- temperament variabelen.

Voor sommige van deze variabelen is gebruik gemaakt van bestaande meetmethoden en meetinstrumenten; wanneer beschikbare meetmethoden en/of meetinstrumenten echter niet aanwezig of geschikt waren voor meting van de doelgroep, zijn deze in eigen beheer ontwikkeld. Hierbij is natuurlijk ook aandacht besteed aan validiteit en reproduceerbaarheid van de meetmethoden.

Het project heeft, inclusief vooronderzoek, 6 jaren geduurd.

Het doel van het onderzoek was drieërlei:

- Het verkrijgen van gegevens van verschillende antropometrische en psychomotorische variabelen, die geschikt zijn om gebruikt te worden tijdens het ontwerpen van dagelijkse gebruiksgoederen.
- Het verkrijgen van inzicht in een patroon van ontwikkeling binnen en tussen de groepen van variabelen.
- Nagaan of, en zo ja welke, verschillen in fysieke en psychomotorische variabelen aanwezig zijn in de verschillende groepen van ongevals-gevoelige kinderen en komen tot ontwerpaanbevelingen voor veiliger produkten.

De metingen van de 2- en 3-jarige kinderen vonden plaats op consultatiebureaus in de periode van september 1990 tot februari 1991. De overige kinderen (4 tot 13 jaar) werden gemeten op basisscholen in het gehele land gedurende de maanden februari 1990 tot oktober 1990.
In iedere provincie is een gemeente uitgekozen, die zo goed mogelijk overeen kwam met het beeld van de samenstelling van de beroepsbevolking in desbetreffende provincie. Daarnaast is per regio een representatieve verdeling qua urbanisatiegraad nagestreefd, waarbij het aantal te meten kinderen per gemeente bepaald werd op basis van het aantal kinderen dat in die regio in een betreffende gemeente-grootte woont. Omdat het aantal te meten kinderen op consultatiebureaus erg klein zou worden, wanneer de steekproeftrekking voor hen ook per provincie gedaan zou worden, is hier een verdeling op regionaal niveau nagestreefd. In tabel 1 wordt de verdeling van de steekproef over het land kort samengevat.

De steekproef bestond uit ongeveer gelijke aantallen jongens en meisjes, gelijkelijk verdeeld over de leeftijdsgroepen. De metingen werden verricht door getrainde meetteams, bestaande uit 5 personen. Drie van hen verrichtten de antropometrische metingen, de andere twee de psychomotorische metingen. Binnen deze sub-groepen werden taken dagelijks gewisseld.

regio	provincie	gemeente	urbanisatie-graad	aantal meewerkende scholen	aantal gemeten kinderen	aantal meewerkende consultatiebureaus	aantal gemeten kinderen
noord	Drenthe	Beilen	(a)	2	95	1	39
	Friesland	Heerenveen	(b)	1	50		
	Groningen	Groningen	(c)	1	57		
oost	Gelderland	Silvolde	(a)	1	78		
	Flevoland	Dronten	(b)	2	113	1	111
	Overijssel	Zwolle	(c)	2	178		
west	Utrecht	Breukelen	(a)	2	182		
	N.-Holland	Beverwijk	(b)	3	151		
	Z.-Holland	Dordrecht	(c)	5	583	3	80
	Z.-Holland	Delft	(c)			1	72
zuid	Zeeland	Borsele	(a)	5	249	1	68
	Limburg	Venray	(b)	3	161		
	N.-Brabant	Oss	(c)	2	95		
totaal				29	1993	7	370

Tabel 1: Overzicht van meetplaatsen en aantallen gemeten kinderen.

De verschillende groepen van variabelen en enkele, belangrijke resultaten worden hierna besproken.

Temperament

Omdat het vermoeden bestond dat temperament van kinderen een rol zou kunnen spelen bij het ontstaan van ongevallen, is deze variabele meegenomen in dit onderzoek. Hiertoe is een vragenlijst opgesteld, bestaande uit 5-punts schalen met op de uiteinden tegengestelde kenmerken. Aan ouders en leerkrachten van de kinderen werd gevraagd deze vragenlijsten in te vullen. Op basis van deze gegevens werd een totaalscore berekend, die beschouwd kan worden als een maat voor 'temperament'.

De resultaten laten zien dat binnen een leeftijdsgroep de scores erg uiteenlopen, hetgeen betekent dat temperament in verschillende mate aanwezig is bij kinderen van dezelfde leeftijd. De gemiddelde waarden per leeftijdsgroep nemen enigszins toe met de leeftijd, en aangezien de scoring zodanig was dat een lage score 'meer temperamentvol' en een hoge score 'minder temperamentvol' betekent, kan geconcludeerd worden dat kinderen in het algemeen iets minder temperamentvol worden met het toenemen van de leeftijd. Het valt op dat de gemiddelde scores van jongens op alle leeftijden lager zijn dan die voor meisjes. Dit bevestigt het beeld dat jongens in het algemeen genomen 'temperamentvoller' zijn dan meisjes.

Lichaamsmaten en lichaamsproportionering

Voor dit onderdeel van het onderzoek zijn 40 lichaamsmaten geselecteerd. De keuze is onder andere gebaseerd op beschrijvingen van ongevallen waarbij produkten betrokken waren. Nagegaan is welke lichaamsmaten bekend zouden moeten zijn om, mits deze tijdens het (her)ontwerpen van produkt op een juiste wijze toegepast zouden worden, in de toekomst een dergelijk ongeval te kunnen voorkomen. Het betreft in dit geval bijvoorbeeld beklemmingsongevallen. Verder zijn segmentmaten ook meegenomen, om op basis daarvan een indruk te kunnen krijgen van de totale lichaamsbouw. Van 2245 kinderen tussen 2 en 13 jaar zijn deze maten gemeten.
Zoals verwacht, nemen de gemiddelde waarden en de standaarddeviaties toe met de leeftijd. Dit betekent dat de verschillen tussen kinderen qua lichaamsafmetingen alsmaar groter worden, ook binnen een leeftijdsgroep.

Voor sommige maten geldt dat ze op alle leeftijden gemiddeld genomen verschillend zijn voor jongens en meisjes, terwijl dat voor andere maten niet of slechts incidenteel het geval is. Het meest opvallend in dit opzicht is dat op elke leeftijd het hoofd van jongens, gemiddeld genomen, groter is dan dat van meisjes. Dit geldt ook voor de maten die als een algemene indicatie voor het type bouw van het skelet beschouwd kunnen worden, namelijk kniebreedte en duimbreedte. Jongens hebben gemiddeld een breder of zwaarder gebouwd skelet dan meisjes. Voor geen enkele maat kan gezegd worden dat bij de meisjes de gemiddelde waarde per leeftijdsgroep steeds groter is dan die voor jongens. Wel bestaat er een tendens tot langere bovenbenen bij de meisjes, wanneer ze vergeleken worden met die van jongens. Het verhoudingsgetal tussen boven- en onderbeen is voor meisjes groter dan dat voor jongens, terwijl er nauwelijks verschillen in onderbeenlengte werden gevonden.

Het omgekeerde geldt voor het verhoudingsgetal tussen schouder en heupbreedte. Dit is voor meisjes kleiner, vooral vanaf de leeftijd van ongeveer 9 jaar, als de heupen van de meisjes breder gaan worden waardoor het verhoudingsgetal kleiner wordt, terwijl dat getal bij jongens groter wordt door een verbreding in hun schouders. Dit betekent derhalve een verandering in de bouw van de romp.

Uit een factoranalyse van de antropometrische variabelen resulteerden 3 factoren: een 'lengte'-, 'volume'- en 'hoofd'-factor, met als belangrijkste maten: knieholte-hoogte, bovenarmomvang en hoofdomvang. Deze variabelen kunnen derhalve gezien worden als belangrijkste representanten of voorspellers van de andere variabelen in desbetreffende factor.

Nagegaan is of kinderen in verschillende regio's van het land verschillen wat betreft lichaamsafmetingen. Het bleek mogelijk enkele verschillen aan te tonen, maar deze kunnen niet beschouwd worden als systematisch verschillend over de regio's van het land. Hetzelfde geldt voor verschillen tussen landelijke en stedelijke gebieden. Etniciteit bleek wel van invloed te zijn op lichaamsafmetingen.

Krachtuitoefening

Acht krachten, uitgeoefend met (duim en) wijsvinger of met de hand, zijn gekozen om gemeten te worden bij de kinderen tussen 4 en 13 jaar, omdat deze gegevens zinvol kunnen zijn tijdens het ontwerpen van produkten, bijvoorbeeld van kinderveilige verpakkingen. De 8 krachten zijn:

- trekkracht van de hand
- duwkracht van de hand
- knijpkracht van de hand
- torsie van de hand
- trekkracht van duim en wijsvinger
- duwkracht van de wijsvinger
- knijpkracht tussen duim en wijsvinger
- torsie met duim en wijsvinger.

In dit deel van het onderzoek participeerden 785 kinderen tussen 4 en 13 jaar. Ook hier nemen de gemiddelde waarden en de standaarddeviaties toe met de leeftijd, zodat ook wat betreft krachtuitoefening gesproken kan worden van een toenemende individualisering van de kinderen.

Opvallend is dat er een min of meer constant verschil bestaat tussen de gemiddelde uitgeoefende krachten van jongens en meisjes. Reeds op 4 jarige leeftijd zijn de jongens gemiddeld genomen sterker dan de meisjes en dit verschil blijft gehandhaafd tot in de oudste leeftijdsgroep van onze landelijke steekproef. Een mogelijke verklaring hiervoor is een verschil in spiermassa tussen de geslachten; dit is hier echter niet onderzocht.

Er blijkt nauwelijks een verschil te zijn tussen gemiddelde krachtuitoefening met de rechter- en met de linkerhand. Ook een verschil tussen voorkeurshand en niet-voorkeurshand kon niet worden aangetoond. Dit duidt op een nog niet volledige differentiatie in spierweefsel tussen beide armen c.q. handen, dan wel op een (nog) niet aantoonbaar verschil in training van beide zijden van het lichaam.

Motorische vaardigheden

Ook deze variabelen werden geacht een rol te spelen in het ontstaan van ongevallen, zodat ook deze gemeten zijn in het onderzoek. Hiervoor is gebruik gemaakt van de verkorte versie van de MOT '87, een test bestemd voor het meten van motorische vaardigheden van kinderen tussen 4 en 13 jaar. De versie, die hier gebruikt is, bestond uit 16 items, waarvan het eerste beschouwd werd als warming-up opdracht. De resultaten op de verschillende opdrachten zijn geanalyseerd en ook hier omgezet in een totaalscore.

De resultaten van de 552 kinderen laten zien dat de gemiddelde score toeneemt met de leeftijd. Hier neemt de standaarddeviatie echter af, hetgeen er op zou kunnen wijzen dat het differentiërend vermogen van de test minder wordt naar mate de geteste kinderen ouder worden. Ook de verschillen tussen de gemiddelde waarden per leeftijdsgroep zijn voor deze oudere kinderen niet meer statistisch significant verschillend van nul. Dit betekent dat de toename in gemiddelde waarden afvlakt.

Gemiddeld genomen scoren de meisjes hoger op de test. Dit zou betekenen dat hun motorische vaardigheden verder ontwikkeld zijn dan die van jongens van gelijke leeftijd. Dit is een opmerkelijke waarneming, omdat algemeen aangenomen wordt dat de klein-motorische vaardigheden van meisjes inderdaad verder ontwikkeld zijn dan die van jongens, maar voor kenmerken die snelheid en kracht vergen (de groot-motorische vaardigheden) zou het beeld andersom moeten zijn. Omdat de verhouding tussen klein- en groot-motorische vaardigheden gelijk zou zijn in deze test, zouden er geen verschillen in totaalscore waargenomen moeten zijn. Dat dit wel het geval is, kan enerzijds te wijten zijn aan de (noodzakelijke) verwijdering van een aantal items uit de oorspronkelijke test –waardoor de balans tussen groot- en klein-motorische opdrachten in de test verstoord zou kunnen zijn–, anderzijds zou geconcludeerd kunnen worden dat meisjes, ook wat betreft vaardigheden die kracht en snelheid vergen, zich sneller ontwikkelen dan jongens.

Uitgaande van het feit dat de validiteit van de test acceptabel is, lijken, gezien de resultaten van de test, de motorische vaardigheden in de leeftijd tussen 4 en 8 jaar het meest duidelijk toe te nemen. Meisjes scoren op alle leeftijden, gemiddeld genomen, hoger dan jongens.

Lenigheid

Voorwaarts reiken in langzit en rotatie van de romp rond de z-as in staande positie zijn in dit onderzoek meegenomen als maten voor lenigheid van het lichaam. Ze zijn gemeten bij 1151 kinderen tussen 2 en 13 jaar. Wat betreft deze laatste maat moest echter geconcludeerd worden dat de betrouwbaarheid en het meetgemak van de metingen niet optimaal was. Dit was reden om de resultaten van deze methode verder buiten beschouwing te laten.

Reiken in langzit leek wel te voldoen als maat voor algemene lenigheid van het lichaam. Alhoewel in de meeste literatuur aangegeven wordt dat het niet noodzakelijk is een correctie toe te passen voor de lengte van de segmenten, is dit hier wel gedaan, omdat de proportionering van het lichaam van kinderen in de periode tussen 2 en 13 jaar nogal verschilt.
De absoluut gereikte afstand blijkt af te nemen met leeftijd. Wordt hierin echter een correctie voor de segmentmaten toegepast, dan neemt de lenigheid toe met leeftijd.

Ook hier blijken de meisjes op alle leeftijden, gemiddeld genomen, hoger te scoren dan de jongens. Dit is overeenkomstig de verwachting.

Technisch inzicht

Deze variabele is meegenomen om te zien in hoeverre kinderen op de hoogte zijn van compatibiliteitsregels, die toegepast moeten worden bij het bedienen van technische produkten. Dit kan beschouwd worden als een onderdeel van technisch inzicht. Aangezien er geen gegevens over eerdere onderzoeken of meetmethoden beschikbaar waren, is zelf een testmethode met bijbehorende instrumentatie ontwikkeld. Deze methode moet gezien worden als een eerste aanzet tot het meten van enkele kenmerken van technisch inzicht.

De opdracht voor de 959 deelnemende kinderen, was het tot stand te brengen van een verplaatsing door elk van vier verschillende typen van bedieningmiddelen op de juiste wijze te activeren. Dit moest leiden tot een horizontale dan wel verticale verplaatsing.
De bedieningsmiddelen waren:
- een paar drukknoppen,
- een draaiknop,
- een hendel,
- een joy-stick.

Deze knoppen waren in een horizontaal dan wel een verticaal vlak geplaatst.

De resultaten lieten zien dat de bedieningsprincipes van de knoppen niet altijd eenduidig waren. Met name de hendel en de joy-stick leverden nogal eens problemen op.

Ook hier is een totaalscore berekend als maat voor 'technisch inzicht'. De scores laten een gevarieerd beeld zien. Met name bij de jongere kinderen (2 en 3 jaar) is de spreiding in resultaten erg groot: voor sommige van hen was het een leuk spelletje, terwijl anderen serieus werkten en hun best deden om de opdrachten zo goed mogelijk uit te voeren. Een groot aantal van de oudste kinderen in de onderzoeksgroep blijkt de maximale score te behalen. Voor deze kinderen is de test te eenvoudig om tussen hen te kunnen differentiëren. De resultaten moeten derhalve met grote voorzichtigheid beschouwd worden. Toch kan eruit geconcludeerd worden dat er een ontwikkeling van 'technisch inzicht' aanwezig blijkt. Men name vanaf de leeftijd van 4 jaar is deze waarneembaar. Dit zou verklaard kunnen worden uit het feit dat kinderen vanaf deze leeftijd vaker met allerlei technische produkten in aanraking komen en daardoor ervaring opdoen in het bedienen ervan. Vanaf deze leeftijd lijken ze die ervaring steeds beter te kunnen toepassen in nieuwe situaties, waarvan deze testmethode een voorbeeld is.

Er van uitgaande dat deze methode een deel van technisch inzicht meet, zou het feit dat jongens op deze test hoger te scoren dan de meisjes een bevestiging van het stereotype beeld kunnen zijn dat meisjes minder 'technisch' zijn dan jongens. Dat dit verschil reeds op jonge leeftijd aanwezig is, zou enerzijds kunnen wijzen op het feit dat er nog steeds verschillen in opvoeding zijn tussen jongens en meisjes. Anderzijds zouden aangeboren verschillen tussen jongens en meisjes als verklaring gegeven kunnen worden. De lagere scores voor meisjes vanaf ongeveer 9 jaar zouden echter ook verklaard kunnen worden uit een lagere motivatie, omdat de test door sommigen van hen als kinderachtig ervaren werd.

Samenhang tussen de groepen van variabelen

Een patroon van ontwikkeling binnen en tussen groepen van variabelen kan tot uiting komen in een overeenkomstige snelheid en type van groei. Correlatie coëfficiënten tussen variabelen in opeenvolgende leeftijdsgroepen vormen de empirische basis voor een dergelijk patroon.

In een hypothese werd gesteld dat het patroon van ontwikkeling binnen de groepen van variabelen verschilt: binnen de antropometrische variabelen werd een duidelijk, min of meer intern bepaald ('nature'), eenduidig patroon verwacht, omdat de vorm van het lichaam geacht wordt minder beïnvloed te worden door externe factoren ('nurture'). Binnen de groep van psychomotorische variabelen werd dit patroon echter minder duidelijk aanwezig geacht, omdat hier een duidelijker invloed van 'nurture' dan van 'nature' werd verwacht. Tussen de groepen van variabelen zou een zelfde soort patroon te zien zijn. De samenhang tussen de meer fysieke variabelen zou duidelijker zijn dan die tussen de meer psychomotorische en temperaments variabelen: de invloed van 'nature' neemt af, terwijl die van 'nurture' toeneemt.

De verschillen in mate van samenhang zouden tot uiting moeten komen in de correlaties binnen en tussen de groepen van variabelen. Deze verschillen in samenhang bleken aantoonbaar, waarmee de hypothesen werden ondersteund. Binnen de groep van antropometrische variabelen is die samenhang duidelijk aanwezig. Dit leidt tot de conclusie dat hier waarschijnlijk sprake is van een intern ('nature') gestuurd patroon van ontwikkeling dat in grote lijnen vast staat bij de geboorte en in mindere mate beïnvloed wordt door factoren van buitenaf. Binnen de groep van psychomotorische variabelen bleken de correlaties duidelijk minder hoog. Dit betekent dat de diversiteit in deze groep groter is. Dit lijkt een min of meer constant gegeven tijdens de periode van ontwikkeling. De correlatie coëfficiënten zijn lager en variëren minder tussen de verschillende leeftijdsgroepen.

De temperamentsvariabelen lijken min of meer onafhankelijk van leeftijd, zodat hier nauwelijks een patroon van ontwikkeling aantoonbaar is. Een mogelijke conclusie zou kunnen zijn dat deze variabelen een vaststaand kenmerk zijn, dat niet verandert gedurende een zekere periode of wellicht zelfs als persoonlijkheidskenmerk een leven lang blijft typeren.

Natuurlijk moet hier opgemerkt worden dat een deel van de resultaten toegeschreven zou kunnen worden aan het optreden van 'cohort-effecten', daar ze gebaseerd zijn op transversale data, maar ook aan de gebruikte methode, waarin aan de ouders gevraagd werd de items te scoren in relatie tot kenmerken van leeftijdsgenootjes.

'Accident liability'

Dit begrip werd hier beschouwd als een tijdelijk kenmerk van kinderen, geoperationaliseerd als de mate waarin kinderen in het afgelopen jaar meer of minder ernstige ongevallen kregen in vergelijking tot andere kinderen van hun leeftijd. Dit werd beoordeeld door zowel ouders als leerkrachten van de kinderen. Wanneer beide beoordelaars van mening waren dat een kind vaker dan leeftijdsgenootjes een ongeval kreeg, werd dit kind beschouwd als een 'ongevallertje'. Waren de meningen hierover verdeeld, dan werd het kind ingedeeld in de categorie 'twijfelachtig'. Waren zowel de ouders als de leerkracht van het kind van mening dat hij/zij niet vaker dan gemiddeld slachtoffer was van een ongeval, dan werd het beschouwd als 'absoluut geen ongevallertje'.

De gedachte was dat een versnelling of vertraging in de ontwikkeling van een kind, wanneer vergeleken met leeftijdsgenootjes, oorzaak zou kunnen zijn van het ontstaan van ongevallen. Om dit na te gaan zijn zowel absolute als relatieve resultaten van de kinderen in de 3 ongevalscategorieën met elkaar vergeleken. Hieruit bleek dat er geen verschillen aantoonbaar waren voor de fysieke en psychomotorische kenmerken van de kinderen. Alleen voor de temperament variabelen bleken duidelijke verschillen aantoonbaar. De kinderen die vaker dan leeftijdsgenootjes een ongeval kregen bleken een temperamentvoller karakter te bezitten dan de andere kinderen.

Voor een ontwerper van produkten voor kinderen betekent dit dat het nauwelijks mogelijk lijkt ongevallen te voorkomen door voor deze kinderen speciale produkten te ontwerpen, omdat de kinderen fysiek en psychomotorisch niet of nauwelijks verschillen. Natuurlijk moeten wel de gebruikelijke eisen ten aanzien van veiligheid en comfort toegepast worden. Dit geldt zowel bij het ontwerpen van produkten die speciaal bestemd zijn voor gebruik door kinderen, als voor overige produkten waar kinderen gewoonlijk mee in aanraking komen.

Conclusie

Dit project heeft dus geresulteerd in een representatieve verzameling van data over antropometrische en psychomotorische kenmerken van in Nederland wonende kinderen. Vooral de lichaamsmaten van 2 tot 13-jarigen, nog aangevuld met die van 0 tot 1,5 jaar uit het regionale vooronderzoek, zijn bruikbaar als richtwaarden en achtergrond bij het ontwerpen van produkten voor dagelijks gebruik door kinderen. In de bijlagen zijn deze gegevens overzichtelijk weergegeven.

Natuurlijk blijft een groot aantal vragen onbeantwoord. Nader onderzoek is gewenst naar onder andere het transformeren van gegevens van lichaamsafmetingen, gemeten in een statische houding, naar afmetingen van het lichaam in een functionele houding. Ook gegevens over gecombineerde krachten zijn noodzakelijk, alsmede over krachten uitgeoefend met andere segmenten of zelfs met het gehele lichaam. Wat betreft technisch inzicht lijkt het gewenst verder te gaan dan alleen het meten van inzicht in enkele compatibiliteitsregels.

Het veiligheidsprobleem, dat in dit project werd onderzocht, leidde niet tot ontwerprichtlijnen. Niet 'accident-proneness', doch voorafgaande ongevalshistorie werd achterhaald door overeenstemming van beoordeling van ouders en leerkrachten. Alle statistische kansen werden gegeven aan de vele verschillende variabelen, om het al dan niet geneigd zijn tot het vaker krijgen van ongevallen te differentiëren. Dat lukte echter alleen met het beoordeelde persoonlijkheidskenmerk temperament. Er bleken geen verschillen in antropometrische en (psycho)motorische kenmerken. 'Ongevallertjes' zijn fysiek niet anders, noch herkenbaar.

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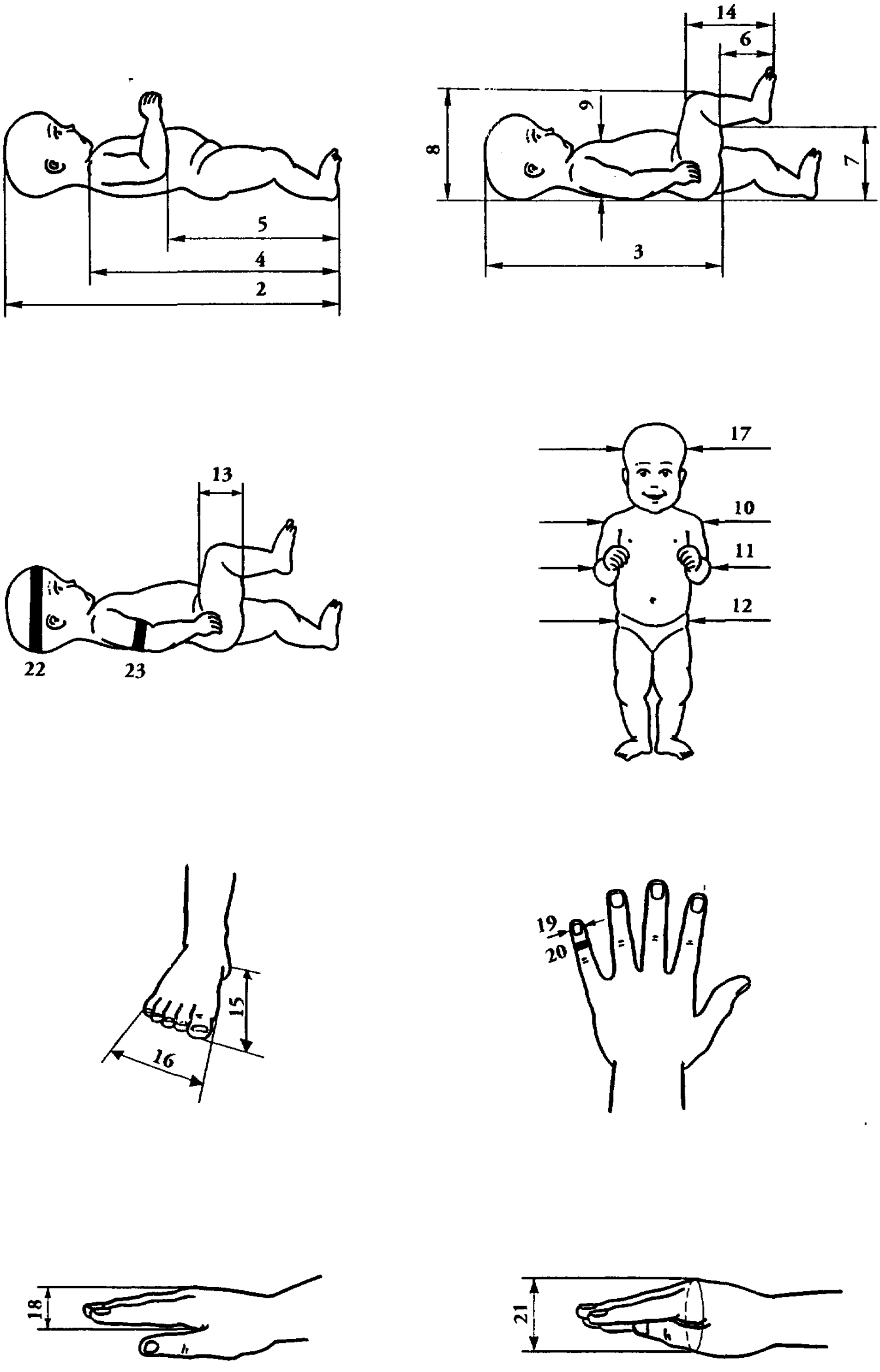
Appendices

A Results of the pilot project (0 - 18 months of age)



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Definitions

Distal:

The distal part of a body segment is that part which is the most distant from the trunk; the opposite of proximal.

Frankfort Plane:

The plane which defines a horizontal position of the head. This plane passes through both tragions and the left orbit (lowest point of the left eye socket).

Glabella:

The anterior point of the forehead between the eyebrows in the midsagittal plane.

Opistocranion:

Point at the back of the head most posterior to the glabella.

Proximal:

The proximal part of a body segment is that part which is nearest to the trunk; the opposite of distal.

Radius (radial):

The bone in the lower arm on the side of the thumb.

Sagittal:

Related to the vertical plane which leads from the front to the back of the body through the middle of the body (midsagittal plane) or to a plane parallel to this plane.

Tragion:

The point at the incision of the tragus (the little cartilaginous part of the ear in front of the external acoustic meatus (cavity) of the ear).

Ulna (ulnar):

The bone in the forearm on the side of the little finger.

A-1 Body mass [kg]

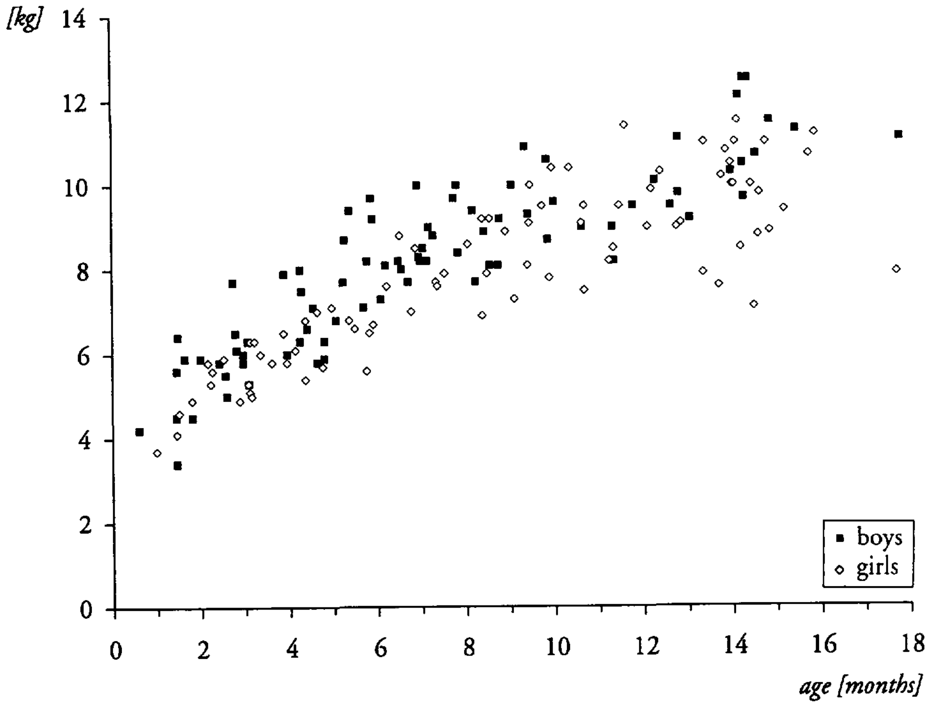
definition: Total body mass of the child.

method: The child lies on a clinical scale.

device: Clinical scale.

results:

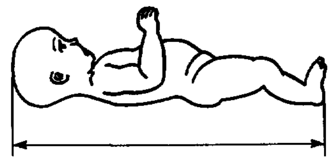
age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	1.0	3.4	5.6	7.7	9	0.8	3.7	5.0	5.9	1.0	5.3
3.0 - 5.9	21	1.3	5.3	7.3	9.7	20	0.6	5.0	6.1	7.1	1.2	6.7
6.0 - 8.9	22	0.8	7.3	8.6	10.0	14	0.8	6.9	8.1	9.2	0.8	8.4
9.0 - 11.9	13	0.8	8.2	9.5	10.9	16	1.2	7.3	9.1	11.4	1.1	9.2
12.0 - 14.9	15	1.1	9.2	10.7	12.5	23	1.2	7.1	9.6	11.5	1.3	10.0
15.0 - 17.9	2	0.1	11.1	11.2	11.3	5	1.5	7.9	9.8	11.2	1.4	10.3



A-2 Supine stature [cm]

definition: Horizontal distance between vertex (top of the head) and the heel of the right foot.

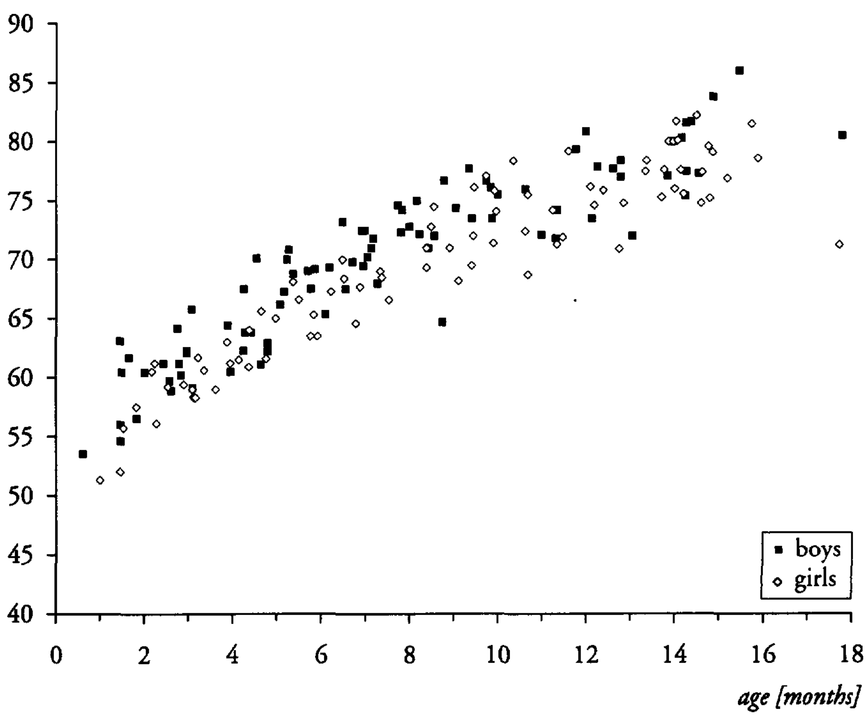
method: The child lies on its back with the head against the vertical part of the measuring table and the legs extended. The sliding part of the measuring table is placed against the heel of the right foot.



device: Measuring table with sliding part.

results:

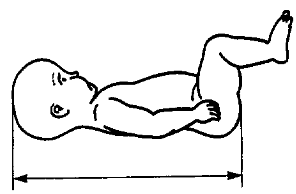
age	boys					girls					boys + girls	
[months]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	3.1	53.5	59.8	64.2	9	3.5	51.3	57.0	61.2	3.5	58.8
3.0 - 5.9	21	3.5	59.1	65.6	70.8	20	2.9	58.3	62.3	68.1	3.6	63.9
6.0 - 8.9	22	3.0	64.7	71.2	76.7	14	2.6	64.6	69.3	74.5	3.0	70.5
9.0 - 11.9	13	2.7	71.8	75.5	80.9	16	3.4	68.2	73.5	79.2	3.2	74.4
12.0 - 14.9	15	3.1	72.0	78.1	83.8	23	2.7	70.9	77.3	82.2	2.9	77.6
15.0 - 17.9	2	3.9	80.5	83.3	86.0	5	4.3	71.2	77.1	81.5	5.0	79.1



A-3 Supine crown-buttock length [cm]

definition: Horizontal distance between vertex (top of the head) and surface of the right buttock.

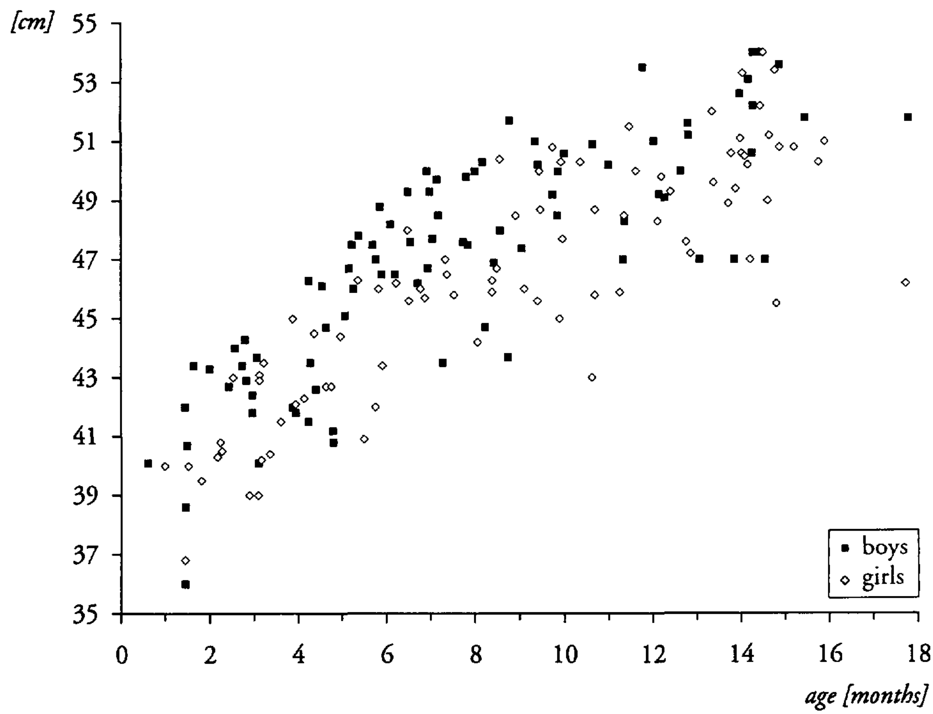
method: The child lies on back with the head against the vertical part of the measuring table and the legs flexed 90° to the torso so that rotation of the pelvis is minimal. The sliding part is placed against the surface of the right buttock.



device: Measuring table with sliding part.

results:

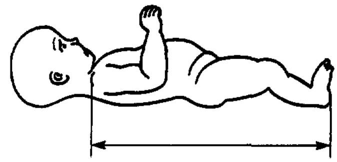
age	boys					girls					boys + girls	
[months]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	2.3	36.0	41.8	44.3	9	1.6	36.8	40.0	43.0	2.2	41.1
3.0 - 5.9	21	2.7	40.1	44.6	48.8	20	1.9	39.0	42.8	46.3	2.5	43.8
6.0 - 8.9	22	2.1	43.5	47.9	51.7	14	1.5	44.2	46.6	50.4	2.0	47.4
9.0 - 11.9	13	1.7	47.0	49.8	53.5	16	2.5	43.0	48.0	51.5	2.3	48.8
12.0 - 14.9	15	2.5	47.0	50.8	54.0	23	2.1	45.5	50.1	54.0	2.3	50.4
15.0 - 17.9	2		51.8	51.8	51.8	5	2.3	46.2	49.6	51.0	2.1	50.3



A-4 Supine shoulder height [cm]

definition: Horizontal distance between heel of the right foot and acromion of the right shoulder [cm].

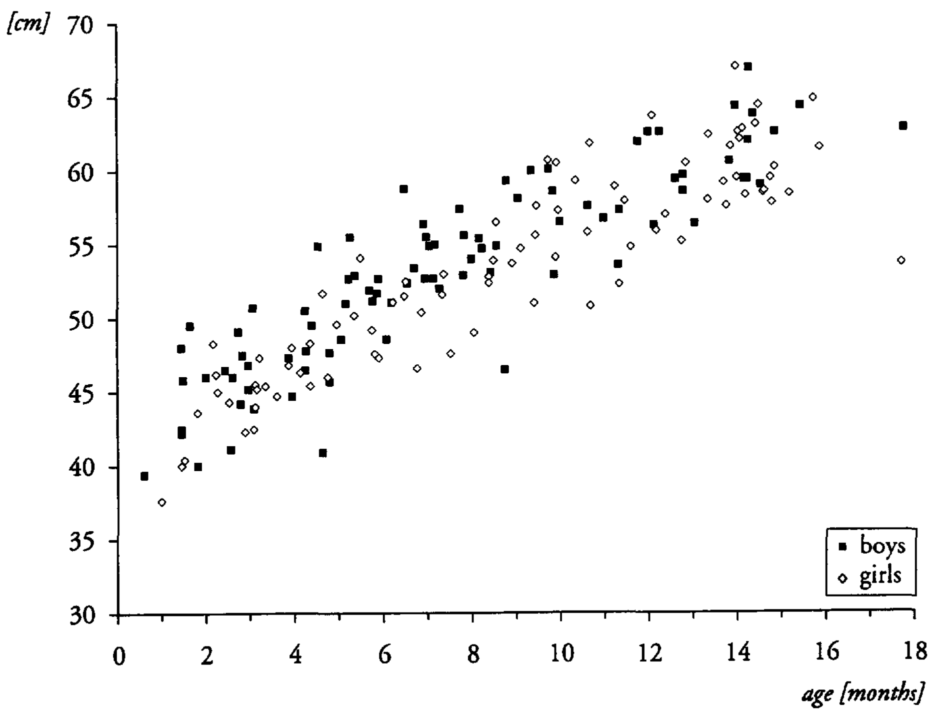
method: The child lies on its back, the feet against the vertical part of the measuring table, legs extended and the upper arm against the body.



device: Measuring table with anthropometer.

results:

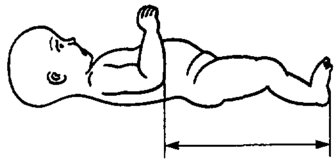
age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	3.1	39.4	45.0	49.5	9	3.3	37.6	43.1	48.3	3.3	44.3
3.0 - 5.9	21	3.7	40.9	49.4	55.5	20	2.7	42.5	47.3	54.1	3.4	48.4
6.0 - 8.9	22	3.0	46.5	54.0	59.3	14	2.6	46.6	51.6	56.5	3.0	53.1
9.0 - 11.9	13	2.9	52.9	58.0	62.6	16	3.4	50.8	56.4	61.8	3.2	57.1
12.0 - 14.9	15	2.9	56.3	60.7	66.9	23	2.9	55.2	60.2	67.0	2.9	60.4
15.0 - 17.9	2	1.1	62.8	63.6	64.3	5	4.7	53.7	59.6	64.8	4.2	60.9



A-5 Supine elbow height [cm]

definition: Horizontal distance between heel of the right foot and the lowest point of the flexed right elbow.

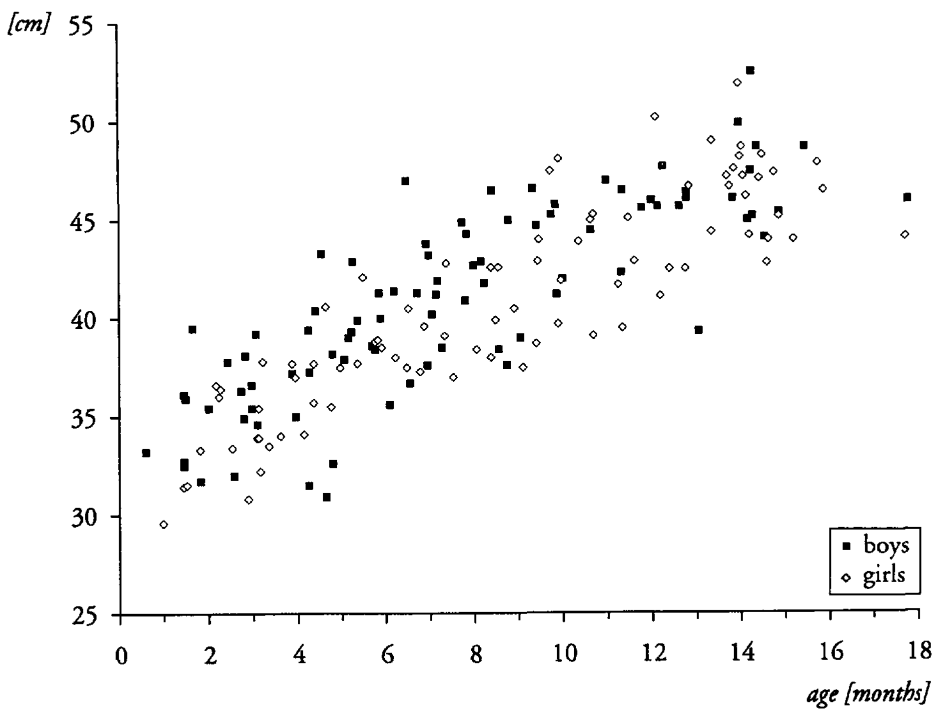
method: The child lies on its back, the feet against the vertical part of the measuring table, legs extended and the upper arm against the body, the elbow flexed 90°.



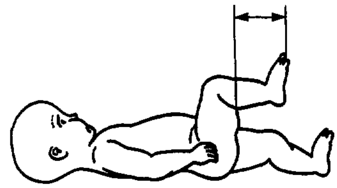
device: Measuring table with anthropometer.

results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	2.4	31.7	35.2	39.5	9	2.6	29.6	33.2	36.6	2.6	34.5
3.0 - 5.9	21	3.4	30.9	37.9	43.3	20	2.6	32.2	36.6	42.1	3.0	37.3
6.0 - 8.9	22	3.1	35.6	41.5	47.0	14	2.0	37.0	39.6	42.8	2.9	40.8
9.0 - 11.9	13	2.5	39.0	44.3	47.0	16	3.2	37.5	42.7	48.1	2.9	43.4
12.0 - 14.9	15	2.9	39.3	46.4	52.5	23	2.7	41.1	46.3	51.9	2.8	46.3
15.0 - 17.9	2	1.9	46.0	47.4	48.7	5	1.9	44.0	45.6	47.9	1.9	46.2



A-6 Popliteal height [cm]



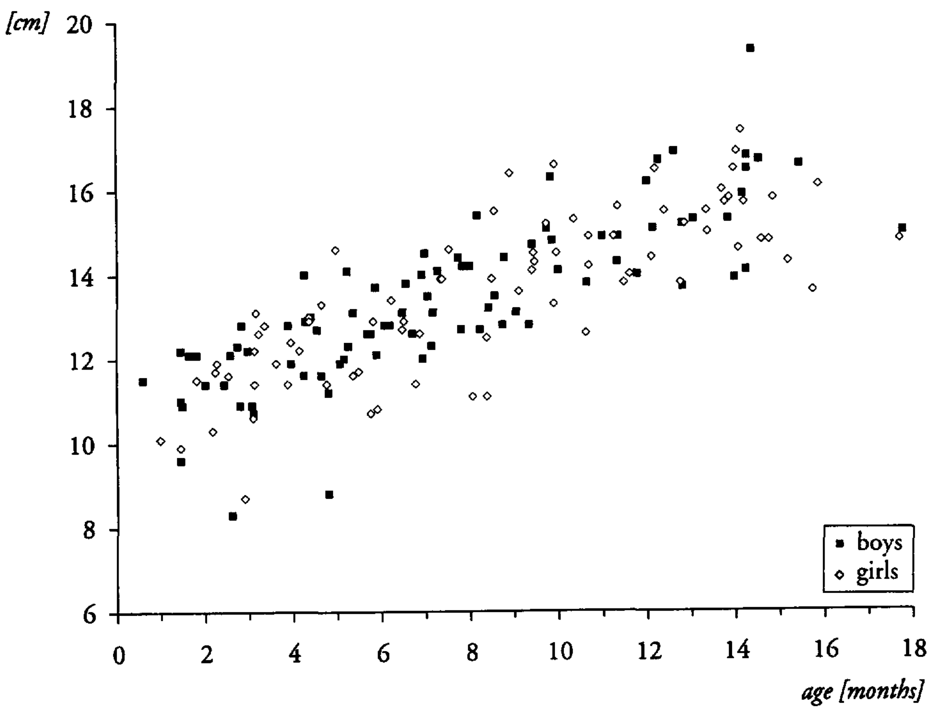
definition: Horizontal distance between heel of the right foot and the hollow of the knee.

method: The child lies on its back with 90° right hip flexion, 90° right knee flexion and 90° right foot flexion.

device: Anthropometer.

results:

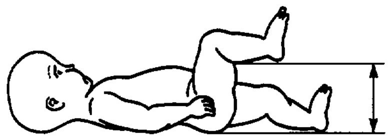
age	boys					girls					boys + girls	
[months]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	1.2	8.3	11.4	12.8	9	1.1	8.7	10.7	11.9	1.2	11.2
3.0 - 5.9	21	1.2	8.8	12.2	14.1	20	1.0	10.6	12.2	14.6	1.1	12.2
6.0 - 8.9	22	0.9	12.0	13.5	15.4	14	1.6	11.1	13.3	16.4	1.2	13.4
9.0 - 11.9	13	1.0	12.8	14.5	16.3	16	1.0	12.6	14.5	16.6	1.0	14.5
12.0 - 14.9	15	1.5	13.7	15.8	19.3	23	0.9	13.8	15.6	17.4	1.2	15.7
15.0 - 17.9	2	1.1	15.0	15.8	16.6	5	1.1	13.6	14.7	16.1	1.1	15.1



A-7 Buttock-popliteal length [cm]

definition: Distance from the horizontal surface of the table to the hollow of the right knee.

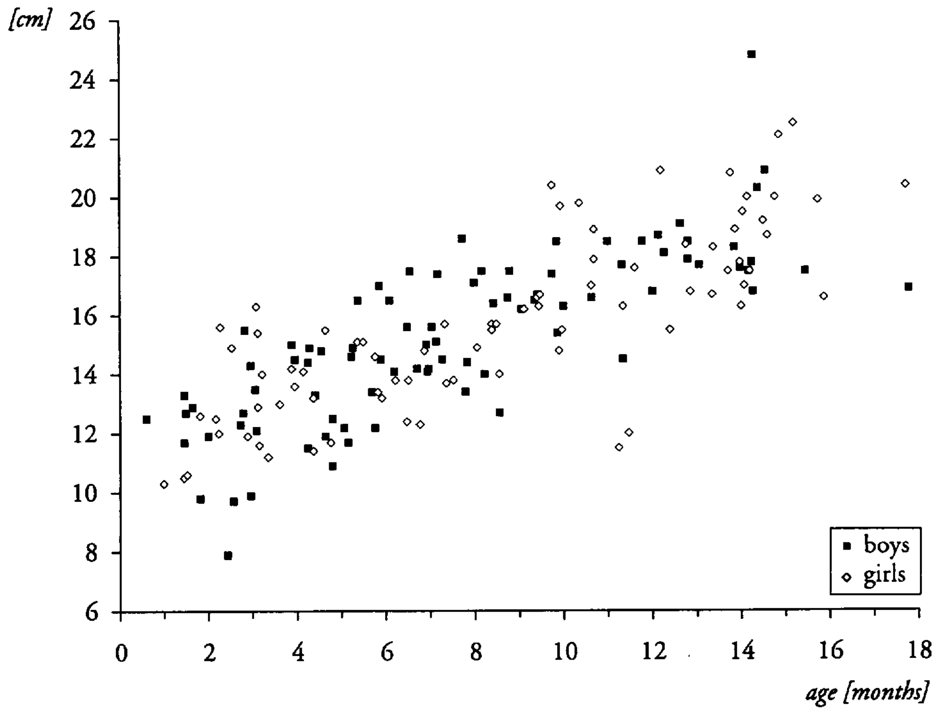
method: The child lies on its back with 90° right hip flexion and 90° right knee flexion.



device: Anthropometer

results:

age	boys					girls					boys + girls	
[months]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	2.0	7.9	11.9	15.5	9	1.9	10.3	12.3	15.6	1.9	12.1
3.0 - 5.9	21	1.7	10.9	13.6	17.0	20	1.5	11.2	13.7	16.3	1.6	13.6
6.0 - 8.9	22	1.6	12.7	15.5	18.6	14	1.2	12.3	14.3	15.7	1.6	15.1
9.0 - 11.9	13	1.2	14.5	16.9	18.5	16	2.5	11.5	16.7	20.4	2.0	16.8
12.0 - 14.9	15	2.0	16.8	18.9	24.8	23	1.7	15.5	18.5	22.1	1.9	18.7
15.0 - 17.9	2	0.4	16.9	17.2	17.5	5	2.4	16.6	19.9	22.5	2.3	19.0

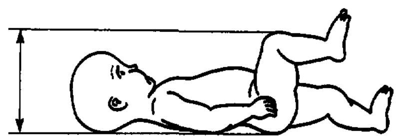


A-8 Buttock-knee length [cm]

definition: Distance from the horizontal surface of the table to the anterior surface of the right knee.

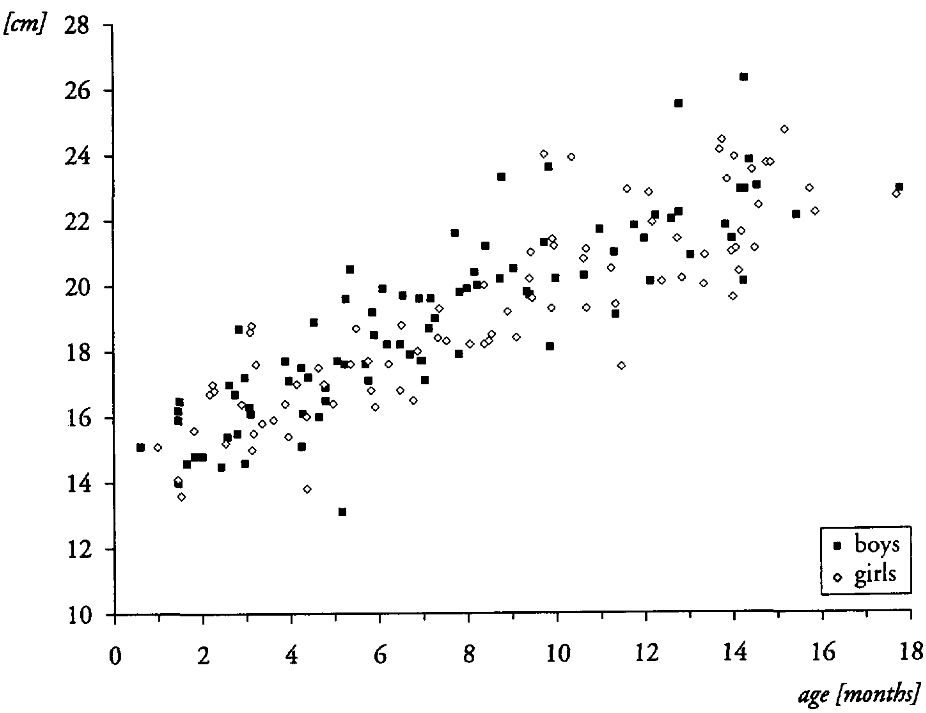
method: The child lies on its back with 90° right hip flexion and 90° right knee flexion.

device: Anthropometer



results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	1.3	14.0	15.7	18.7	9	1.2	13.6	15.6	17.0	1.2	15.7
3.0 - 5.9	21	1.6	13.1	17.3	20.5	20	1.3	13.8	16.7	18.8	1.5	17.0
6.0 - 8.9	22	1.5	17.1	19.4	23.3	14	0.9	16.5	18.3	20.0	1.4	19.0
9.0 - 11.9	13	1.4	18.1	20.7	23.6	16	1.8	17.5	20.7	24.0	1.6	20.7
12.0 - 14.9	15	1.8	20.1	22.5	26.3	23	1.5	19.6	22.0	24.4	1.6	22.2
15.0 - 17.9	2	0.6	22.1	22.5	22.9	5	1.1	22.2	23.1	24.7	0.9	22.9

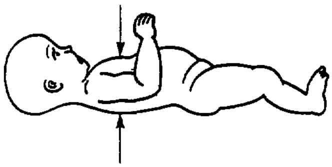


A-9 Breast depth [cm]

definition: Vertical distance between the horizontal surface of the table and the breast at the nipples.

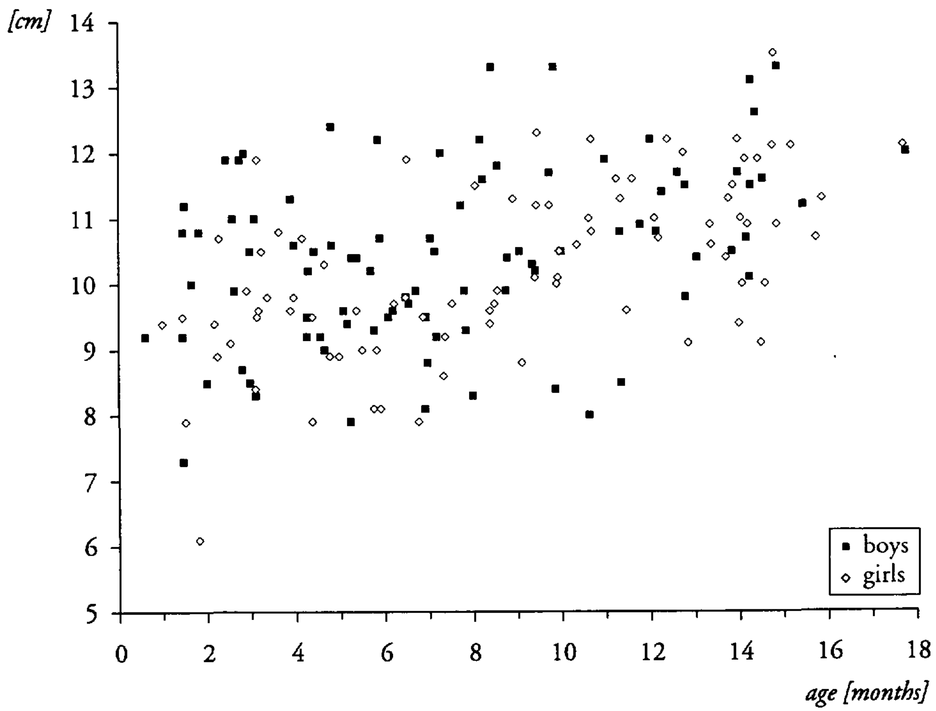
method: The child lies on its back.

device: Anthropometer.



results:

age [months]	boys					girls					boys + girls	
	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	1.4	7.3	10.1	12.0	9	1.3	6.1	9.0	10.7	1.5	9.7
3.0 - 5.9	21	1.1	7.9	10.1	12.4	20	1.0	7.9	9.5	11.9	1.1	9.8
6.0 - 8.9	22	1.3	8.1	10.2	13.3	14	1.1	7.9	9.8	11.9	1.2	10.1
9.0 - 11.9	13	1.6	8.0	10.6	13.3	16	0.9	8.8	10.8	12.3	1.2	10.7
12.0 - 14.9	15	1.0	9.8	11.4	13.3	23	1.1	9.1	11.0	13.5	1.1	11.2
15.0 - 17.9	2	0.6	11.2	11.6	12.0	5	0.7	10.7	11.6	12.1	0.6	11.6

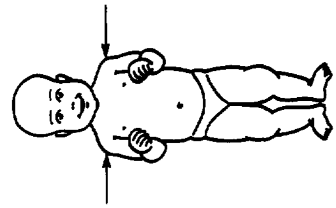


A-10 Shoulder breadth [cm]

definition: The distance across the shoulders.

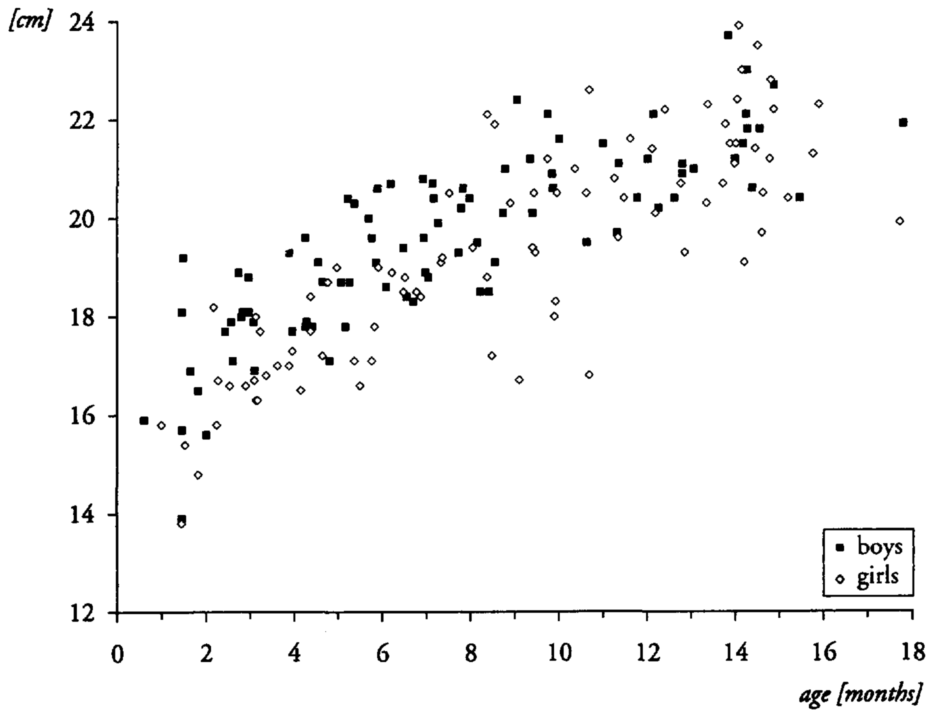
method: The child lies on its back with the upper arms against the body.

device: Anthropometer



results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	1.4	13.9	17.3	19.2	9	1.3	13.8	16.0	18.2	1.5	16.8
3.0 - 5.9	21	1.1	16.9	18.7	20.6	20	0.9	16.3	17.4	19.0	1.2	18.1
6.0 - 8.9	22	0.9	18.3	19.6	21.0	14	1.4	17.2	19.4	22.1	1.1	19.5
9.0 - 11.9	13	0.9	19.5	20.9	22.4	16	1.7	16.7	19.8	22.6	1.5	20.3
12.0 - 14.9	15	1.0	20.2	21.6	23.7	23	1.3	19.1	21.4	23.9	1.2	21.5
15.0 - 17.9	2	1.1	20.4	21.2	21.9	5	1.1	19.9	21.0	22.3	1.0	21.0

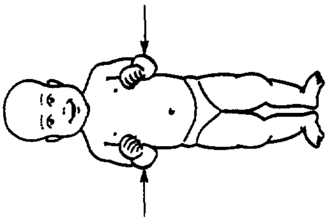


A-11 Breadth across the elbows [cm]

definition: Maximum distance between the lateral sides of the elbow.

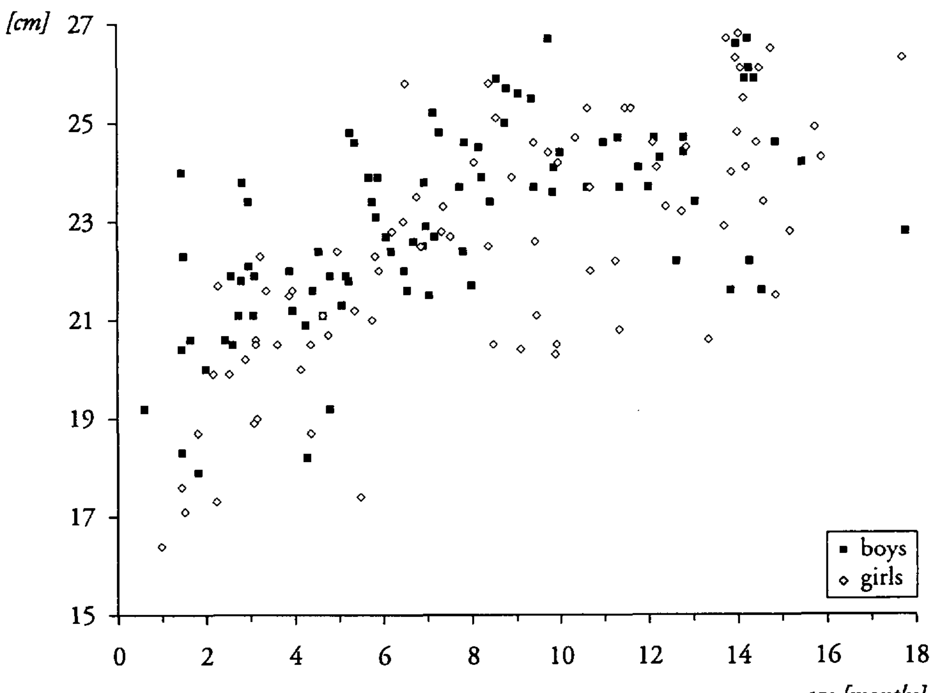
method: The child lies on its back the upper arms against the body. The elbows flexed 90°.

device: Anthropometer.



results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	1.8	17.9	21.1	24.0	9	1.8	16.4	18.8	21.7	2.1	20.3
3.0 - 5.9	21	1.6	18.2	22.0	24.8	20	1.3	17.4	20.7	22.4	1.6	21.3
6.0 - 8.9	22	1.4	21.5	23.4	25.9	14	1.4	20.5	23.5	25.8	1.4	23.4
9.0 - 11.9	13	0.9	23.6	24.5	26.7	16	1.9	20.3	23.0	25.3	1.7	23.6
12.0 - 14.9	15	1.8	21.6	24.3	26.7	23	1.7	20.6	24.5	26.8	1.7	24.4
15.0 - 17.9	2	1.0	22.8	23.5	24.2	5	1.5	22.8	24.6	26.3	1.3	24.2

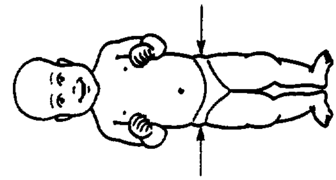


A-12 Hip breadth [cm]

definition: Maximum breadth across the hips.

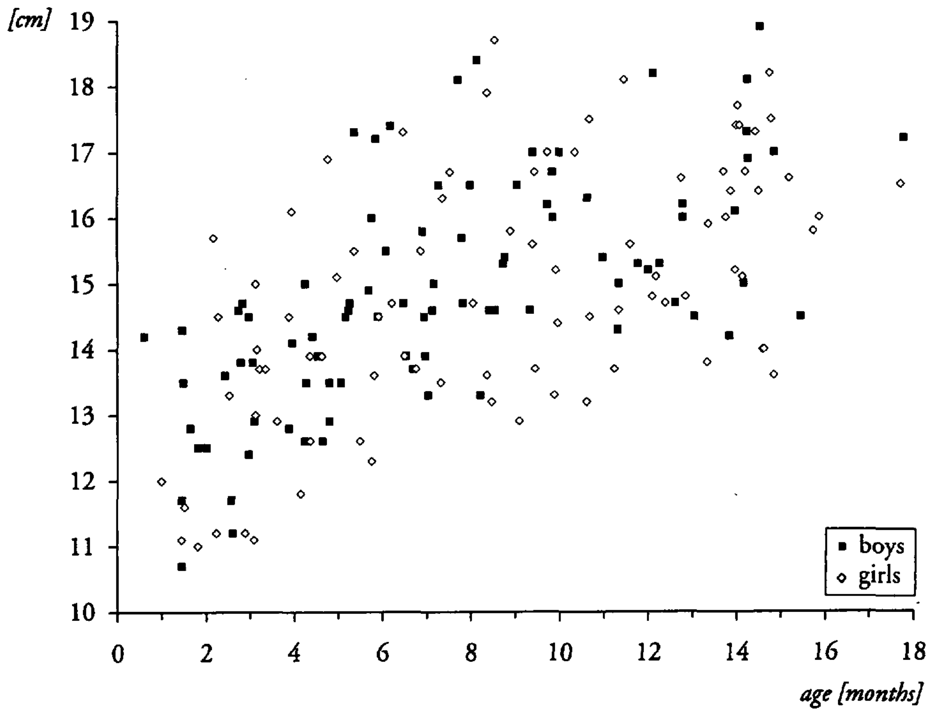
method: The child lies on its back, the legs fully extended.

device: Anthropometer



results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	1.3	10.7	13.0	14.7	9	1.7	11.0	12.4	15.7	1.5	12.8
3.0 - 5.9	21	1.3	12.6	14.2	17.3	20	1.4	11.1	13.8	16.9	1.4	14.0
6.0 - 8.9	22	1.4	13.3	15.2	18.4	14	1.8	13.2	15.4	18.7	1.5	15.3
9.0 - 11.9	13	0.9	14.3	15.8	17.0	16	1.7	12.9	15.2	18.1	1.4	15.5
12.0 - 14.9	15	1.5	14.2	16.3	18.9	23	1.4	13.6	15.9	18.2	1.4	16.0
15.0 - 17.9	2	1.9	14.5	15.9	17.2	5	0.4	15.8	16.2	16.6	0.9	16.1

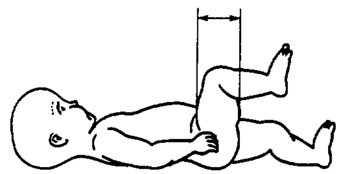


A-13 Thigh thickness [cm]

definition: Distance between front and back of the right thigh midway between hip and knee joint.

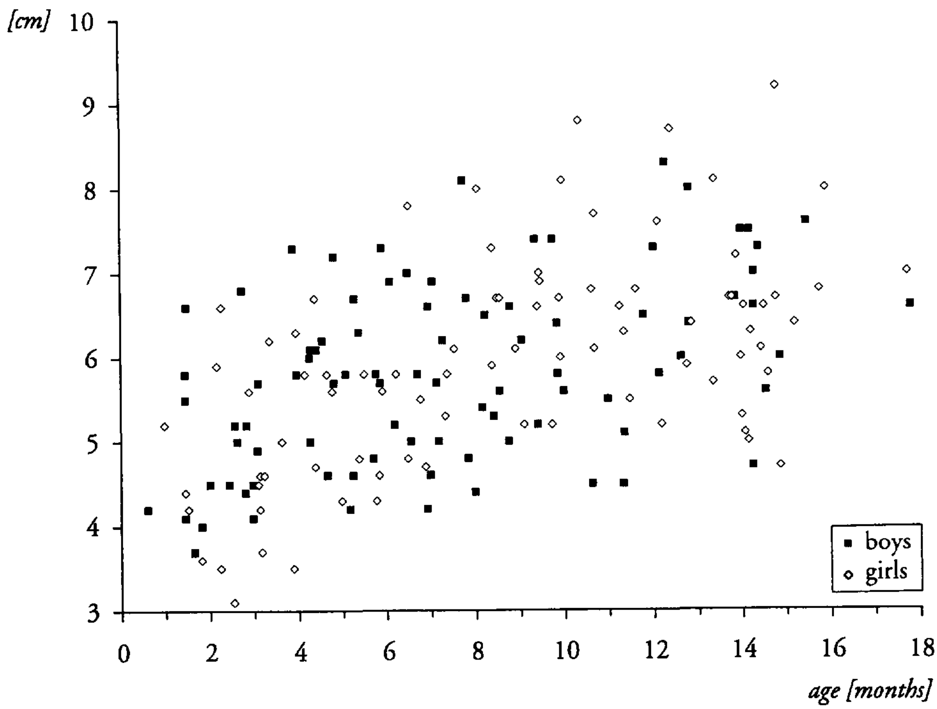
method: The child lies on its back with 90° right hip flexion and 90° right knee flexion.

device: Anthropometer.



results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	0.9	3.7	4.9	6.8	9	1.2	3.1	4.7	6.6	1.0	4.8
3.0 - 5.9	21	0.9	4.2	5.8	7.3	20	0.9	3.5	5.0	6.7	1.0	5.4
6.0 - 8.9	22	1.0	4.2	5.8	8.1	14	1.0	4.7	6.2	8.0	1.0	5.9
9.0 - 11.9	13	1.0	4.5	6.0	7.4	16	1.0	5.2	6.6	8.8	1.0	6.3
12.0 - 14.9	15	1.0	4.7	6.7	8.3	23	1.2	4.7	6.4	9.2	1.1	6.5
15.0 - 17.9	2	0.7	6.6	7.1	7.6	5	0.7	6.4	7.1	8.0	0.6	7.1

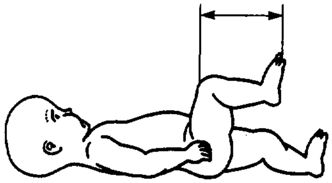


A-14 Knee-foot length [cm]

definition: Horizontal distance from the superior surface of the right knee to the heel of the right foot.

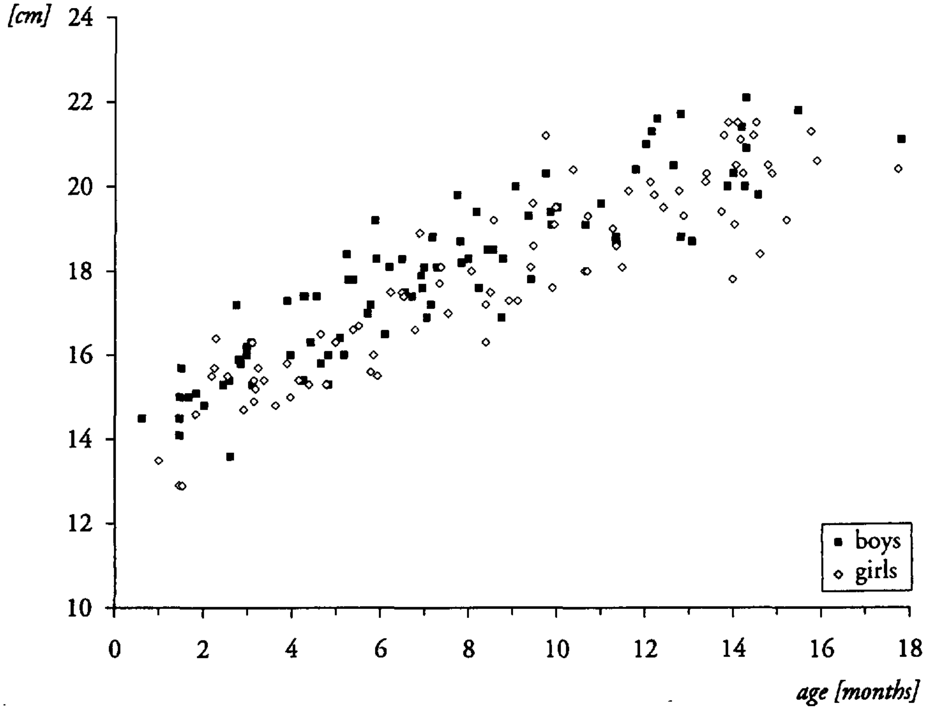
method: The child lies on its back with 90° right knee flexion and 90° right foot flexion.

device: Anthropometer



results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	0.9	13.6	15.3	17.2	9	1.3	12.9	14.6	16.4	1.1	15.0
3.0 - 5.9	21	1.1	15.3	16.9	19.2	20	0.6	14.8	15.7	16.7	1.1	16.3
6.0 - 8.9	22	0.8	16.5	18.0	19.8	14	0.8	16.3	17.6	19.2	0.8	17.9
9.0 - 11.9	13	0.8	17.8	19.5	21.0	16	1.1	17.3	18.9	21.2	1.0	19.1
12.0 - 14.9	15	1.1	18.7	20.5	22.1	23	1.0	17.8	20.2	21.5	1.0	20.3
15.0 - 17.9	2	0.5	21.1	21.5	21.8	5	0.9	19.2	20.4	21.3	0.9	20.7

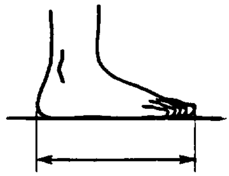


A-15 Foot length [cm]

definition: Distance from the heel to the longest toe of the right foot parallel to the long axis of the foot.

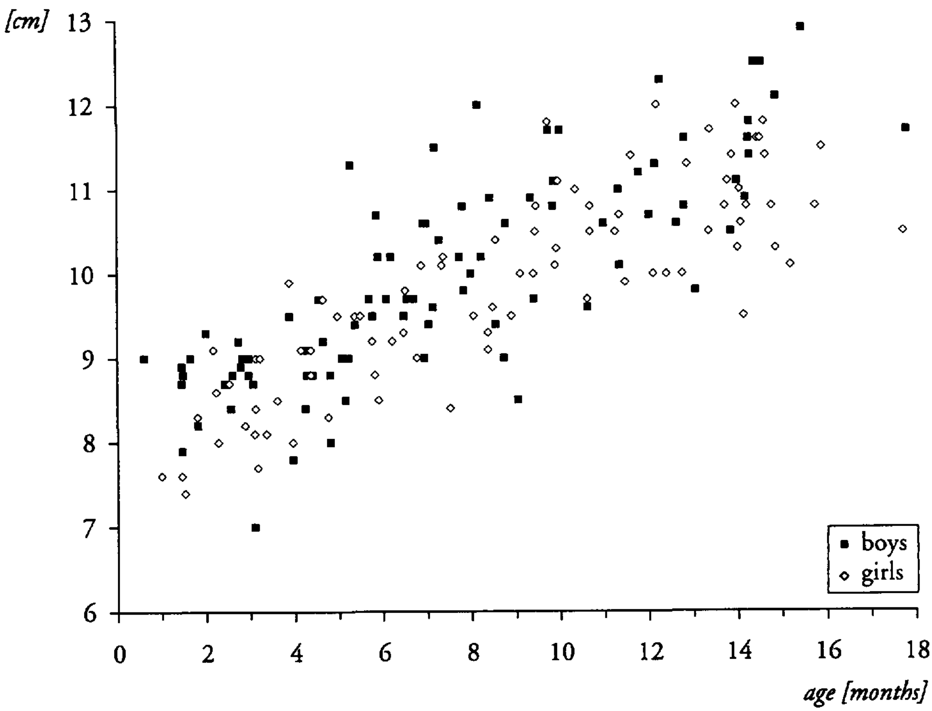
method: The child lies on its back. The foot is flexed 90° and the toes are extended.

device: Anthropometer.



results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	0.4	7.9	8.8	9.3	9	0.6	7.4	8.2	9.1	0.5	8.6
3.0 - 5.9	21	1.0	7.0	9.1	11.3	20	0.6	7.7	8.8	9.9	0.8	9.0
6.0 - 8.9	22	0.8	9.0	10.1	12.0	14	0.5	8.4	9.5	10.4	0.7	9.9
9.0 - 11.9	13	0.9	8.5	10.6	11.7	16	0.6	9.7	10.6	11.8	0.7	10.6
12.0 - 14.9	15	0.8	9.8	11.4	12.5	23	0.7	9.5	10.9	12.0	0.8	11.1
15.0 - 17.9	2	0.8	11.7	12.3	12.9	5	0.6	10.1	10.7	11.5	1.0	11.3

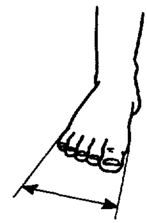


A-16 Foot breadth [cm]

definition: Maximum breadth across the ball of the right foot.

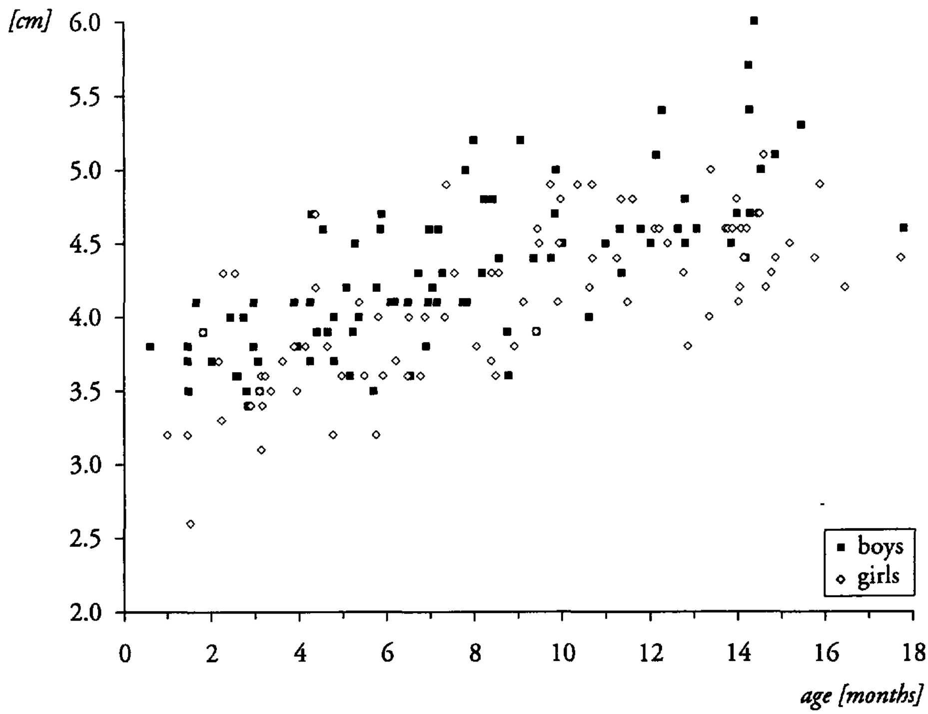
method: The child lies on its back. The foot is 90° flexed and the toes are extended.

device: Anthropometer.



results:

age			boys					girls			boys + girls	
[months]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	0.2	3.4	3.8	4.1	9	0.6	2.6	3.5	4.3	0.4	3.7
3.0 - 5.9	21	0.4	3.5	4.0	4.7	20	0.4	3.1	3.7	4.7	0.4	3.9
6.0 - 8.9	22	0.4	3.6	4.3	5.2	14	0.4	3.6	4.0	4.9	0.4	4.2
9.0 - 11.9	13	0.3	3.9	4.5	5.2	16	0.3	3.9	4.5	4.9	0.3	4.5
12.0 - 14.9	15	0.5	4.4	5.0	6.0	23	0.3	3.8	4.5	5.1	0.5	4.7
15.0 - 17.9	2	0.5	4.6	4.9	5.3	5	0.3	4.2	4.5	4.9	0.4	4.6

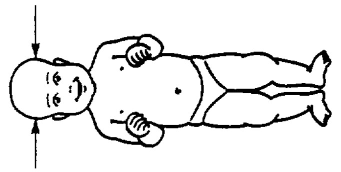


A-17 Head breadth [cm]

definition: Maximum breadth of the head just above the ears.

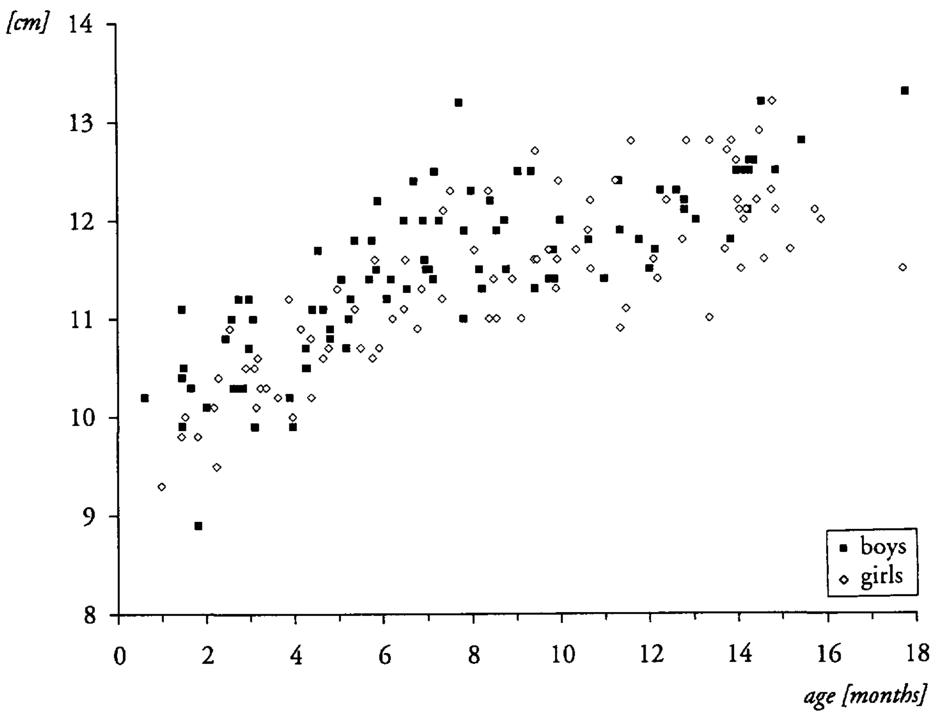
method: The child lies on its back.

device: Anthropometer.



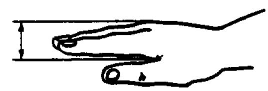
results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	0.6	8.9	10.5	11.2	9	0.5	9.3	10.0	10.9	0.6	10.3
3.0 - 5.9	21	0.6	9.9	11.0	12.2	20	0.4	10.0	10.6	11.6	0.6	10.8
6.0 - 8.9	22	0.5	11.0	11.8	13.2	14	0.5	10.9	11.5	12.3	0.5	11.7
9.0 - 11.9	13	0.4	11.3	11.8	12.5	16	0.6	10.9	11.8	12.8	0.5	11.8
12.0 - 14.9	15	0.4	11.7	12.3	13.2	23	0.6	11.0	12.2	13.2	0.5	12.2
15.0 - 17.9	2	0.4	12.8	13.1	13.3	5	0.3	11.5	11.8	12.1	0.7	12.2



A-18 Hand thickness [cm]

definition: Maximum distance between the palm and the back of the hand at the middle finger joint.

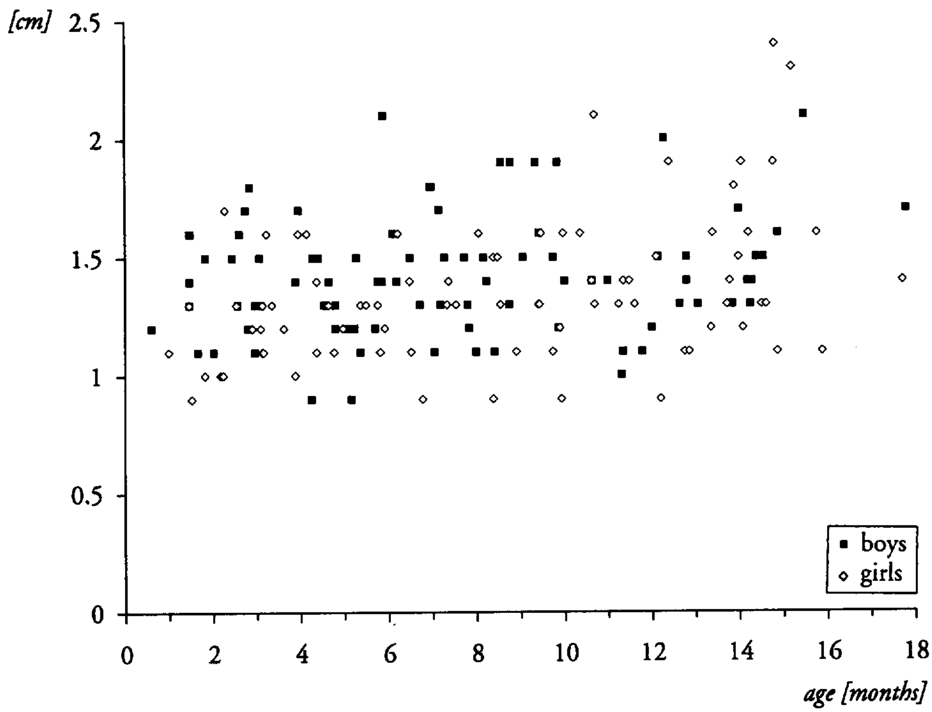


method: The right hand and fingers are fully extended.

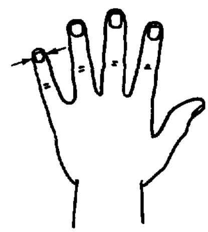
device: Sliding calliper.

results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	0.2	1.1	1.4	1.8	9	0.2	0.9	1.2	1.7	0.3	1.3
3.0 - 5.9	21	0.3	0.9	1.4	2.1	20	0.2	1.0	1.3	1.6	0.2	1.3
6.0 - 8.9	22	0.3	1.1	1.5	1.9	14	0.2	0.9	1.3	1.6	0.3	1.4
9.0 - 11.9	13	0.3	1.0	1.4	1.9	16	0.3	0.9	1.4	2.1	0.3	1.4
12.0 - 14.9	15	0.2	1.3	1.5	2.0	23	0.4	0.9	1.5	2.4	0.3	1.5
15.0 - 17.9	2	0.3	1.7	1.9	2.1	5	0.5	1.1	1.6	2.3	0.4	1.7



A-19 Little finger breadth [cm]



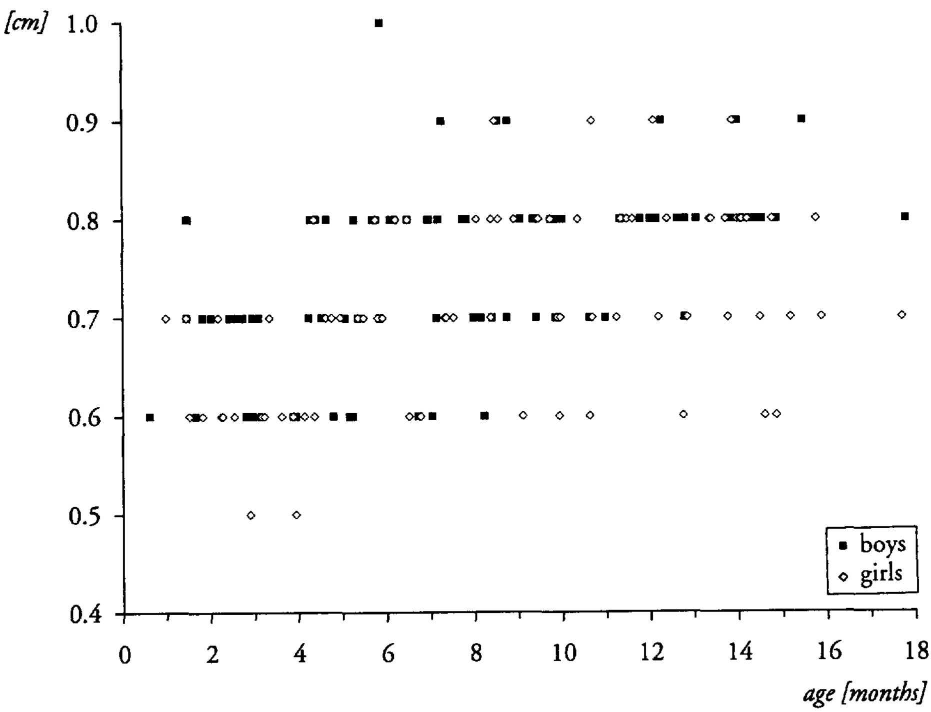
definition: Maximum distance from the radial to the ulnar side of the little finger at the distal interphalangial joint.

method: The right hand and fingers are extended and the fingers spread.

device: Sliding calliper.

results:

age	boys					girls					boys + girls	
[months]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	0.1	0.6	0.7	0.8	9	0.1	0.5	0.6	0.7	0.1	0.7
3.0 - 5.9	21	0.1	0.6	0.7	1.0	20	0.1	0.5	0.7	0.8	0.1	0.7
6.0 - 8.9	22	0.1	0.6	0.8	0.9	14	0.1	0.6	0.7	0.9	0.1	0.8
9.0 - 11.9	13	0.0	0.7	0.8	0.8	16	0.1	0.6	0.7	0.9	0.1	0.8
12.0 - 14.9	15	0.0	0.7	0.8	0.9	23	0.1	0.6	0.8	0.9	0.1	0.8
15.0 - 17.9	2	0.1	0.8	0.9	0.9	5	0.1	0.7	0.7	0.8	0.1	0.8

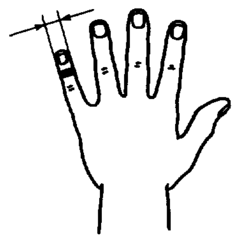


A-20 Little finger diameter [cm]

definition: Maximum diameter of the little finger at the distal interphalangial joint.

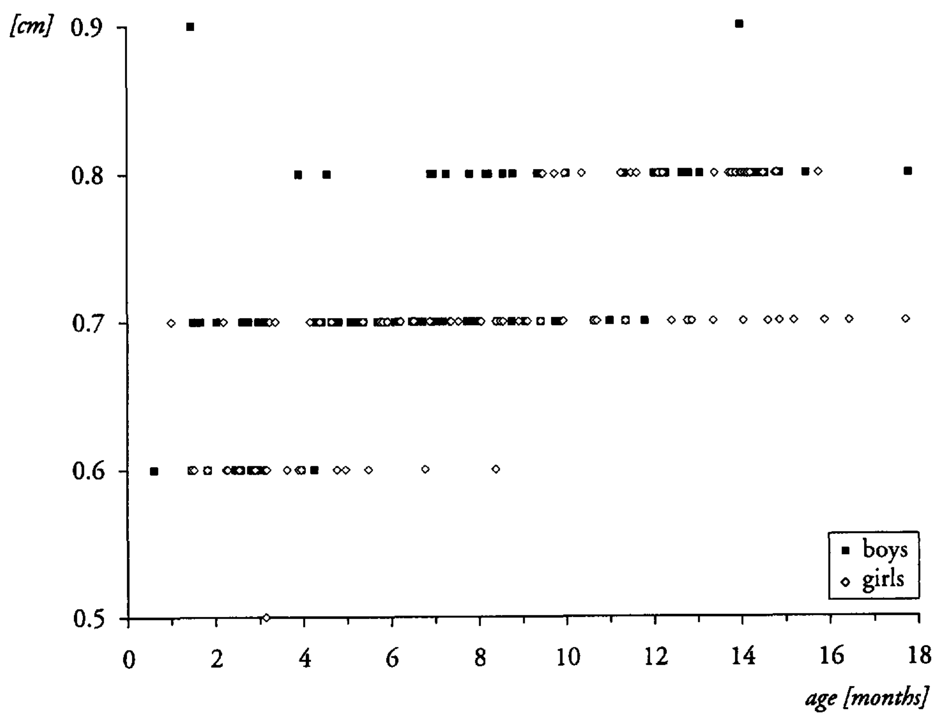
method: The diameter through which the distal joint of the extended little finger of the right hand just can pass is recorded.

device: Finger measuring board with holes of different diameter.



results:

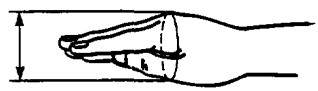
age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	0.1	0.6	0.7	0.9	9	0.0	0.6	0.6	0.7	0.1	0.6
3.0 - 5.9	21	0.0	0.6	0.7	0.8	20	0.1	0.5	0.6	0.7	0.1	0.7
6.0 - 8.9	22	0.0	0.7	0.7	0.8	14	0.0	0.6	0.7	0.7	0.1	0.7
9.0 - 11.9	13	0.0	0.7	0.7	0.8	16	0.1	0.7	0.8	0.8	0.1	0.7
12.0 - 14.9	15	0.0	0.7	0.8	0.9	23	0.0	0.7	0.8	0.8	0.0	0.8
15.0 - 17.9	2	0.0	0.8	0.8	0.8	5	0.0	0.7	0.7	0.8	0.1	0.7



A-21 Hand diameter [cm]

definition: Minimum diameter of the hand, when in its smallest configuration.

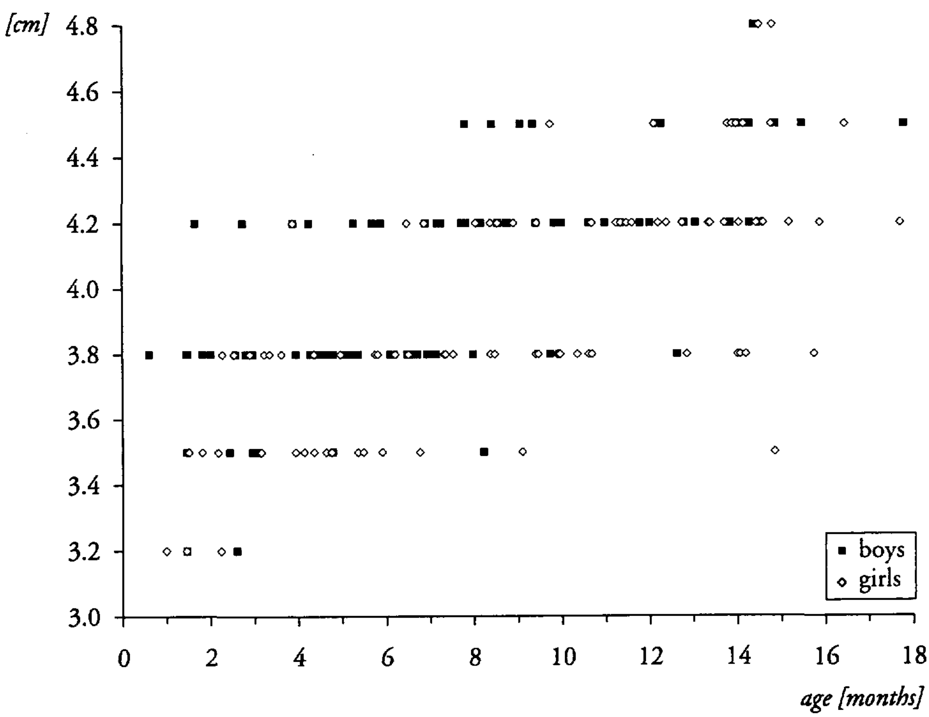
method: The extended right hand is reduced to its narrowest configuration. The smallest diameter through which the measurer can pull the child's right hand –without forcing it– is recorded.



device: Measuring board with holes of different diameters.

results:

age	boys					girls					boys + girls	
[months]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	0.3	3.2	3.7	4.2	9	0.3	3.2	3.5	3.8	0.3	3.6
3.0 - 5.9	21	0.3	3.5	3.9	4.2	20	0.2	3.5	3.6	4.2	0.3	3.8
6.0 - 8.9	22	0.3	3.5	4.0	4.5	14	0.2	3.5	4.0	4.2	0.3	4.0
9.0 - 11.9	13	0.2	3.8	4.2	4.5	16	0.3	3.5	4.0	4.5	0.3	4.1
12.0 - 14.9	15	0.2	3.8	4.4	4.8	23	0.3	3.5	4.2	4.8	0.3	4.3
15.0 - 17.9	2	0.2	4.5	4.5	4.5	5	0.2	3.8	4.2	4.5	0.3	4.3

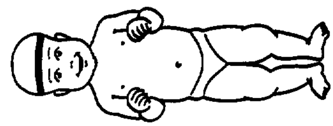


A-22 Head circumference [cm]

definition: Maximum about horizontal circumference of the head measured just above the glabella and over the opisthocranion.

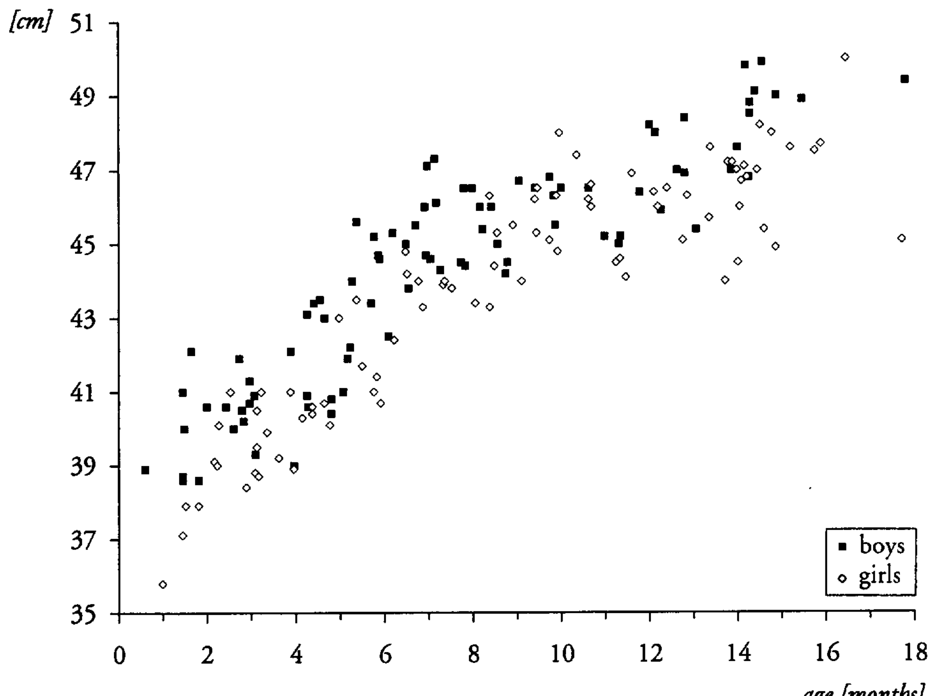
method: The child's head is supported away from the table.

device: Measuring tape.



results:

age [months]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
0.0 - 2.9	16	1.1	38.6	40.2	42.1	9	1.6	35.8	38.5	41.0	1.5	39.6
3.0 - 5.9	21	1.9	39.0	42.4	45.6	20	1.3	38.7	40.5	43.5	1.8	41.5
6.0 - 8.9	22	1.1	42.5	45.2	47.3	14	1.0	42.4	44.2	46.3	1.2	44.8
9.0 - 11.9	13	0.9	45.0	46.2	48.2	16	1.2	44.0	45.8	48.0	1.1	46.0
12.0 - 14.9	15	1.4	45.4	47.9	49.9	23	1.1	44.0	46.4	48.2	1.4	47.0
15.0 - 17.9	2	0.4	48.9	49.2	49.4	5	1.7	45.1	47.6	50.0	1.6	48.0



A-23 Upper arm circumference [cm]

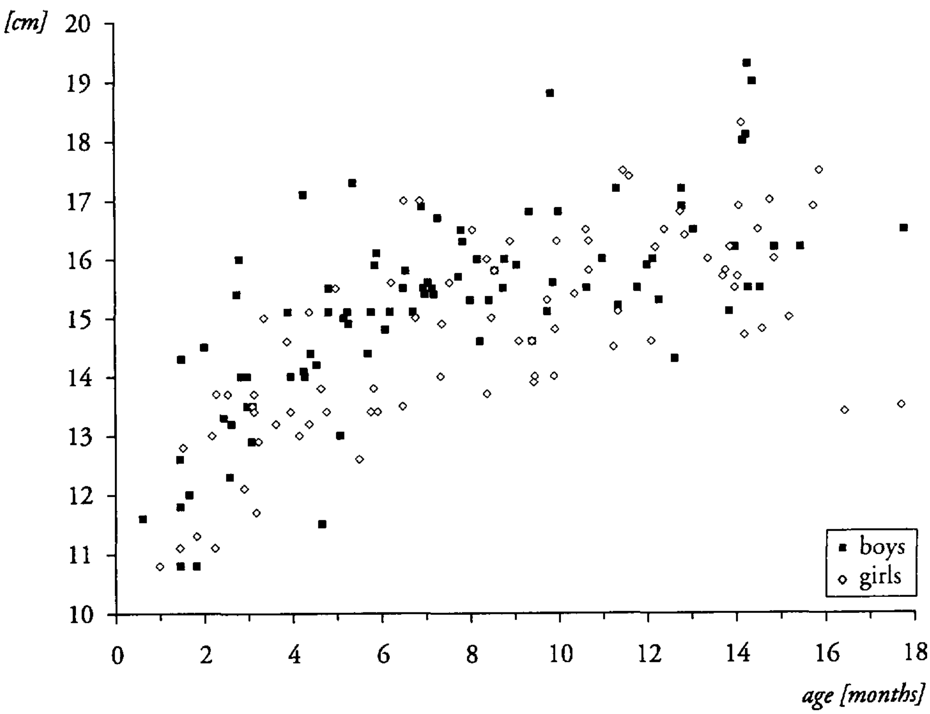
definition: Maximum circumference of the upper arm perpendicular to the long axis of the body, midway between shoulder and elbow.

method: The child's right arm is extended.

device: Measuring tape.

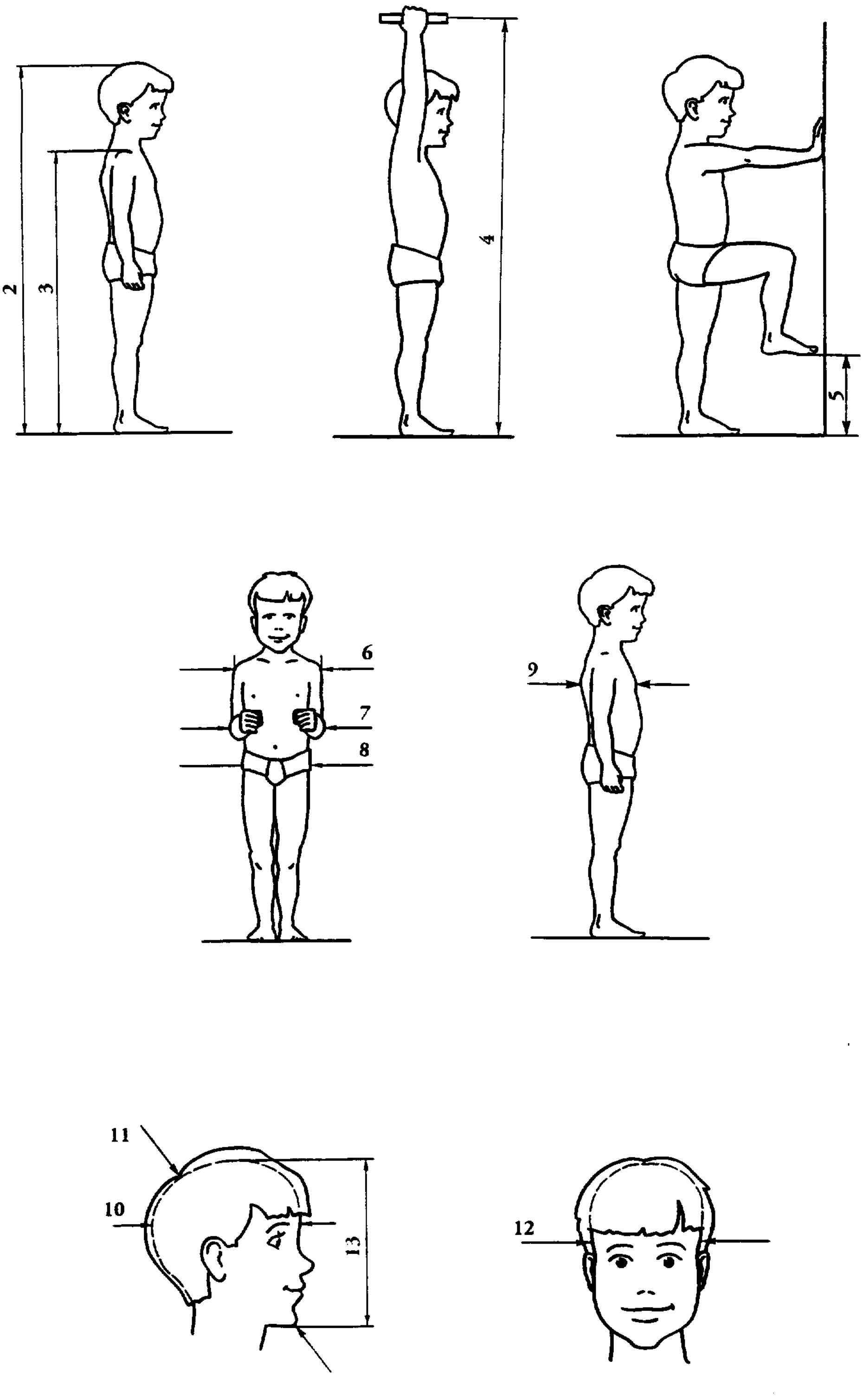
results:

age	boys					girls					boys + girls	
[months]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
0.0 - 2.9	16	1.5	10.8	13.1	16.0	9	1.2	10.8	12.2	13.7	1.5	12.8
3.0 - 5.9	21	1.4	11.5	14.7	17.3	20	0.9	11.7	13.6	15.5	1.3	14.2
6.0 - 8.9	22	0.6	14.6	15.7	16.9	14	1.1	13.5	15.4	17.0	0.8	15.6
9.0 - 11.9	13	1.1	14.6	16.1	18.8	16	1.2	13.9	15.4	17.5	1.2	15.7
12.0 - 14.9	15	1.5	14.3	16.6	19.3	23	0.9	14.6	16.1	18.3	1.2	16.3
15.0 - 17.9	2	0.2	16.2	16.4	16.5	5	1.9	13.4	15.3	17.5	1.6	15.6



B Results of the present project (children between 2 and 13 years of age)

All measurements are taken in millimetres, except body mass, which is measured in hectograms. The measurements are taken on the right side of the body, unless otherwise indicated.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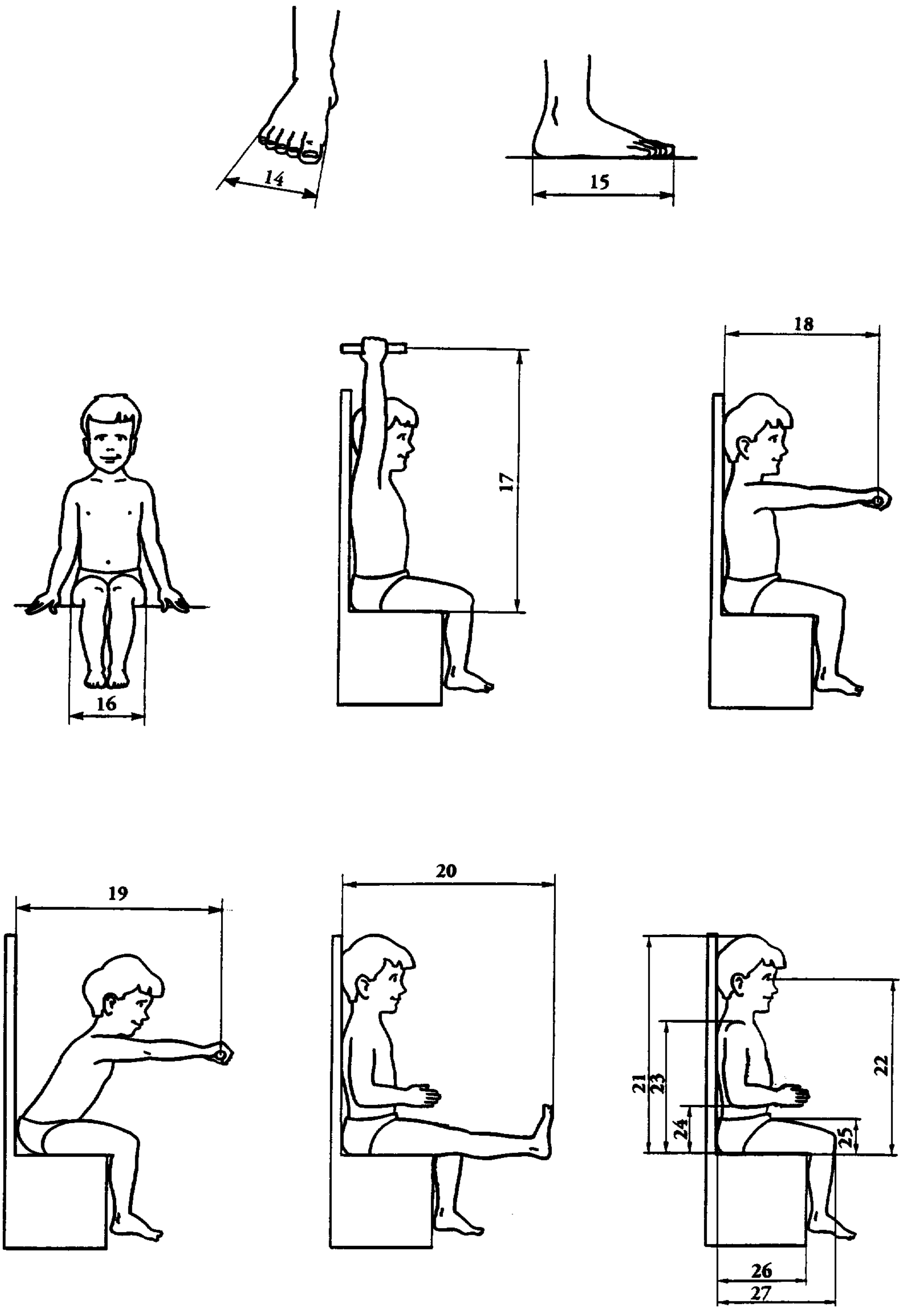
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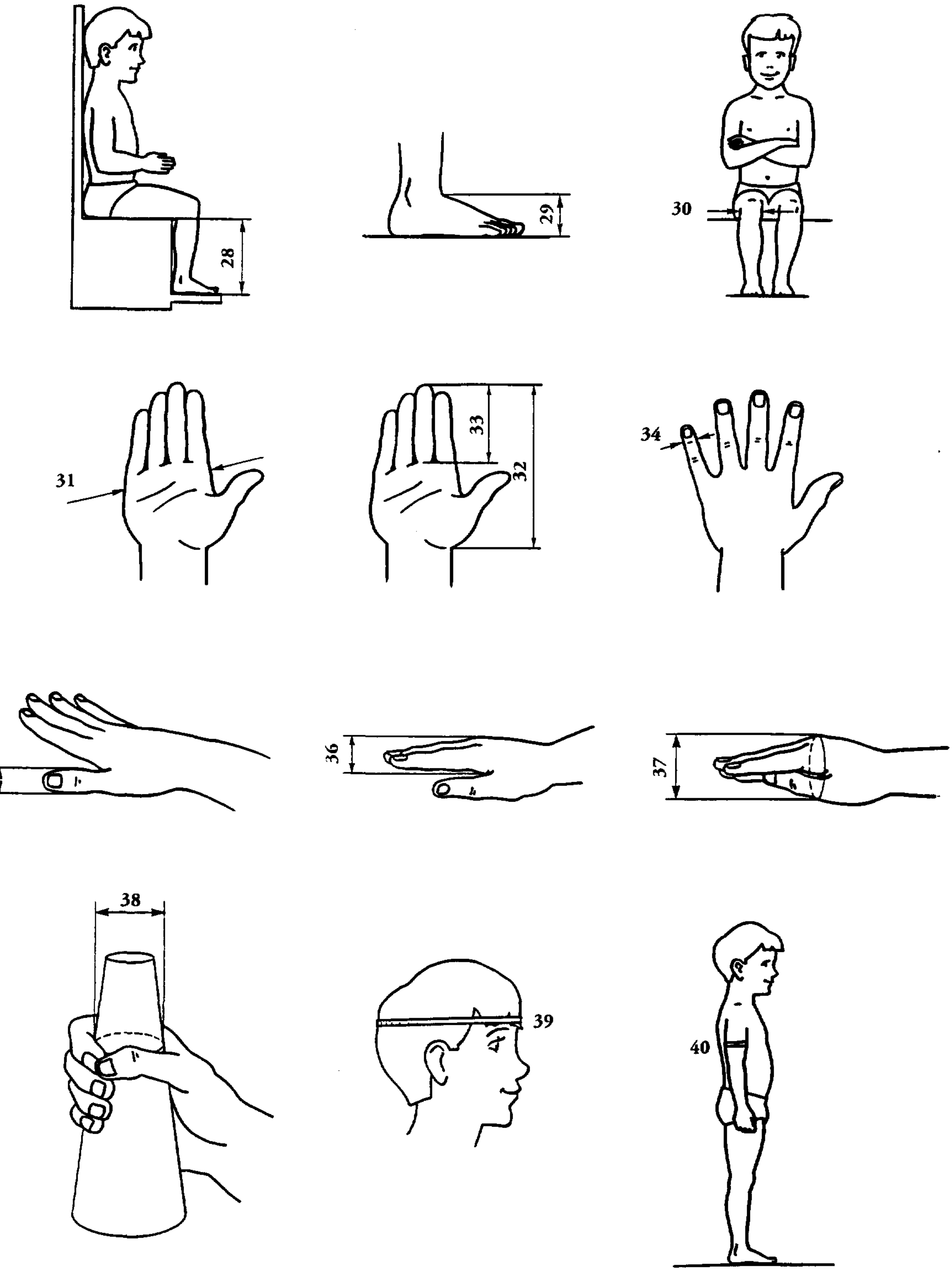
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B-1 Body mass [kg]

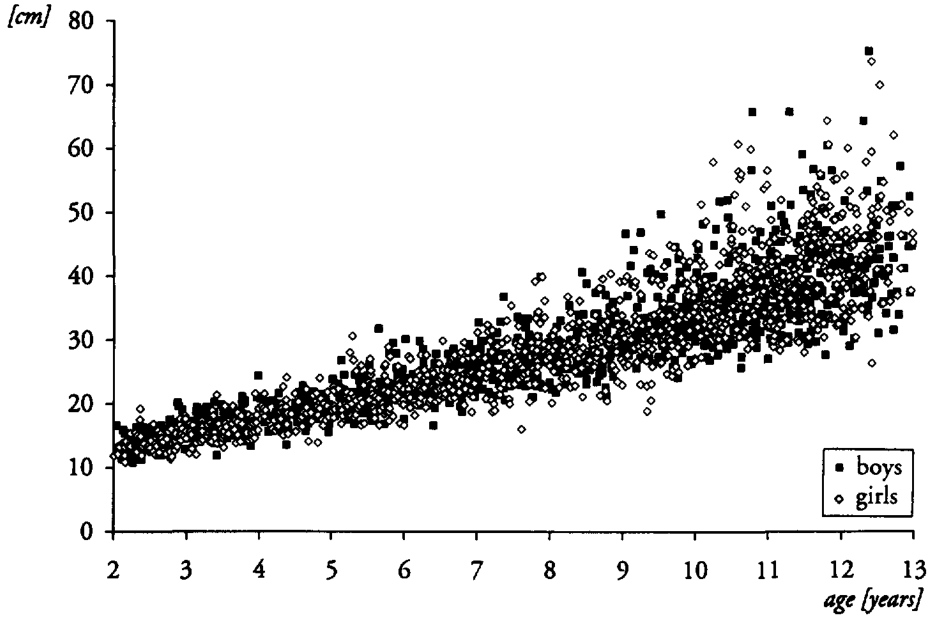
definition: Total mass of the body.

method: The child stands on a scale.

device: Scale.

results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	1.9	11.3	14.5	19.0	92	1.6	11.7	14.1	17.6	1.8	14.3
3.0– 3.9	97	2.0	13.8	17.0	21.0	86	1.8	12.9	16.0	19.6	2.0	16.5
4.0– 4.9	85	2.0	15.5	18.6	21.8	79	2.1	15.0	18.4	22.7	2.1	18.5
5.0– 5.9	86	2.8	17.3	21.6	28.0	94	3.0	16.6	21.0	28.0	3.0	21.3
6.0– 6.9	98	2.5	19.4	23.5	29.3	92	2.6	19.4	23.6	29.6	2.6	23.5
7.0– 7.9	106	3.6	20.9	26.4	33.7	93	4.3	19.0	26.9	36.2	3.9	26.6
8.0– 8.9	96	4.1	22.3	28.9	38.0	95	4.1	21.2	29.2	39.2	4.1	29.1
9.0– 9.9	122	4.9	26.3	32.9	44.6	122	5.2	23.1	32.1	43.6	5.1	32.5
10.0–10.9	134	6.1	27.3	36.4	51.7	136	7.0	30.2	38.6	56.4	6.7	37.5
11.0–11.9	143	7.1	29.7	40.0	56.5	151	7.1	29.6	40.6	55.0	7.1	40.3
12.0–12.9	78	7.4	31.0	42.5	57.1	79	8.6	33.0	44.4	62.0	8.0	43.4

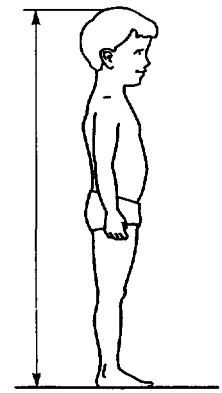


B-2 Stature [cm]

definition: The vertical distance from the floor to the top of the head (vertex).

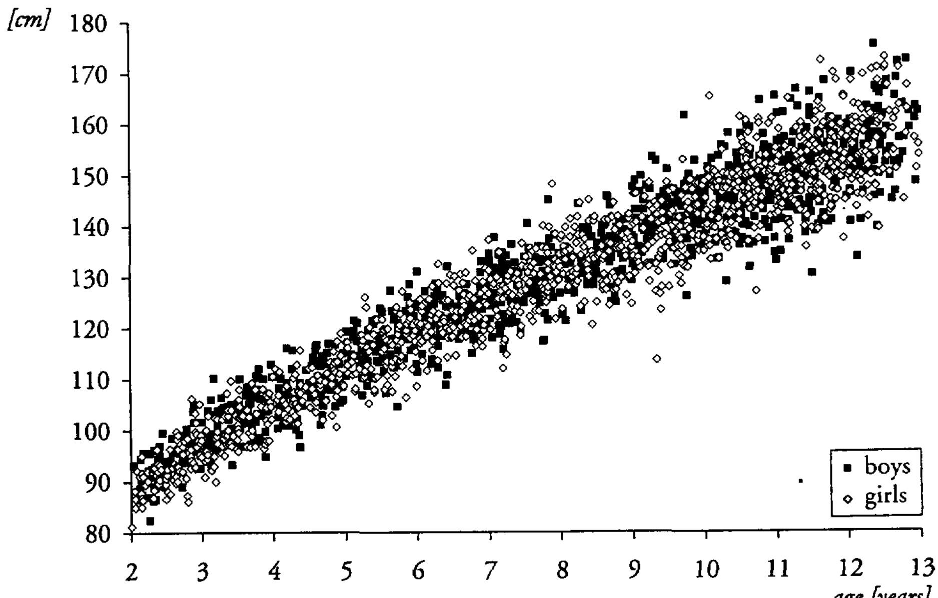
method: The child stands erect, feet together, the head oriented in the Frankfort Plane.

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0 – 2.9	81	4.5	86.5	93.9	101.8	92	4.6	85.0	92.9	103.4	4.6	93.3
3.0 – 3.9	97	4.4	94.8	102.1	110.7	86	4.5	92.2	100.4	109.2	4.5	101.3
4.0 – 4.9	85	4.7	100.2	108.5	116.7	79	4.0	101.8	108.2	115.6	4.3	108.4
5.0 – 5.9	86	4.8	107.4	117.0	126.1	94	4.9	107.5	115.9	125.0	4.9	116.4
6.0 – 6.9	98	4.7	111.4	122.5	132.1	92	4.9	113.6	122.7	132.6	4.8	122.6
7.0 – 7.9	106	5.3	118.1	128.7	137.7	93	5.7	117.1	128.6	139.7	5.5	128.7
8.0 – 8.9	96	5.0	123.2	134.0	144.2	95	5.4	124.1	134.1	144.4	5.2	134.0
9.0 – 9.9	122	5.5	132.4	141.8	152.7	122	6.4	127.0	139.2	148.7	6.1	140.5
10.0 – 10.9	134	6.8	133.5	146.0	159.2	136	6.6	135.9	147.1	160.5	6.7	146.6
11.0 – 11.9	143	7.0	138.8	150.9	164.6	151	6.7	139.3	151.0	165.0	6.9	150.9
12.0 – 12.9	78	8.0	140.6	156.3	171.9	79	7.7	143.5	156.6	170.8	7.8	156.4

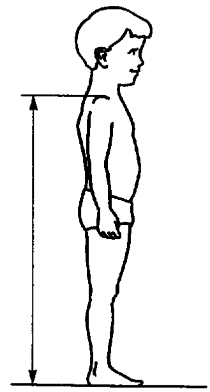


B-3 Shoulder height standing [cm]

definition: The vertical distance from the floor to the acromion.

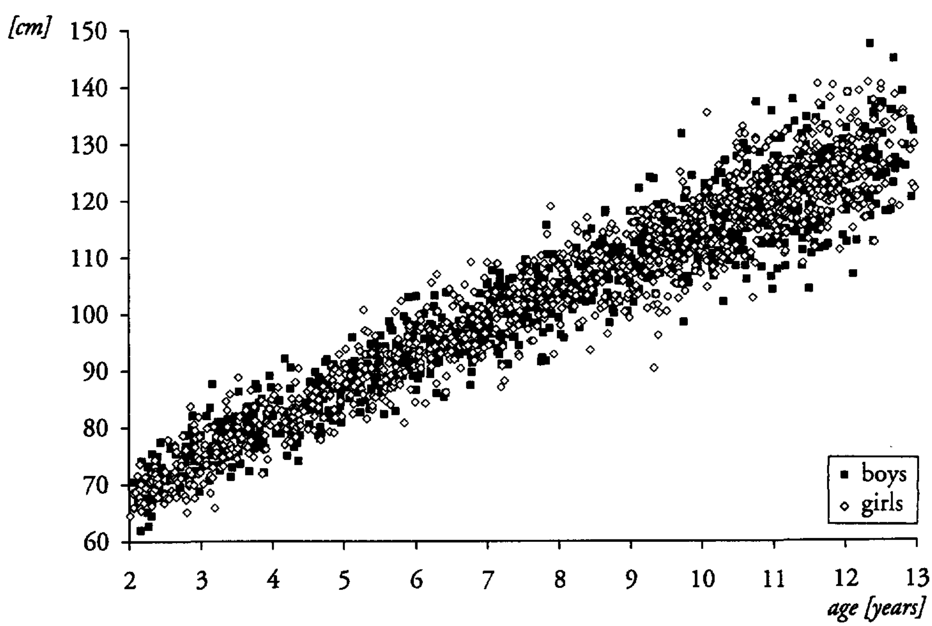
method: The child stands erect, feet together. The shoulders are relaxed and the arms hang down freely.

device: Automated anthropometer.

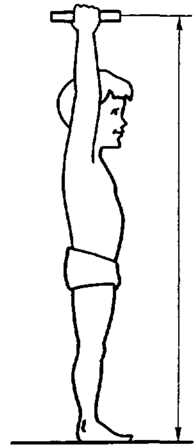


results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0 – 2.9	81	4.0	64.5	71.9	78.8	92	4.0	65.4	71.4	80.5	4.0	71.6
3.0 – 3.9	97	4.0	72.1	79.0	87.7	86	4.1	70.1	77.9	85.9	4.1	78.5
4.0 – 4.9	85	4.1	76.6	83.4	91.5	79	3.8	77.7	83.8	90.7	3.9	83.6
5.0 – 5.9	86	4.2	82.8	91.0	98.7	94	4.4	82.4	90.5	100.4	4.3	90.7
6.0 – 6.9	98	4.1	86.1	95.8	103.6	92	4.8	87.7	96.5	107.0	4.5	96.1
7.0 – 7.9	106	4.7	91.7	101.4	109.6	93	5.2	90.8	102.1	110.3	4.9	101.7
8.0 – 8.9	96	4.3	97.5	106.6	115.0	95	4.9	98.0	106.9	115.7	4.6	106.7
9.0 – 9.9	122	5.0	104.2	113.1	123.9	122	5.9	100.4	111.6	120.4	5.5	112.4
10.0 – 10.9	134	5.9	106.5	117.5	128.8	136	6.1	108.3	118.6	131.0	6.1	118.1
11.0 – 11.9	143	6.4	110.5	121.7	133.7	151	6.1	111.6	122.7	135.7	6.3	122.2
12.0 – 12.9	78	7.4	112.5	126.8	139.0	79	6.6	116.7	127.3	139.3	7.0	127.0



B-4 Reaching height standing [cm]



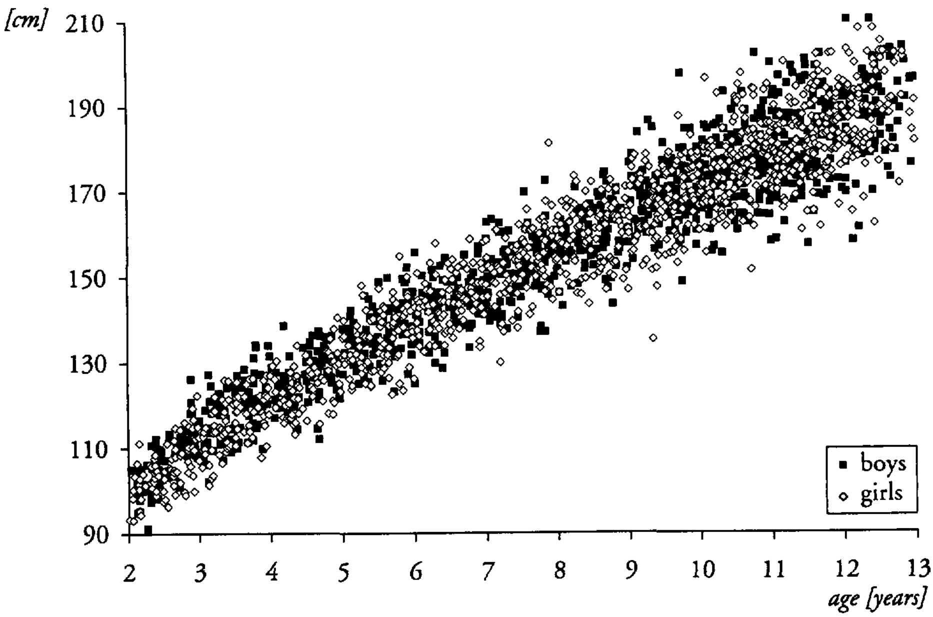
definition: The vertical distance from the floor to the mid-point of the grip device.

method: The child stands erect, feet together. The right arm and shoulder are extended to maximum vertical reach. The grip device remains horizontal and in a sagittal plane.

device: Automated anthropometer.

results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0– 2.9	81	6.5	95.3	106.5	118.3	92	6.1	94.4	105.3	116.7	6.3	105.9
3.0– 3.9	97	6.7	107.1	118.0	133.6	86	6.0	103.6	116.0	126.3	6.4	117.0
4.0– 4.9	85	5.9	114.5	126.2	136.4	79	5.9	115.7	124.8	135.5	5.9	125.5
5.0– 5.9	86	6.5	125.4	137.0	149.6	94	6.8	123.7	135.4	148.0	6.7	136.2
6.0– 6.9	98	6.4	129.7	144.4	156.5	92	6.1	133.7	144.4	158.1	6.2	144.4
7.0– 7.9	106	7.1	138.2	152.0	163.4	93	7.9	137.9	153.1	166.6	7.5	152.5
8.0– 8.9	96	6.6	146.1	159.7	172.1	95	7.3	146.0	159.5	172.2	6.9	159.6
9.0– 9.9	122	7.4	157.3	169.6	184.6	122	8.4	151.9	167.0	179.0	8.0	168.3
10.0–10.9	134	9.0	158.0	175.6	193.1	136	8.9	161.7	176.7	194.0	9.0	176.2
11.0–11.9	143	9.0	167.6	182.1	199.1	151	8.6	165.9	181.9	199.3	8.8	182.0
12.0–12.9	78	10.3	169.4	188.5	203.7	79	9.8	168.1	188.5	205.0	10.0	188.5

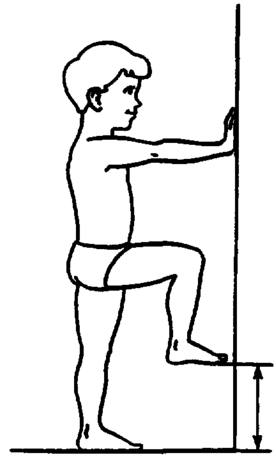


B-5 Step height [cm]

definition: The vertical distance from the floor to the ball of the foot.

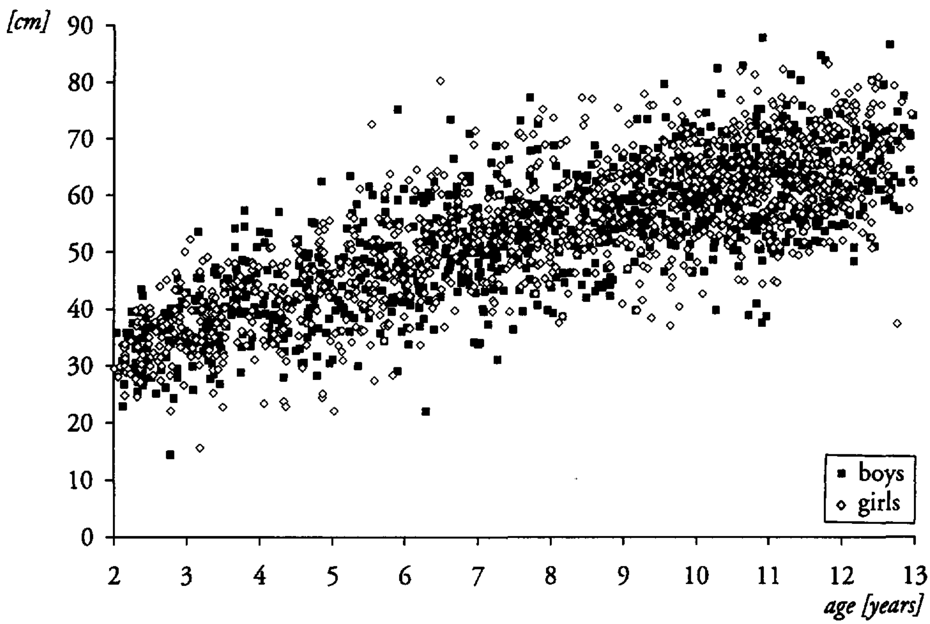
method: The child stands erect facing the wall with palms of the hands resting lightly against the wall at shoulder level for balance. Subject raises right foot to maximum height from the floor. The left leg remains stretched.

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0 – 2.9	81	5.7	24.3	33.7	43.5	92	5.4	24.8	34.3	45.1	5.5	34.0
3.0 – 3.9	97	6.4	27.7	39.7	54.3	86	6.5	25.2	38.6	48.5	6.5	39.2
4.0 – 4.9	85	7.3	30.5	41.7	55.4	79	7.9	23.8	41.5	54.0	7.6	41.6
5.0 – 5.9	86	8.1	31.0	47.0	61.6	94	8.4	28.4	45.1	61.6	8.3	46.0
6.0 – 6.9	98	8.4	34.2	50.4	66.5	92	7.9	36.9	52.1	69.0	8.2	51.2
7.0 – 7.9	106	8.4	36.4	52.6	68.8	93	8.0	41.1	54.1	71.0	8.2	53.3
8.0 – 8.9	96	7.1	42.0	54.8	67.2	95	7.8	40.9	57.3	75.4	7.5	56.0
9.0 – 9.9	122	6.7	46.7	59.7	73.5	122	8.7	40.4	59.4	75.9	7.7	59.6
10.0 – 10.9	134	8.4	39.7	61.0	77.9	136	7.2	48.2	61.9	74.3	7.8	61.5
11.0 – 11.9	143	7.5	51.1	62.8	75.9	151	7.5	49.8	63.6	76.8	7.5	63.2
12.0 – 12.9	78	7.0	51.0	65.2	79.5	79	8.2	52.0	66.8	79.3	7.6	66.0

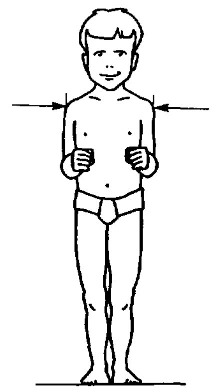


B-6 Shoulder breadth [cm]

definition: The horizontal breadth across the shoulders.

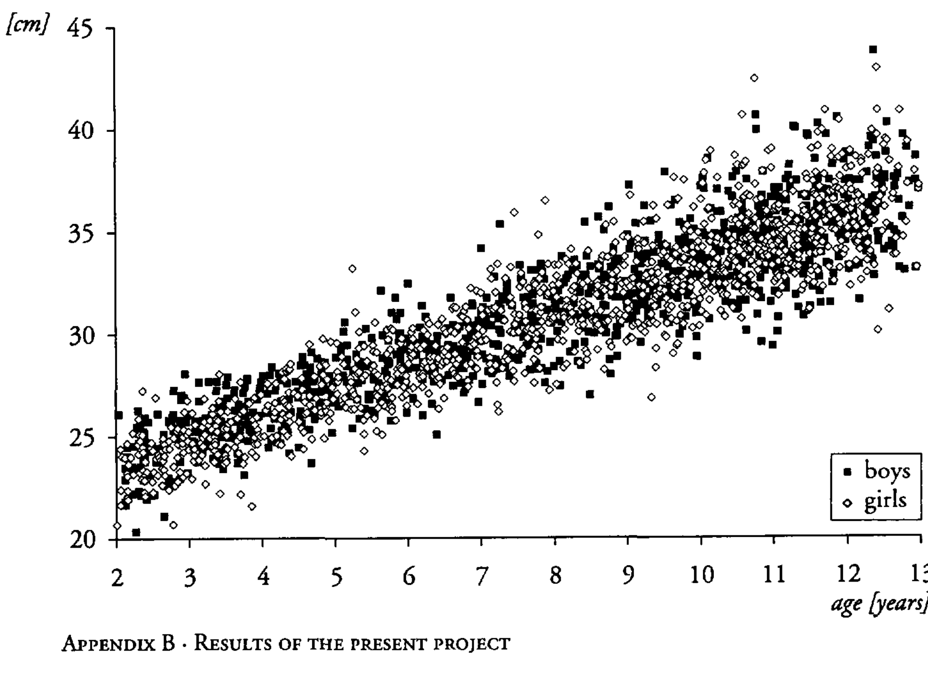
method: The child stands erect, the upper arms at sides and the elbows flexed 90°, the lower arms are horizontal, parallel and directed forward.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	1.6	21.6	24.3	27.1	92	1.3	21.6	24.0	26.8	1.4	24.1
3.0 – 3.9	97	1.1	23.7	25.6	27.8	86	1.2	22.2	25.0	27.1	1.2	25.3
4.0 – 4.9	85	1.3	24.5	26.8	28.8	79	1.3	24.6	26.7	29.5	1.3	26.8
5.0 – 5.9	86	1.4	25.9	28.2	31.0	94	1.5	25.1	27.8	30.6	1.5	28.0
6.0 – 6.9	98	1.3	26.6	29.1	31.5	92	1.3	26.9	29.2	32.0	1.3	29.2
7.0 – 7.9	106	1.6	28.1	30.4	33.4	93	1.9	27.3	30.7	34.8	1.7	30.5
8.0 – 8.9	96	1.7	28.0	31.6	35.4	95	1.7	28.4	31.5	34.7	1.7	31.6
9.0 – 9.9	122	1.6	30.0	32.8	36.3	122	2.0	29.3	32.5	36.6	1.8	32.7
10.0 – 10.9	134	1.9	30.7	34.2	37.9	136	2.1	31.1	34.5	38.9	2.0	34.3
11.0 – 11.9	143	2.1	31.3	35.1	39.7	151	1.9	32.1	35.2	39.1	2.0	35.1
12.0 – 12.9	78	2.1	33.0	36.2	39.7	79	2.3	32.3	36.1	40.9	2.2	36.1

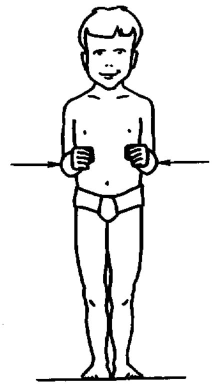


B-7 Breadth across the elbows [cm]

definition: The maximum horizontal distance between the lateral sides of the elbows.

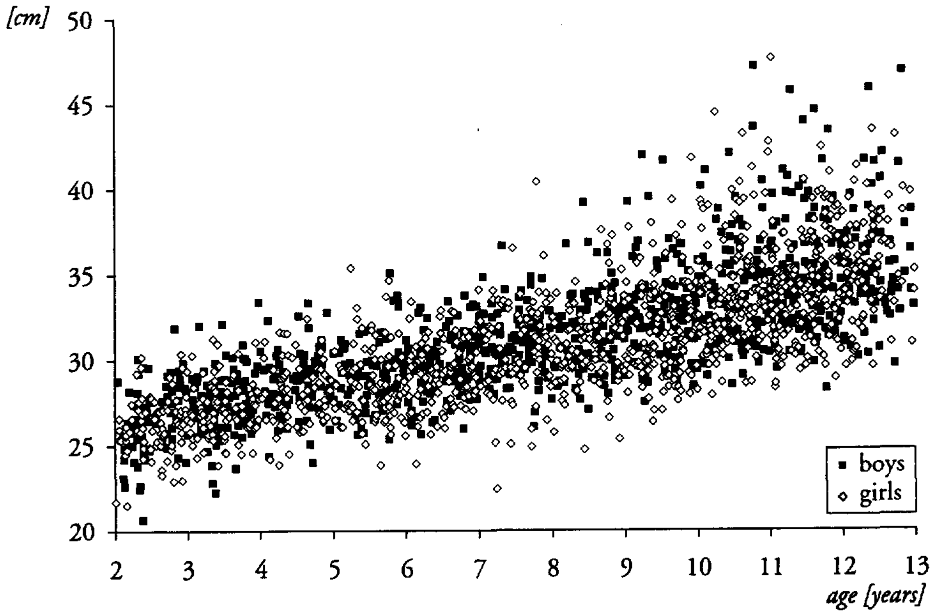
method: The child stands erect, the upper arms at sides and the elbows flexed 90°, the lower arms are horizontal, parallel and directed forward.

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0 – 2.9	81	2.1	22.6	26.6	29.9	92	1.7	22.9	26.2	29.6	1.9	26.4
3.0 – 3.9	97	1.8	23.7	27.6	32.0	86	1.6	24.5	27.1	31.0	1.7	27.4
4.0 – 4.9	85	1.8	25.1	28.7	32.6	79	1.8	24.5	28.2	31.6	1.8	28.4
5.0 – 5.9	86	1.9	25.8	29.2	33.5	94	2.1	25.6	28.6	33.7	2.0	28.9
6.0 – 6.9	98	1.8	26.2	29.8	33.2	92	2.0	26.1	29.2	32.9	1.9	29.5
7.0 – 7.9	106	1.9	28.0	30.8	34.8	93	2.7	25.1	30.7	36.1	2.3	30.8
8.0 – 8.9	96	2.2	28.0	31.6	36.8	95	2.4	25.8	31.0	36.7	2.3	31.3
9.0 – 9.9	122	2.6	28.6	32.7	39.3	122	2.8	27.6	31.7	37.9	2.7	32.2
10.0 – 10.9	134	3.0	29.7	33.8	41.1	136	3.2	29.7	34.0	41.3	3.1	33.9
11.0 – 11.9	143	3.1	30.4	34.8	41.7	151	3.1	29.6	34.4	39.9	3.1	34.6
12.0 – 12.9	78	3.3	30.3	35.6	42.1	79	3.1	29.9	35.4	41.3	3.2	35.5

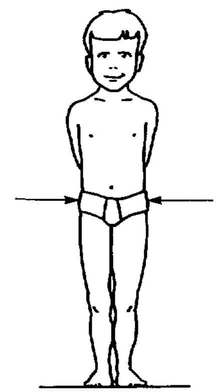


B-8 Hip breadth standing [cm]

definition: The maximum horizontal distance across the hips.

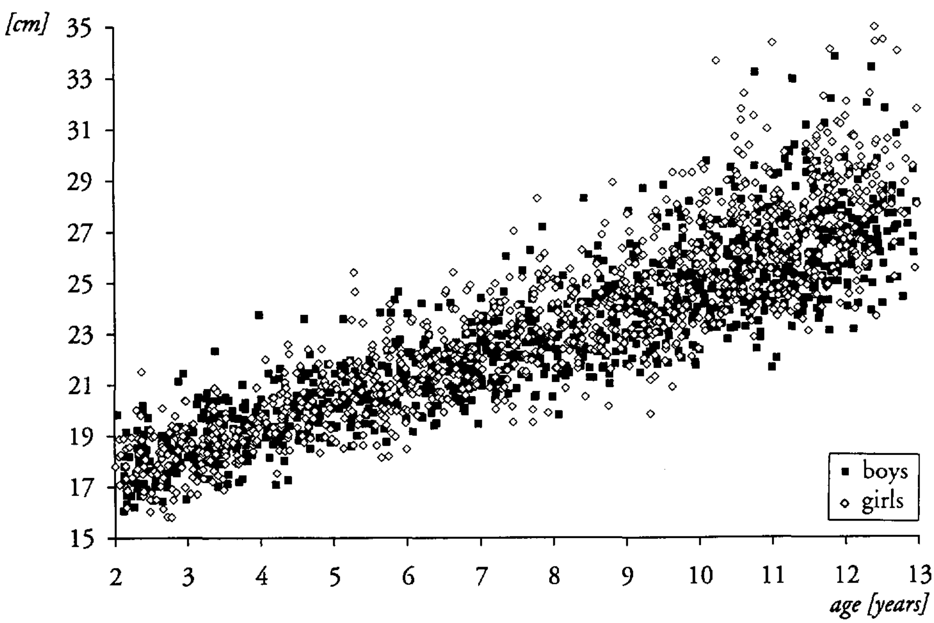
method: The child stands erect with the feet together.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	1.1	16.3	18.1	20.2	92	1.1	16.0	18.1	20.4	1.1	18.1
3.0 – 3.9	97	1.1	17.2	19.1	21.0	86	0.9	16.9	18.7	20.8	1.0	18.9
4.0 – 4.9	85	1.1	18.0	20.0	21.8	79	1.1	18.4	20.1	22.4	1.1	20.1
5.0 – 5.9	86	1.2	19.0	20.9	23.8	94	1.4	18.5	20.9	24.2	1.3	20.9
6.0 – 6.9	98	1.1	19.5	21.5	24.1	92	1.2	20.0	21.9	24.7	1.2	21.7
7.0 – 7.9	106	1.3	20.6	22.7	25.5	93	1.7	19.9	23.0	26.2	1.5	22.8
8.0 – 8.9	96	1.4	21.2	23.3	26.1	95	1.5	20.9	23.7	26.9	1.5	23.5
9.0 – 9.9	122	1.6	21.9	24.5	27.9	122	1.8	21.3	24.6	28.2	1.7	24.5
10.0 – 10.9	134	1.8	22.9	25.6	29.5	136	2.2	23.3	26.5	31.3	2.0	26.1
11.0 – 11.9	143	2.1	23.7	26.6	31.1	151	2.2	23.8	27.2	31.3	2.1	26.9
12.0 – 12.9	78	1.9	24.1	27.2	31.8	79	2.4	24.5	28.4	34.4	2.2	27.8

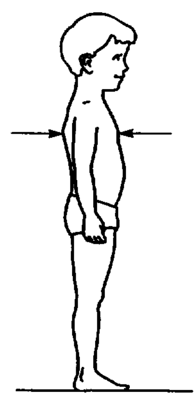


B-9 Breast depth [cm]

definition: The maximum horizontal distance between the front and back of the trunk at the nipples.

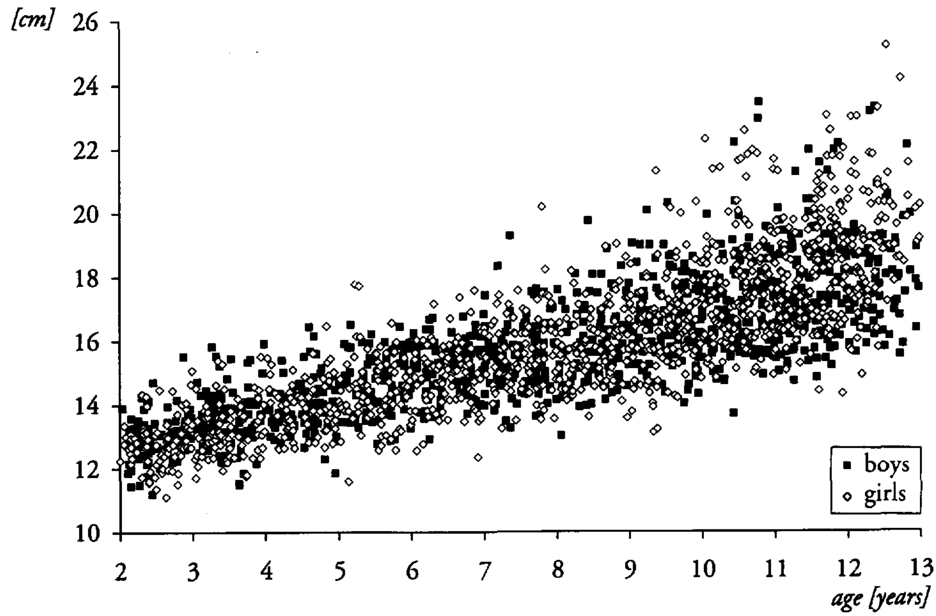
method: The child stands erect. This measurement is taken during normal breathing.

device: Automated anthropometer.



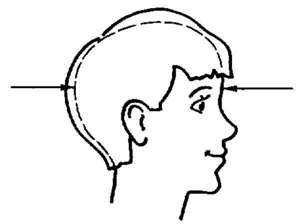
results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	0.7	11.5	13.0	14.3	92	0.8	11.5	12.8	14.5	0.8	12.9
3.0– 3.9	97	0.9	11.9	13.6	15.5	86	0.8	11.8	13.2	15.3	0.9	13.4
4.0– 4.9	85	0.9	12.7	14.0	15.7	79	0.8	12.6	13.9	15.5	0.8	13.9
5.0– 5.9	86	0.9	12.9	14.7	16.2	94	1.0	12.6	14.5	16.6	1.0	14.6
6.0– 6.9	98	0.9	13.6	15.1	16.7	92	1.0	12.8	15.0	17.2	1.0	15.0
7.0– 7.9	106	1.1	13.7	15.5	17.5	93	1.2	13.5	15.6	17.6	1.1	15.6
8.0– 8.9	96	1.2	14.0	15.8	18.3	95	1.1	14.1	15.9	18.6	1.2	15.9
9.0– 9.9	122	1.2	14.4	16.6	19.0	122	1.4	13.9	16.4	20.0	1.3	16.5
10.0–10.9	134	1.5	14.8	17.2	20.4	136	1.8	15.1	17.7	21.8	1.7	17.4
11.0–11.9	143	1.6	15.2	17.6	21.3	151	1.7	15.5	18.2	21.8	1.7	17.9
12.0–12.9	78	1.6	15.8	18.0	22.1	79	2.0	15.7	19.2	23.3	1.9	18.6



B-10 Head length [cm]

definition: The horizontal distance from glabella (most anterior protrusion of the forehead, between the eyebrows) to opistocranion (most posterior point from glabella on the back of the head).

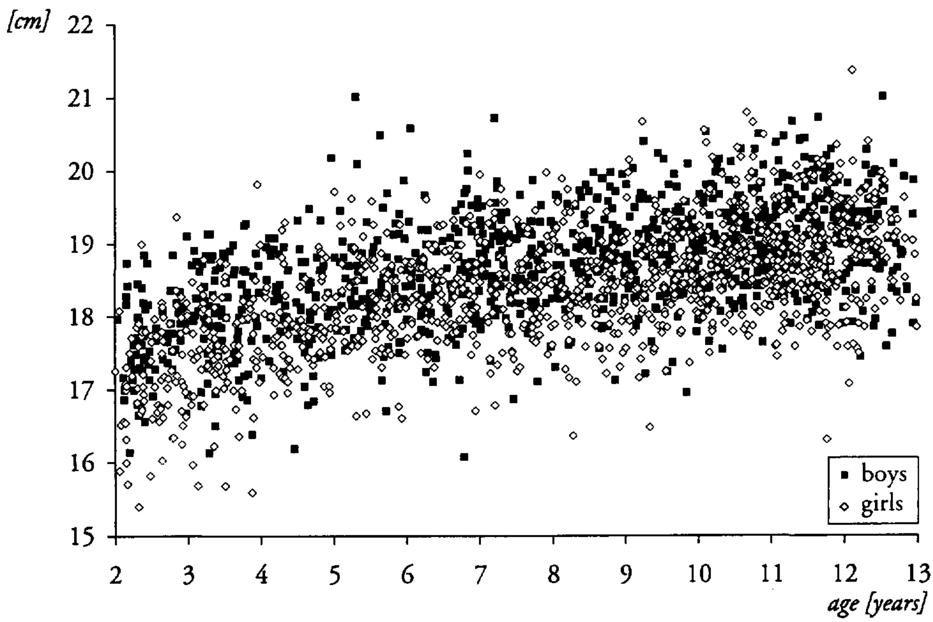


method: The child stands erect with the head oriented in the Frankfort Plane.

device: Automated anthropometer.

results:

age [years]	boys					girls					boys + girls	
	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0– 2.9	81	0.6	16.7	17.7	18.9	92	0.7	15.8	17.2	18.4	0.7	17.4
3.0– 3.9	97	0.7	16.5	18.0	19.1	86	0.7	15.7	17.6	18.8	0.7	17.8
4.0– 4.9	85	0.7	16.8	18.2	19.3	79	0.6	17.0	17.9	19.0	0.6	18.0
5.0– 5.9	86	0.7	17.5	18.5	20.1	94	0.6	16.7	18.2	19.6	0.7	18.3
6.0– 6.9	98	0.7	17.1	18.5	20.0	92	0.6	17.4	18.4	19.4	0.6	18.5
7.0– 7.9	106	0.6	17.6	18.7	19.8	93	0.6	17.3	18.4	19.6	0.6	18.5
8.0– 8.9	96	0.6	17.6	18.8	20.0	95	0.6	17.2	18.4	19.6	0.7	18.6
9.0– 9.9	122	0.6	17.4	18.9	20.1	122	0.6	17.4	18.6	19.6	0.7	18.7
10.0–10.9	134	0.6	18.0	19.0	20.3	136	0.7	17.8	18.9	20.4	0.6	19.0
11.0–11.9	143	0.7	18.1	19.2	20.4	151	0.7	17.6	18.9	20.1	0.7	19.0
12.0–12.9	78	0.7	17.8	19.0	20.1	79	0.7	17.6	19.0	20.1	0.7	19.0

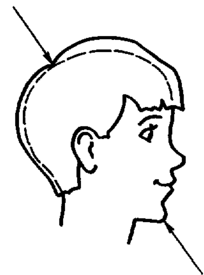


B-11 Chin to crown length [cm]

definition: The rectilinear distance from chin to crown.

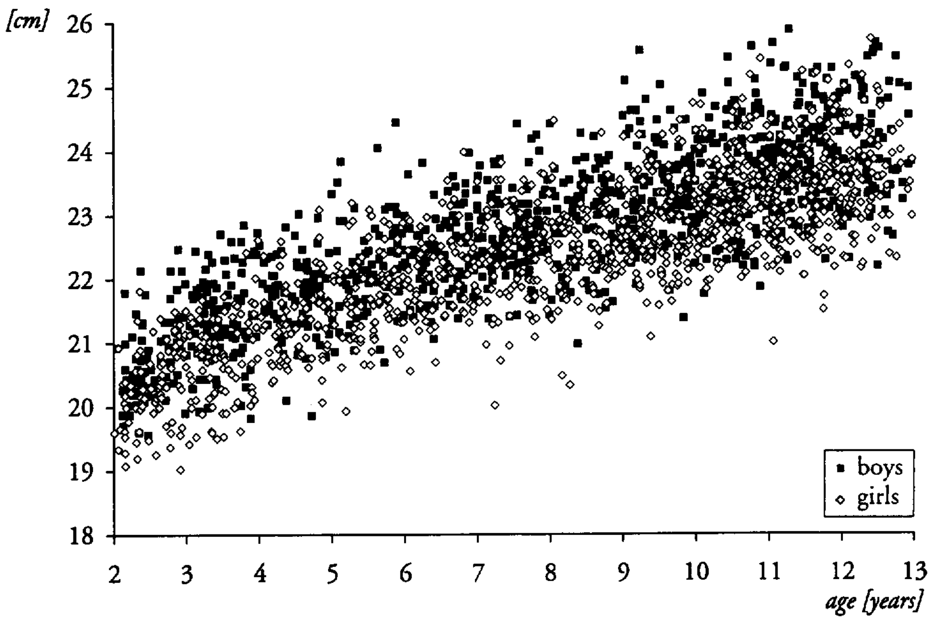
method: The child stands erect with the head oriented in the Frankfort Plane and jaws closed.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	0.6	19.7	20.8	22.1	92	0.6	19.2	20.3	21.5	0.7	20.5
3.0 – 3.9	97	0.7	20.0	21.4	22.7	86	0.7	19.5	20.8	22.0	0.7	21.1
4.0 – 4.9	85	0.6	20.8	21.7	22.8	79	0.6	20.4	21.3	22.6	0.6	21.5
5.0 – 5.9	86	0.7	20.9	22.2	23.8	94	0.7	20.7	21.7	23.0	0.7	22.0
6.0 – 6.9	98	0.6	21.4	22.4	23.6	92	0.6	21.2	22.1	23.5	0.6	22.3
7.0 – 7.9	106	0.7	21.4	22.7	24.0	93	0.7	21.0	22.3	23.6	0.7	22.6
8.0 – 8.9	96	0.7	21.6	22.9	24.2	95	0.7	21.3	22.5	23.8	0.7	22.7
9.0 – 9.9	122	0.7	22.1	23.3	24.8	122	0.7	21.6	22.9	24.2	0.8	23.1
10.0 – 10.9	134	0.8	22.2	23.5	25.1	136	0.7	22.1	23.3	24.7	0.7	23.4
11.0 – 11.9	143	0.7	22.7	23.9	25.3	151	0.8	22.0	23.4	24.8	0.8	23.6
12.0 – 12.9	78	0.8	22.7	24.0	25.6	79	0.8	22.3	23.6	25.2	0.8	23.8

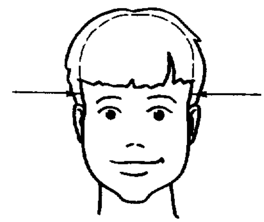


B-12 Head breadth [cm]

definition: The maximum breadth of the head above the ears, at right angles to the midsagittal plane.

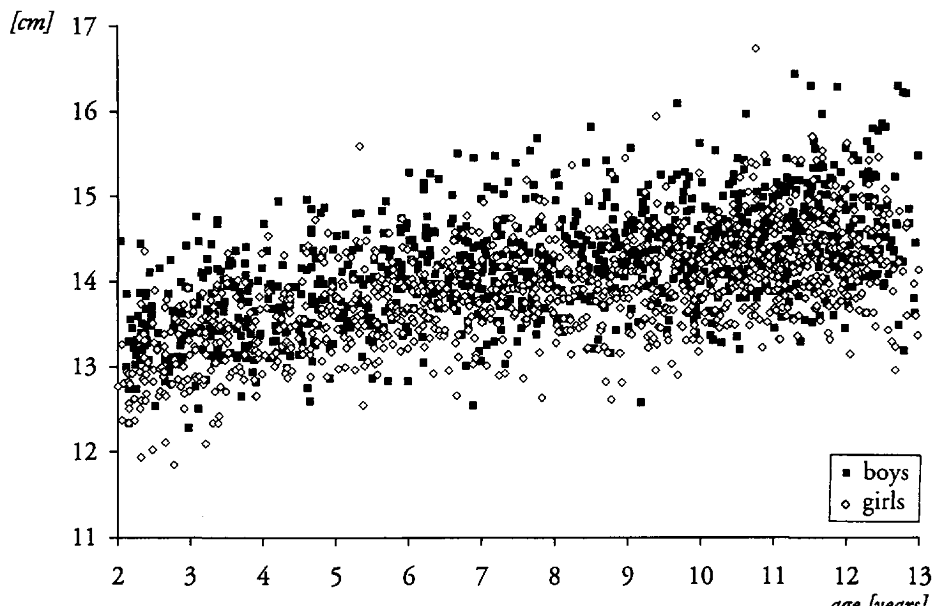
method: The child stands erect with the head in the Frankfort Plane.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	0.4	12.5	13.4	14.4	92	0.5	12.0	13.0	13.9	0.5	13.2
3.0– 3.9	97	0.5	12.8	13.6	14.7	86	0.5	12.3	13.3	14.0	0.5	13.5
4.0– 4.9	85	0.5	12.9	13.8	14.9	79	0.4	12.9	13.6	14.5	0.5	13.7
5.0– 5.9	86	0.5	12.9	13.9	14.8	94	0.5	13.0	13.7	14.6	0.5	13.8
6.0– 6.9	98	0.5	13.1	14.1	15.3	92	0.4	13.0	13.8	14.6	0.5	14.0
7.0– 7.9	106	0.5	13.3	14.2	15.4	93	0.5	12.9	14.0	14.9	0.5	14.1
8.0– 8.9	96	0.5	13.3	14.3	15.4	95	0.5	12.8	13.9	15.3	0.5	14.1
9.0– 9.9	122	0.5	13.5	14.4	15.3	122	0.5	13.2	14.0	15.0	0.6	14.2
10.0–10.9	134	0.5	13.3	14.4	15.4	136	0.5	13.5	14.3	15.4	0.5	14.4
11.0–11.9	143	0.6	13.5	14.6	15.7	151	0.5	13.4	14.3	15.5	0.6	14.5
12.0–12.9	78	0.7	13.6	14.7	16.2	79	0.5	13.2	14.3	15.4	0.6	14.5

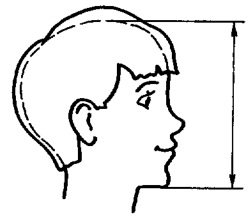


B-13 Head height [cm]

definition: The height of the head perpendicular to the Frankfort Plane, from menton to vertex.

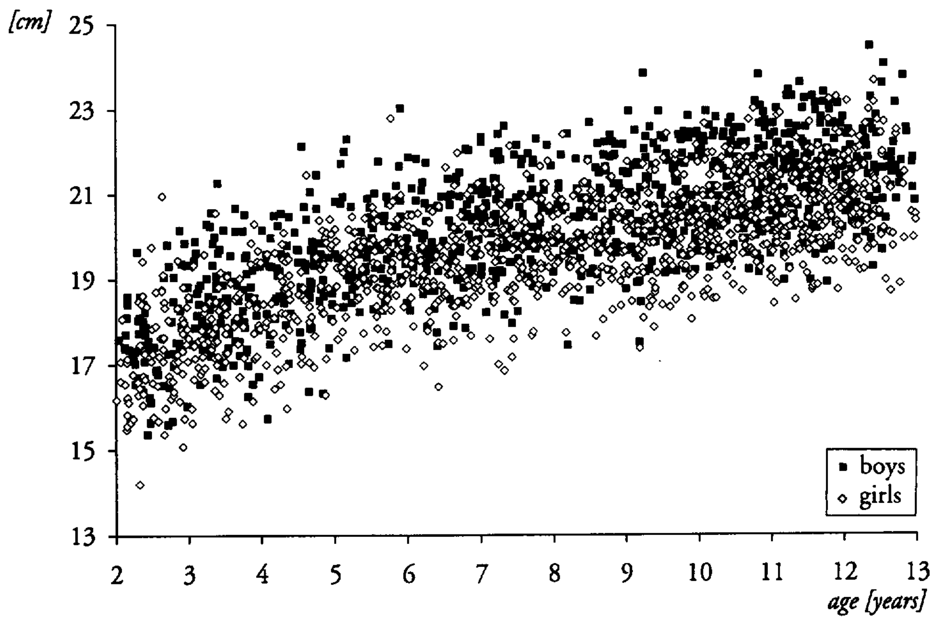
method: The child stands erect with the head in the Frankfort Plane.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	1.1	15.7	17.6	19.8	92	1.2	15.4	17.2	19.5	1.2	17.4
3.0 – 3.9	97	1.1	16.5	18.5	20.6	86	1.1	15.7	17.8	19.9	1.1	18.2
4.0 – 4.9	85	1.1	16.4	19.0	21.1	79	1.1	16.4	18.6	20.4	1.2	18.8
5.0 – 5.9	86	1.1	18.2	19.8	22.0	94	1.0	17.4	19.3	20.8	1.0	19.5
6.0 – 6.9	98	1.1	17.9	19.9	22.0	92	1.0	17.5	19.3	21.3	1.1	19.6
7.0 – 7.9	106	1.1	18.3	20.4	22.3	93	1.0	17.2	19.6	21.7	1.1	20.0
8.0 – 8.9	96	1.0	18.5	20.5	22.4	95	0.9	18.0	20.0	21.6	1.0	20.3
9.0 – 9.9	122	1.1	18.9	20.8	22.8	122	1.0	18.1	20.1	21.8	1.1	20.4
10.0 – 10.9	134	1.0	19.4	21.2	22.9	136	1.0	18.7	20.6	22.1	1.0	20.9
11.0 – 11.9	143	1.0	19.5	21.5	23.3	151	1.0	18.8	20.8	22.7	1.1	21.1
12.0 – 12.9	78	1.0	19.9	21.6	23.8	79	1.1	19.0	20.9	23.1	1.1	21.3

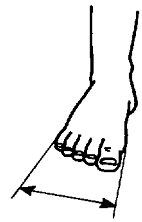


B-14 Foot breadth [cm]

definition: The maximum width across the ball of the right foot.

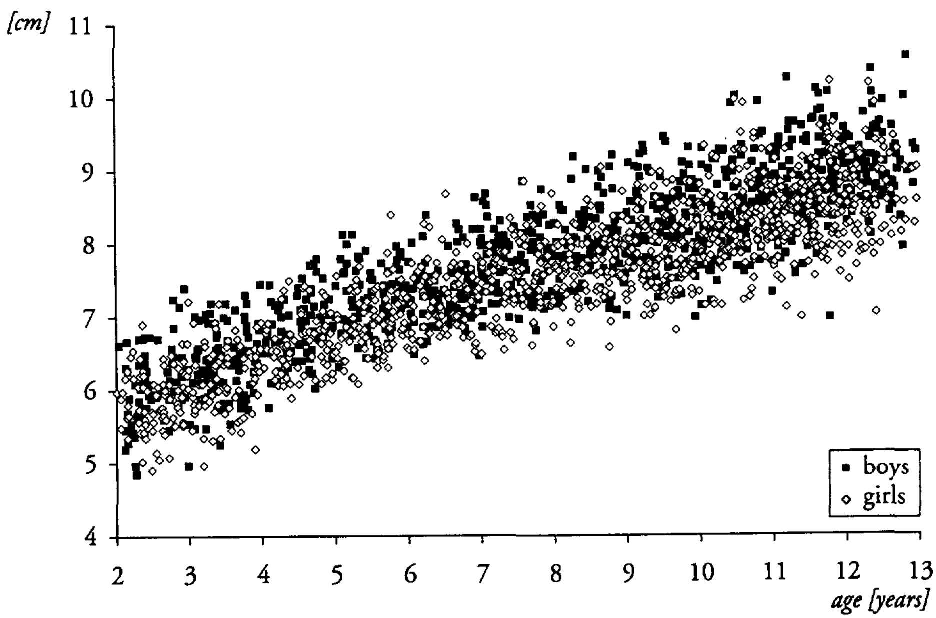
method: The child stands erect with feet slightly apart, weight evenly distributed. The distance is measured at right angles to the long axis of the foot.

device: Automated anthropometer.



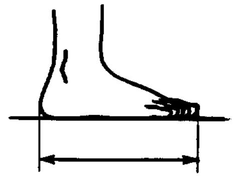
results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	0.5	5.0	6.0	7.1	92	0.4	5.1	5.9	6.6	0.5	5.9
3.0 – 3.9	97	0.5	5.5	6.4	7.2	86	0.4	5.3	6.1	6.9	0.5	6.3
4.0 – 4.9	85	0.4	6.1	6.8	7.7	79	0.4	6.1	6.6	7.4	0.4	6.7
5.0 – 5.9	86	0.4	6.4	7.2	8.0	94	0.4	6.2	6.9	7.7	0.5	7.1
6.0 – 6.9	98	0.4	6.6	7.3	8.3	92	0.4	6.5	7.2	8.2	0.4	7.3
7.0 – 7.9	106	0.5	7.0	7.7	8.6	93	0.5	6.6	7.5	8.5	0.5	7.6
8.0 – 8.9	96	0.5	7.1	8.0	9.0	95	0.4	6.9	7.7	8.6	0.5	7.8
9.0 – 9.9	122	0.5	7.3	8.2	9.3	122	0.5	7.1	7.9	8.8	0.5	8.1
10.0 – 10.9	134	0.6	7.5	8.5	9.5	136	0.6	7.2	8.3	9.4	0.6	8.4
11.0 – 11.9	143	0.6	7.7	8.8	9.8	151	0.5	7.5	8.5	9.5	0.6	8.6
12.0 – 12.9	78	0.5	8.3	9.1	10.0	79	0.5	7.7	8.6	9.5	0.6	8.8



B-15 Foot length [cm]

definition: The maximum horizontal distance from the heel to the longest toe of the right foot, parallel to the long axis of the foot.

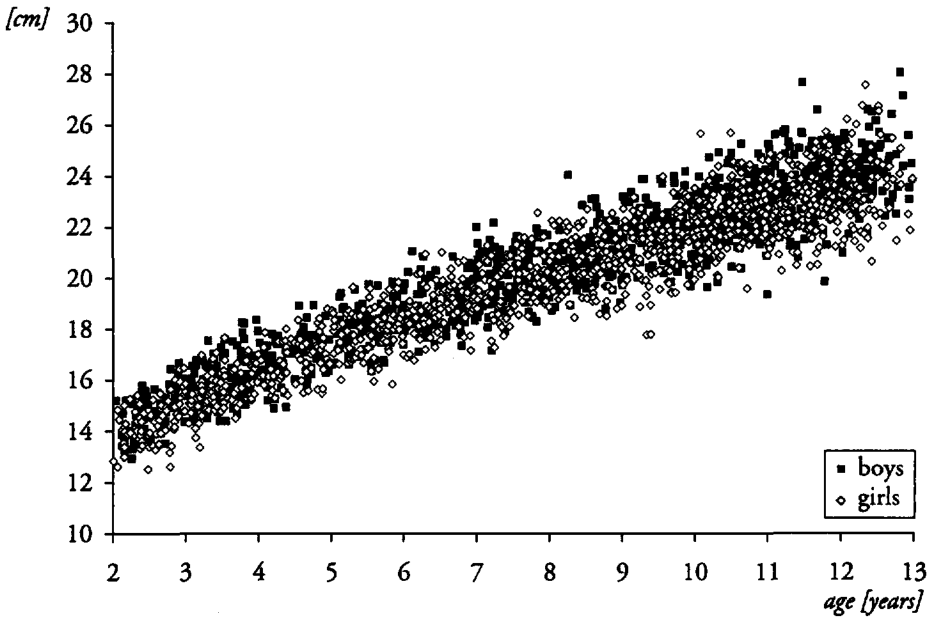


method: The child stands erect with feet slightly apart, weight evenly distributed. The heel is projected onto the floor with the blades of the anthropometer.

device: Automated anthropometer.

results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0– 2.9	81	0.8	13.3	14.8	16.3	92	0.9	12.6	14.4	16.0	0.9	14.6
3.0– 3.9	97	0.9	14.4	16.0	18.2	86	0.8	14.1	15.6	17.1	0.9	15.8
4.0– 4.9	85	0.8	15.2	16.9	18.5	79	0.8	15.4	16.8	18.4	0.8	16.9
5.0– 5.9	86	0.9	16.6	18.2	19.7	94	0.9	16.0	17.8	19.6	0.9	18.0
6.0– 6.9	98	0.9	17.4	19.0	20.8	92	0.9	17.0	18.9	20.7	0.9	19.0
7.0– 7.9	106	1.0	18.3	20.0	21.7	93	1.0	17.7	19.8	21.6	1.0	19.9
8.0– 8.9	96	1.0	18.8	20.8	23.1	95	1.1	18.6	20.6	22.3	1.1	20.7
9.0– 9.9	122	1.0	20.0	21.9	23.9	122	1.2	18.9	21.3	23.3	1.1	21.6
10.0–10.9	134	1.2	20.4	22.6	24.9	136	1.1	20.3	22.5	24.5	1.2	22.5
11.0–11.9	143	1.4	21.3	23.4	25.7	151	1.2	20.9	22.9	25.0	1.3	23.1
12.0–12.9	78	1.2	21.7	24.2	26.6	79	1.5	21.3	23.5	26.7	1.4	23.8

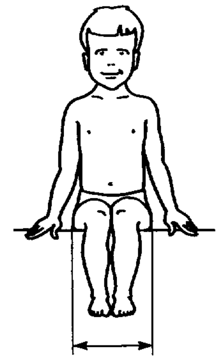


B-16 Hip breadth, seated [cm]

definition: The maximum horizontal distance across the hips, parallel to the seat.

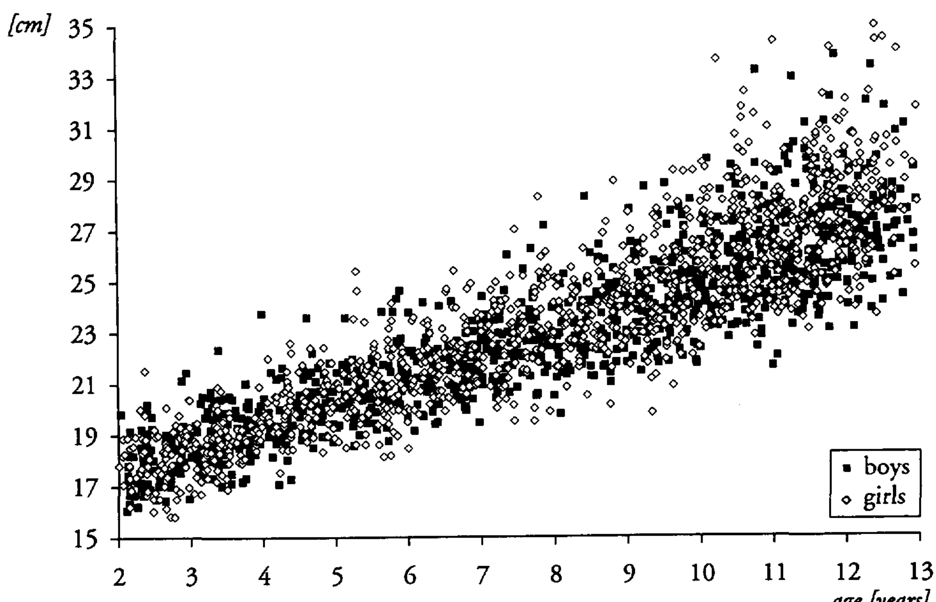
method: The child sits erect, the thighs are supported, the lower legs hang down freely with the knees together.

device: Automated anthropometer.

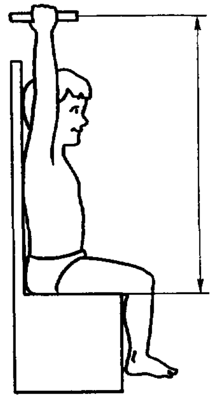


results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	1.4	16.8	19.1	21.7	92	1.4	16.9	19.2	22.4	1.4	19.1
3.0– 3.9	97	1.3	17.8	20.1	23.1	86	1.2	17.5	19.8	22.4	1.3	20.0
4.0– 4.9	85	1.4	18.5	21.4	24.0	79	1.4	19.3	21.6	24.2	1.4	21.5
5.0– 5.9	86	1.6	20.2	22.4	26.4	94	1.8	19.4	22.2	26.1	1.7	22.3
6.0– 6.9	98	1.4	20.1	22.8	25.4	92	1.7	20.4	23.3	26.5	1.6	23.1
7.0– 7.9	106	1.7	21.3	23.9	27.9	93	2.1	20.7	24.6	28.6	1.9	24.2
8.0– 8.9	96	1.8	21.8	24.6	28.0	95	1.9	21.4	25.3	28.6	1.8	24.9
9.0– 9.9	122	2.1	22.7	26.0	31.1	122	2.3	22.4	26.1	30.6	2.2	26.0
10.0–10.9	134	2.3	23.9	27.1	32.4	136	2.8	24.4	28.3	34.7	2.6	27.7
11.0–11.9	143	2.5	24.8	28.2	34.2	151	2.7	24.3	28.9	34.1	2.6	28.5
12.0–12.9	78	2.3	24.7	28.6	32.8	79	3.1	25.1	30.4	38.1	2.9	29.5



B-17 Reaching height, seated [cm]



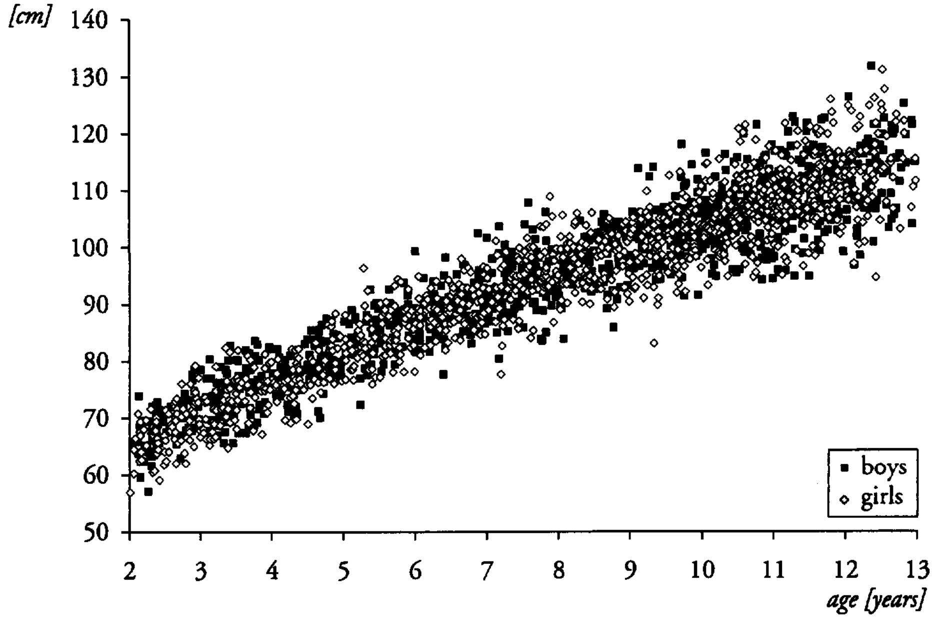
definition: The vertical distance from the horizontal surface to the mid-point of the grip device.

method: The child sits erect, the thighs are supported. The right arm and shoulder are extended to maximum vertical reach, while the buttocks keep touching the surface. The lower legs hang down freely. The grip device remains horizontal and in a sagittal plane, the left arm hangs down.

device: Automated anthropometer.

results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0– 2.9	81	4.2	61.6	68.7	77.7	92	4.3	60.3	68.0	76.1	4.3	68.3
3.0– 3.9	97	4.6	66.7	74.5	83.0	86	4.2	66.3	73.5	81.6	4.4	74.0
4.0– 4.9	85	4.2	70.8	79.0	87.1	79	4.2	69.6	78.2	86.4	4.2	78.6
5.0– 5.9	86	4.1	77.6	85.2	92.6	94	4.3	76.8	84.1	94.0	4.2	84.6
6.0– 6.9	98	4.3	81.7	89.5	98.2	92	3.6	82.4	89.2	96.4	4.0	89.3
7.0– 7.9	106	4.9	85.0	93.5	103.6	93	5.1	84.1	94.4	104.0	5.0	93.9
8.0– 8.9	96	4.3	89.2	97.4	104.5	95	4.3	90.0	97.6	105.6	4.3	97.5
9.0– 9.9	122	4.7	94.3	102.8	113.8	122	5.1	91.1	101.0	109.8	5.0	101.9
10.0–10.9	134	5.7	95.3	106.0	116.5	136	5.6	97.0	106.4	118.5	5.6	106.2
11.0–11.9	143	5.9	96.0	109.5	121.7	151	5.7	98.4	109.9	121.1	5.8	109.7
12.0–12.9	78	6.6	100.9	113.1	125.2	79	7.1	100.4	113.5	126.1	6.8	113.3

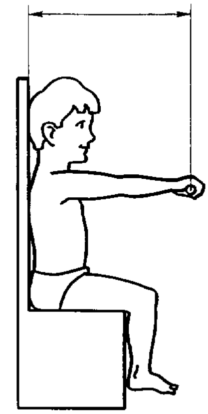


B-18 Arm length [cm]

definition: The horizontal distance from the back of the measuring chair to the most distal point of the grip device.

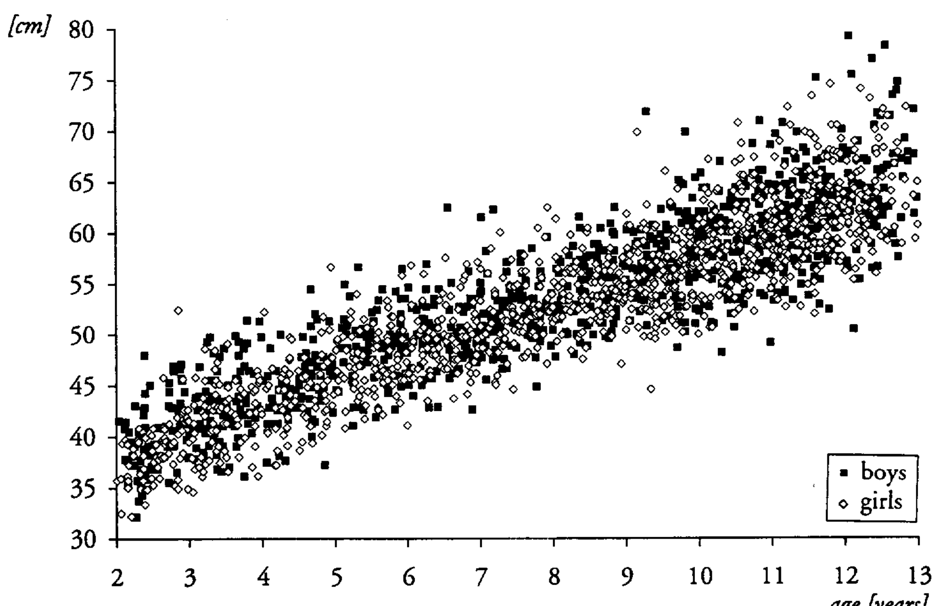
method: The child sits upright against the back of the measuring chair. The right arm is extended to maximal horizontal grip reach, while the shoulder blades remain against the back of the chair.

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0 – 2.9	81	3.5	34.3	40.1	46.9	92	3.1	33.4	38.7	45.6	3.4	39.4
3.0 – 3.9	97	3.6	36.8	43.2	49.9	86	3.2	36.2	42.0	48.4	3.5	42.6
4.0 – 4.9	85	3.3	37.7	45.0	51.6	79	3.6	38.6	44.3	51.8	3.5	44.6
5.0 – 5.9	86	3.2	42.6	48.6	54.9	94	3.1	41.8	47.4	53.3	3.2	48.0
6.0 – 6.9	98	3.2	42.9	49.9	56.3	92	3.1	44.2	49.6	56.9	3.2	49.8
7.0 – 7.9	106	3.1	46.7	52.0	58.5	93	3.4	45.3	52.2	60.1	3.2	52.1
8.0 – 8.9	96	3.2	48.9	54.7	60.9	95	2.8	48.4	54.0	60.1	3.0	54.4
9.0 – 9.9	122	3.8	51.1	57.6	65.2	122	3.8	49.8	55.9	62.9	3.9	56.8
10.0 – 10.9	134	4.2	51.1	59.3	66.9	136	4.0	52.2	59.3	67.2	4.1	59.3
11.0 – 11.9	143	4.1	53.8	61.6	69.6	151	4.4	53.6	61.4	70.5	4.3	61.5
12.0 – 12.9	78	5.6	55.4	64.6	77.0	79	4.2	56.4	63.6	72.3	4.9	64.1

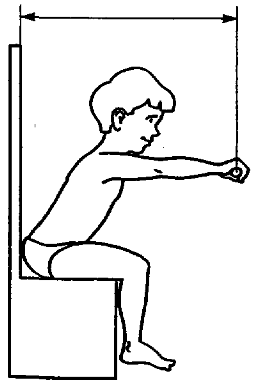


B-19 Reaching depth, seated [cm]

definition: The horizontal distance from the back of the measuring chair to the mid-point of the grip device.

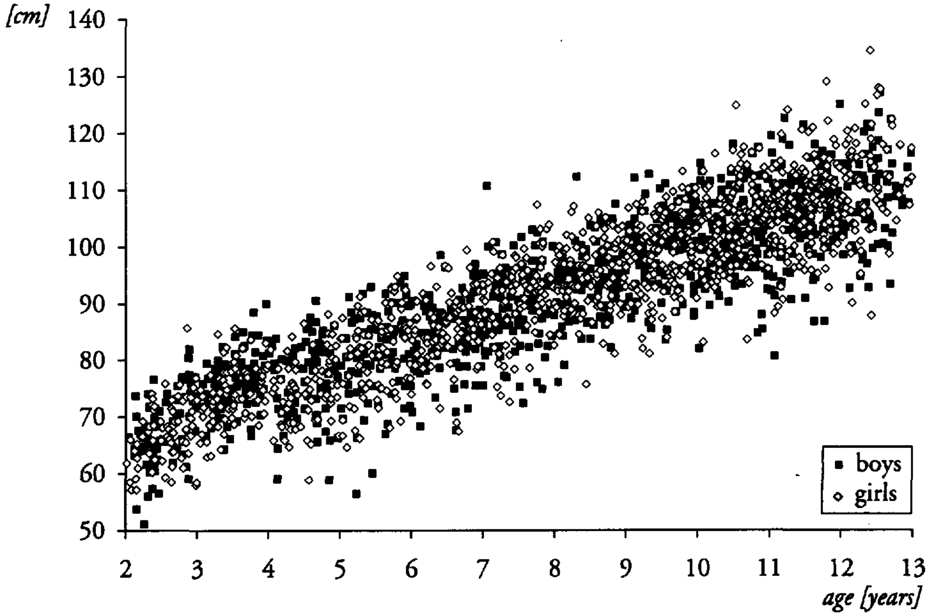
method: The child sits with its buttocks against the back of the measuring chair. The right arm and the trunk are extended to maximum horizontal grip reach, while the body is flexed at the hips. The thighs are supported and the lower legs hang down freely.

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0 – 2.9	81	6.5	56.0	68.0	77.5	92	5.8	57.2	67.4	77.0	6.1	67.7
3.0 – 3.9	97	4.8	66.7	76.0	85.0	86	4.9	64.3	74.1	83.6	4.9	75.1
4.0 – 4.9	85	6.6	64.5	76.4	86.8	79	5.9	65.2	74.9	86.3	6.3	75.7
5.0 – 5.9	86	7.6	66.3	81.2	93.0	94	6.9	66.7	81.2	92.9	7.2	81.2
6.0 – 6.9	98	6.3	70.8	84.8	96.4	92	5.8	71.4	85.8	96.5	6.1	85.3
7.0 – 7.9	106	7.0	75.5	89.8	101.8	93	6.7	75.2	91.2	103.1	6.9	90.5
8.0 – 8.9	96	6.1	82.1	93.9	104.9	95	6.0	82.8	95.0	106.0	6.1	94.4
9.0 – 9.9	122	6.2	86.6	99.4	110.3	122	6.6	83.9	98.8	110.0	6.4	99.1
10.0 – 10.9	134	6.9	88.0	102.3	114.6	136	6.9	93.4	103.6	116.5	6.9	103.0
11.0 – 11.9	143	7.5	90.8	106.1	118.8	151	6.8	92.7	106.9	120.6	7.1	106.5
12.0 – 12.9	78	7.5	93.3	108.7	122.3	79	8.5	95.1	110.9	127.7	8.0	109.8

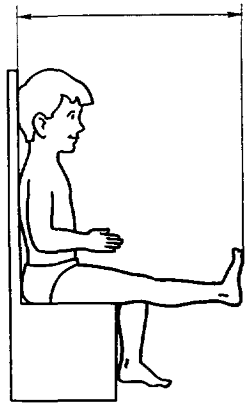


B-20 Buttock-foot length, seated [cm]

definition: The horizontal distance from buttock to the sole of the foot of the stretched leg.

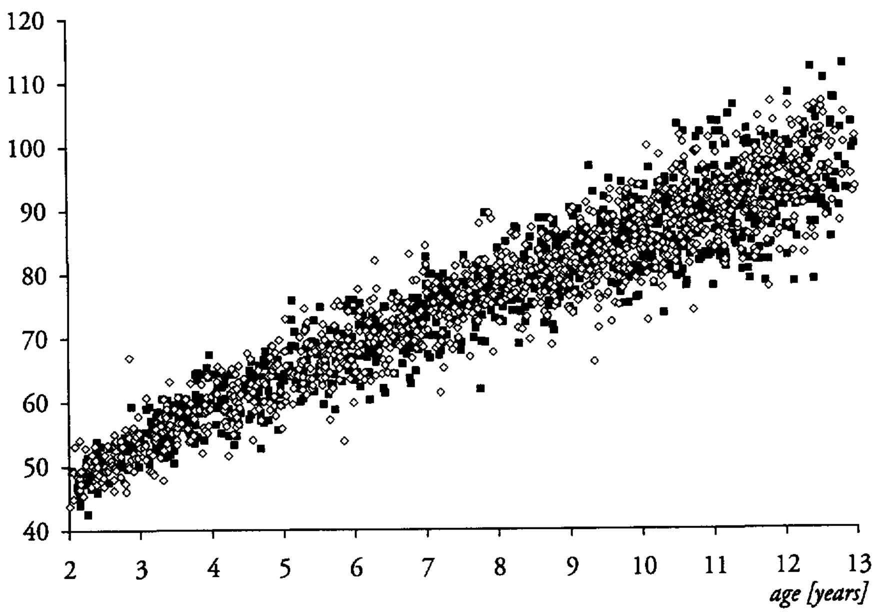
method: The child sits erect, its thighs supported. The left lower leg hangs down freely. The right leg is stretched horizontally, while the foot is at right angles to the leg. The most distal point of the buttocks is projected onto the seat by means of the back of the measuring chair. The distance is measured from the back of the chair to the sole of the right foot.

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0– 2.9	81	3.0	45.1	50.8	55.2	92	3.4	45.4	50.8	56.1	3.2	50.8
3.0– 3.9	97	3.6	51.2	57.1	64.5	86	3.3	49.2	56.3	62.9	3.5	56.7
4.0– 4.9	85	3.4	54.7	60.9	66.5	79	3.8	54.9	61.7	68.8	3.6	61.3
5.0– 5.9	86	3.9	60.0	66.8	75.8	94	4.0	59.6	66.6	75.0	4.0	66.7
6.0– 6.9	98	4.0	62.0	70.6	78.1	92	4.3	63.8	71.2	82.1	4.1	70.9
7.0– 7.9	106	4.2	67.3	75.3	82.1	93	4.6	66.9	75.8	87.9	4.4	75.5
8.0– 8.9	96	4.5	71.8	79.5	88.3	95	4.0	71.2	79.6	86.6	4.3	79.5
9.0– 9.9	122	4.5	76.1	84.8	93.6	122	5.2	73.7	83.4	93.1	4.9	84.1
10.0–10.9	134	5.6	78.3	88.1	102.0	136	5.4	79.5	89.0	99.2	5.5	88.5
11.0–11.9	143	6.0	81.0	91.5	102.0	151	5.0	82.1	92.0	101.4	5.5	91.8
12.0–12.9	78	7.0	82.6	95.7	110.3	79	5.7	85.3	96.2	106.0	6.3	95.9

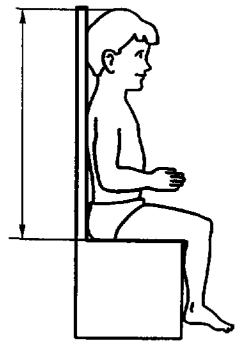


B-21 Sitting height [cm]

definition: The vertical distance from the seat to the vertex (top of the head).

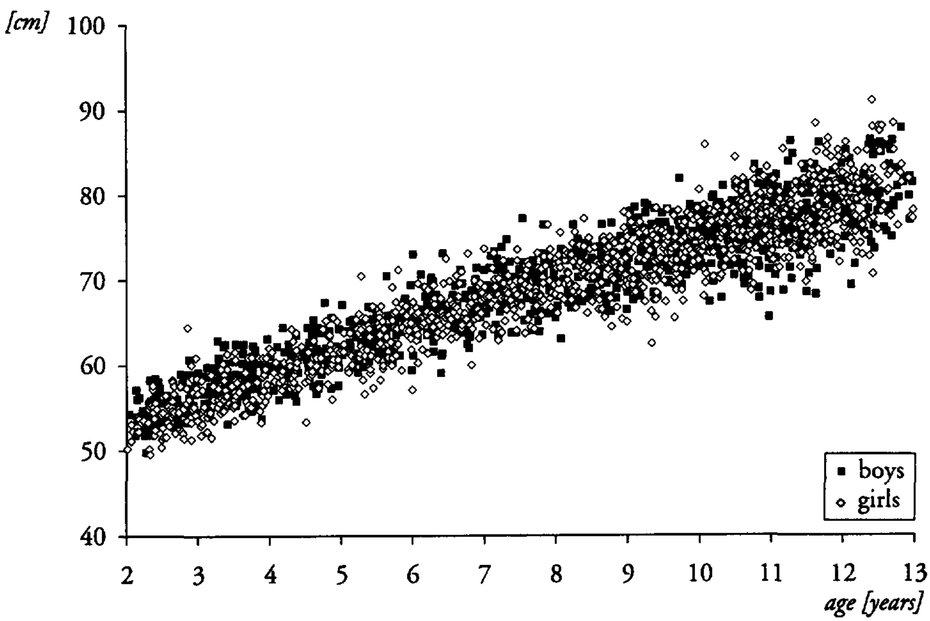
method: The child sits erect with the head oriented in the Frankfort Plane. The thighs are supported and the lower legs hang down freely.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	2.3	51.8	55.4	59.2	92	2.5	50.2	54.4	60.1	2.5	54.9
3.0– 3.9	97	2.3	54.7	58.1	62.5	86	2.4	52.2	56.7	61.4	2.4	57.4
4.0– 4.9	85	2.5	56.5	60.8	65.4	79	2.3	57.1	60.1	65.2	2.4	60.5
5.0– 5.9	86	2.2	59.8	63.9	67.9	94	2.9	57.4	63.1	69.2	2.6	63.5
6.0– 6.9	98	2.7	61.2	66.4	71.4	92	2.6	61.4	66.4	72.5	2.6	66.4
7.0– 7.9	106	2.7	64.0	69.0	73.9	93	2.7	63.7	68.7	73.6	2.7	68.9
8.0– 8.9	96	2.7	66.3	70.9	76.6	95	2.9	65.4	71.1	76.1	2.8	71.0
9.0– 9.9	122	2.9	68.5	74.2	78.7	122	3.2	66.3	72.9	78.3	3.1	73.6
10.0–10.9	134	3.5	67.9	75.7	81.3	136	3.3	70.1	76.2	82.1	3.4	76.0
11.0–11.9	143	3.5	70.5	77.7	83.6	151	3.6	72.1	78.0	85.3	3.6	77.8
12.0–12.9	78	3.7	73.7	80.0	86.4	79	4.1	73.0	80.2	88.1	3.9	80.1

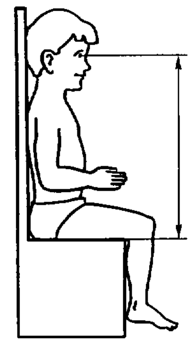


B-22 Eye height, seated [cm]

definition: The vertical distance from the seat to the inner corner of the right eye.

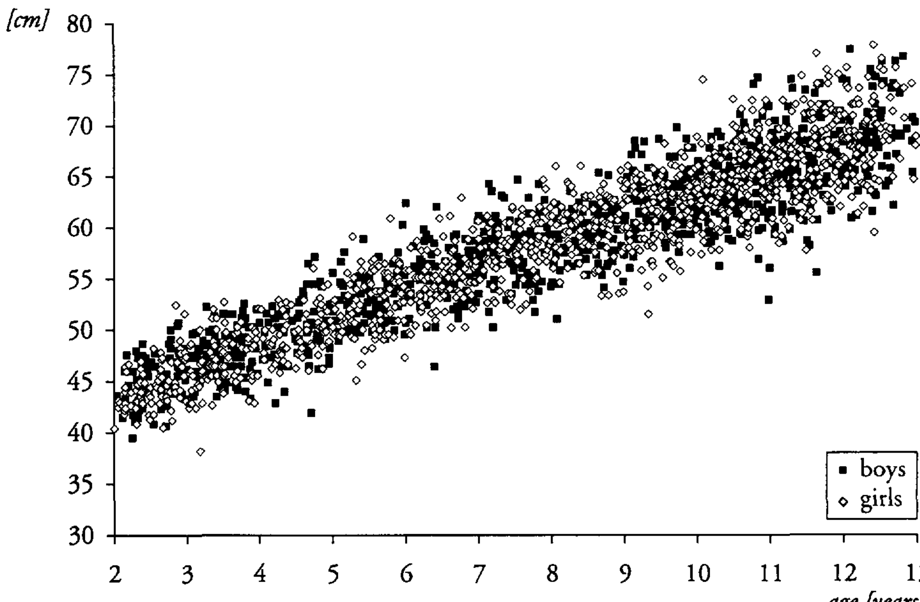
method: The child sits erect with the head oriented in the Frankfort Plane. The thighs are supported and the lower legs hang down freely.

device: Automated anthropometer.



results:

age [years]	boys					girls					boys + girls	
	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0– 2.9	81	2.5	40.8	45.1	50.0	92	2.3	40.8	44.6	49.0	2.4	44.8
3.0– 3.9	97	2.3	43.6	47.6	52.0	86	2.7	42.4	46.7	52.0	2.5	47.2
4.0– 4.9	85	2.9	44.0	49.7	54.7	79	2.2	46.2	49.6	54.2	2.6	49.7
5.0– 5.9	86	2.3	49.6	53.1	57.6	94	2.9	46.6	52.6	56.9	2.7	52.8
6.0– 6.9	98	2.8	50.3	55.3	61.2	92	2.6	50.2	55.0	60.9	2.7	55.1
7.0– 7.9	106	2.9	52.9	57.8	63.6	93	2.7	52.5	57.9	62.1	2.8	57.8
8.0– 8.9	96	2.6	54.5	59.4	63.6	95	2.9	53.6	60.1	65.6	2.8	59.8
9.0– 9.9	122	2.7	58.0	62.9	68.5	122	3.3	55.8	61.8	67.4	3.0	62.3
10.0–10.9	134	3.7	56.9	64.3	72.0	136	3.4	58.6	65.0	71.7	3.6	64.7
11.0–11.9	143	3.6	59.4	66.4	73.4	151	3.8	60.0	66.8	74.8	3.7	66.6
12.0–12.9	78	3.9	61.6	68.7	76.3	79	3.9	62.1	69.3	75.7	3.9	69.0

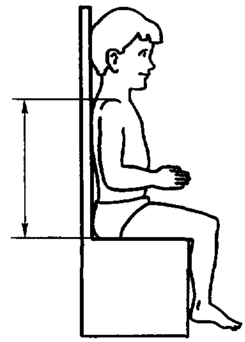


B-23 Shoulder height, seated [cm]

definition: The vertical distance from the seat to the acromion.

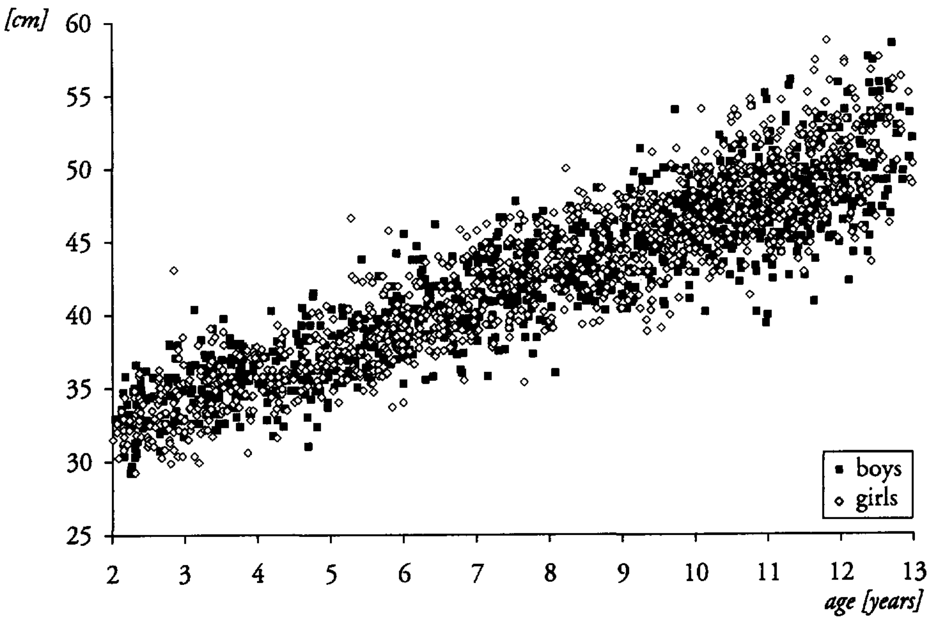
method: The child sits erect, the thighs supported and the lower legs hang down freely. The shoulders are relaxed and the arms are at the sides.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	2.0	29.7	33.7	37.9	92	2.2	30.2	33.2	37.7	2.1	33.4
3.0– 3.9	97	1.8	32.4	35.5	39.1	86	2.0	30.6	34.8	38.5	1.9	35.2
4.0– 4.9	85	2.2	32.4	36.2	40.5	79	1.7	33.5	36.3	40.2	2.0	36.3
5.0– 5.9	86	2.0	35.3	38.3	42.6	94	2.5	34.0	38.2	42.6	2.3	38.2
6.0– 6.9	98	2.2	36.0	40.4	44.7	92	2.2	36.8	40.3	45.3	2.2	40.3
7.0– 7.9	106	2.4	37.6	42.2	46.7	93	2.3	38.0	42.4	46.4	2.4	42.3
8.0– 8.9	96	2.0	40.3	43.5	47.1	95	2.5	39.4	44.2	48.4	2.3	43.8
9.0– 9.9	122	2.5	40.8	45.8	50.0	122	2.6	40.0	45.3	50.3	2.6	45.6
10.0–10.9	134	2.8	40.2	47.3	52.2	136	2.8	42.9	48.0	53.6	2.8	47.6
11.0–11.9	143	2.8	43.3	48.6	53.6	151	2.9	44.2	49.4	55.2	2.9	49.0
12.0–12.9	78	3.3	44.2	50.7	57.4	79	3.1	45.5	51.1	57.1	3.2	50.9

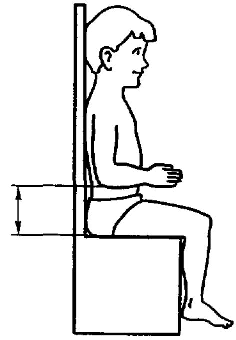


B-24 Elbow height, seated [cm]

definition: The vertical distance from the seat to the lowest bony point of the flexed elbow.

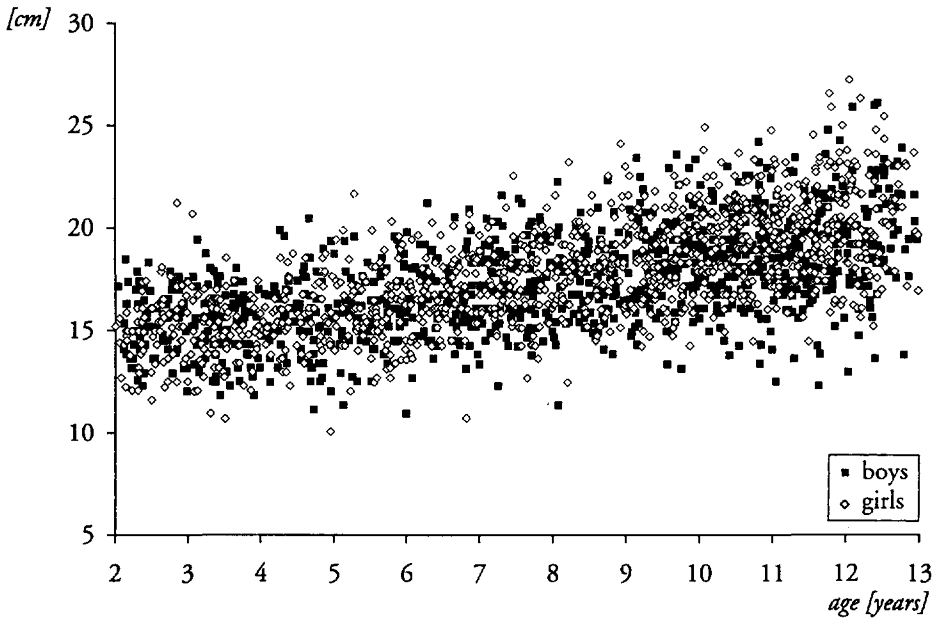
method: The child sits erect, the thighs supported and the lower legs hanging down freely. The upper arm hangs down and the forearm is at right angles to the upper arm.

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0– 2.9	81	1.6	12.6	15.4	17.9	92	1.7	12.1	15.1	17.9	1.6	15.2
3.0– 3.9	97	1.6	12.3	15.3	18.0	86	1.7	12.0	14.9	17.4	1.6	15.1
4.0– 4.9	85	1.9	12.5	15.6	19.6	79	1.7	13.0	15.7	18.5	1.8	15.6
5.0– 5.9	86	1.8	12.5	15.9	19.4	94	1.9	12.7	16.1	19.9	1.9	16.0
6.0– 6.9	98	1.7	13.4	16.7	20.6	92	1.7	13.9	16.8	20.1	1.7	16.7
7.0– 7.9	106	1.9	14.3	17.4	20.6	93	1.8	14.3	17.3	21.0	1.8	17.4
8.0– 8.9	96	1.9	14.1	17.4	21.0	95	2.0	14.7	18.1	23.0	2.0	17.8
9.0– 9.9	122	2.1	14.7	18.3	22.9	122	2.0	14.7	18.4	22.1	2.1	18.4
10.0–10.9	134	2.2	14.3	18.8	22.9	136	2.1	16.0	19.5	23.4	2.2	19.1
11.0–11.9	143	2.2	14.2	18.9	22.8	151	2.1	16.1	19.9	23.7	2.2	19.4
12.0–12.9	78	2.7	13.8	19.7	25.9	79	2.6	16.1	20.3	25.5	2.7	20.0

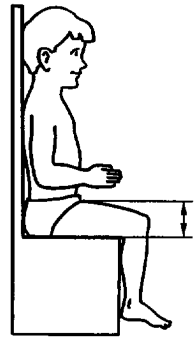


B-25 Thigh thickness, seated [cm]

definition: The vertical distance from the seat to the highest point on the superior surface of the thigh at the abdominal-thigh junction.

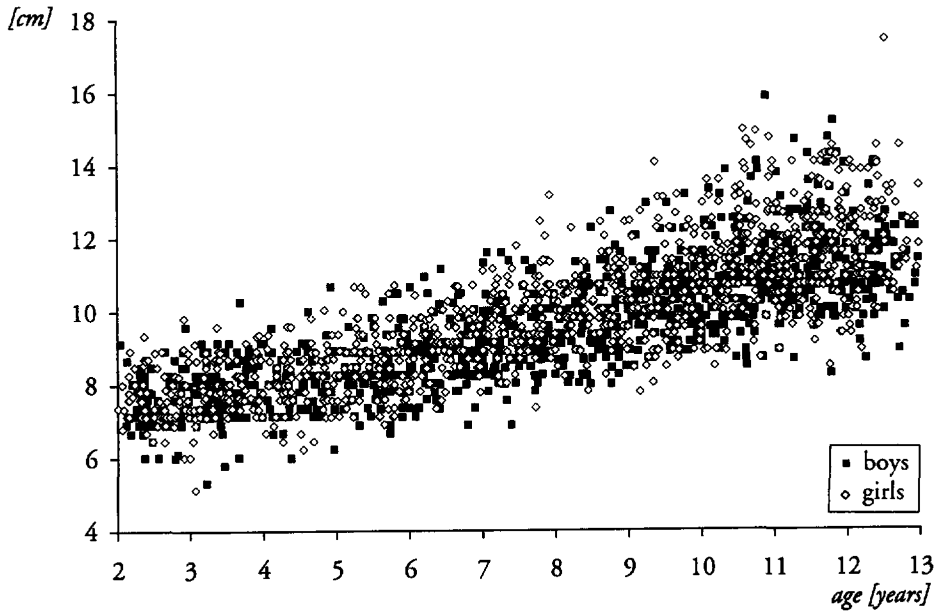
method: The child sits erect, the thighs supported and the lower legs hanging down freely.

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0 – 2.9	81	0.7	6.0	7.6	8.9	92	0.7	6.5	7.7	9.0	0.7	7.6
3.0 – 3.9	97	0.8	6.0	7.9	9.2	86	0.7	6.7	7.9	9.3	0.7	7.9
4.0 – 4.9	85	0.8	6.7	8.0	9.6	79	0.8	6.5	8.1	9.6	0.8	8.1
5.0 – 5.9	86	0.8	6.9	8.4	10.3	94	0.9	7.1	8.6	10.7	0.9	8.5
6.0 – 6.9	98	0.9	7.1	8.7	10.7	92	0.8	7.8	9.2	10.7	0.8	8.9
7.0 – 7.9	106	1.0	7.8	9.3	11.4	93	1.0	8.0	9.8	12.1	1.0	9.5
8.0 – 8.9	96	1.0	8.0	9.7	11.8	95	0.9	8.3	10.1	12.3	1.0	9.9
9.0 – 9.9	122	0.9	8.9	10.3	12.2	122	1.2	8.5	10.5	13.1	1.1	10.4
10.0 – 10.9	134	1.2	8.7	10.9	13.8	136	1.3	8.9	11.5	14.5	1.3	11.2
11.0 – 11.9	143	1.3	9.6	11.3	14.3	151	1.3	9.4	11.6	14.2	1.3	11.4
12.0 – 12.9	78	1.0	9.2	11.3	13.4	79	1.4	9.6	12.0	14.5	1.3	11.6

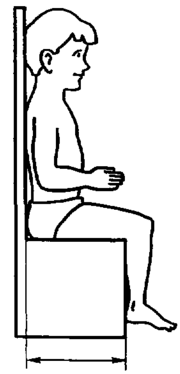


B-26 Buttock-popliteal length, seated [cm]

definition: The horizontal distance from the back of the measuring chair to the hollow of the knee parallel to the long axis of the upper leg.

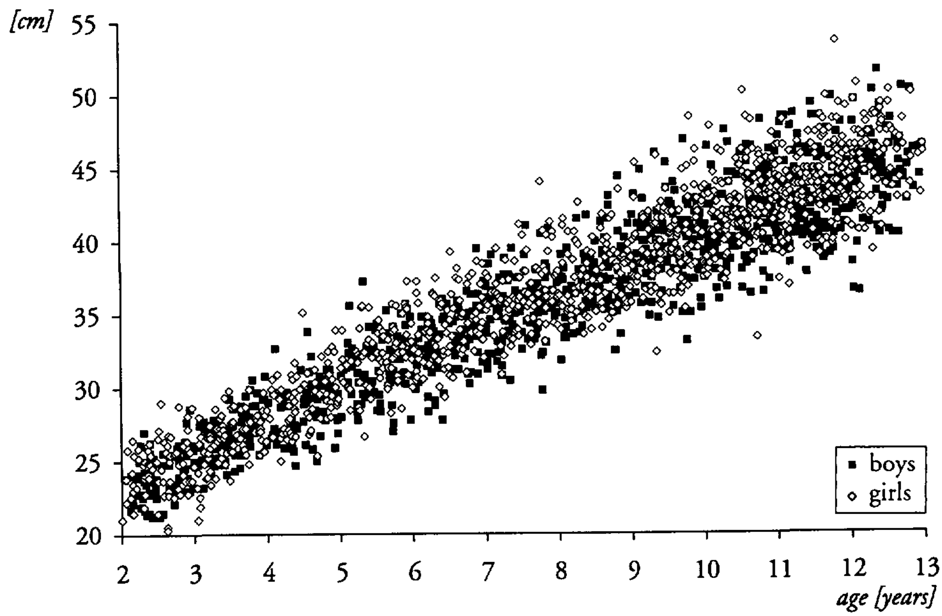
method: The child sits erect, with the posterior part of the right buttock against the back of the measuring chair and the hollow of the knee against the front of the measuring chair. The thighs are supported and the lower legs hang down freely. The distance is measured from the back of the measuring chair to the front of the chair.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	1.6	21.4	24.1	27.0	92	1.8	21.0	24.6	28.7	1.7	24.4
3.0– 3.9	97	1.6	24.1	26.7	29.9	86	1.8	22.5	26.5	29.7	1.7	26.6
4.0– 4.9	85	1.9	25.7	28.5	32.1	79	2.0	26.3	29.2	32.8	2.0	28.9
5.0– 5.9	86	2.1	27.8	31.5	35.6	94	2.0	28.4	32.1	35.7	2.1	31.8
6.0– 6.9	98	2.1	28.8	33.2	36.9	92	2.2	30.5	34.2	38.5	2.2	33.7
7.0– 7.9	106	2.2	31.3	35.4	39.5	93	2.2	32.8	36.3	41.1	2.3	35.8
8.0– 8.9	96	2.5	32.5	37.2	42.4	95	2.2	33.9	37.6	41.8	2.3	37.4
9.0– 9.9	122	2.5	35.0	39.8	44.9	122	2.6	35.6	39.9	45.4	2.6	39.8
10.0–10.9	134	2.6	36.7	41.4	46.5	136	2.6	37.9	42.5	47.3	2.6	41.9
11.0–11.9	143	2.6	39.1	42.9	48.4	151	2.6	39.3	43.9	48.5	2.6	43.4
12.0–12.9	78	2.9	38.5	44.7	50.3	79	2.5	40.6	45.6	50.0	2.8	45.2

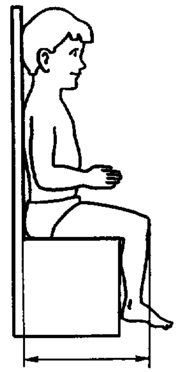


B-27 Buttock-knee length, seated [cm]

definition: The horizontal distance from the posterior surface of the right buttock to the anterior surface of the knee parallel to the long axis of the upper leg.

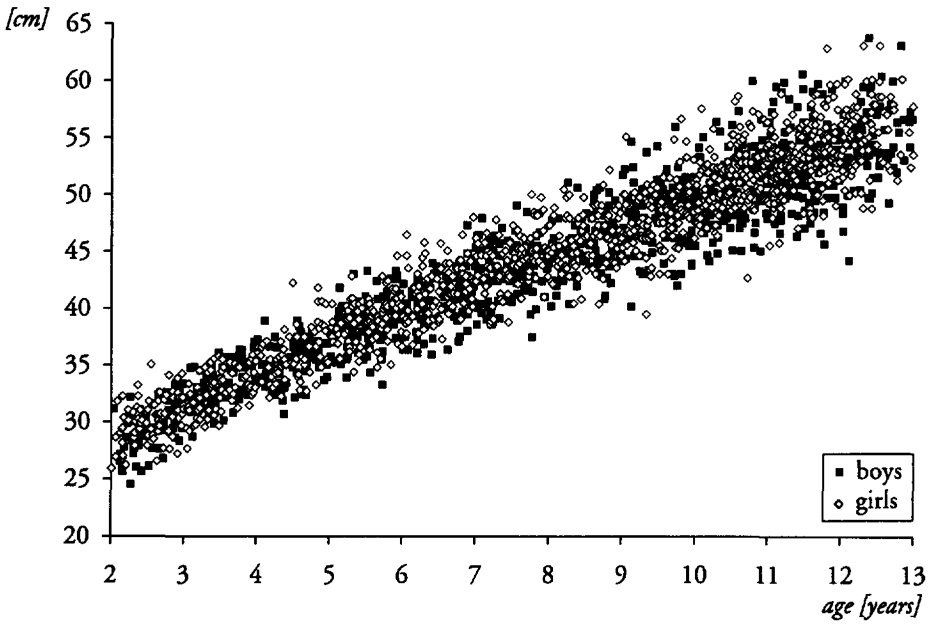
method: The child sits erect, the thighs are supported and the lower legs hang down freely. The posterior part of the buttocks is projected onto the seat at the back of the measuring chair. The distance is measured from this back to the anterior part of the knee at the kneecap (patella).

device: Automated anthropometer.



results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
2.0 – 2.9	81	2.1	25.7	29.6	33.3	92	1.9	26.6	30.2	34.2	2.0	29.9
3.0 – 3.9	97	1.7	30.1	33.2	36.4	86	1.9	29.5	32.8	35.7	1.8	33.1
4.0 – 4.9	85	1.8	32.1	35.2	38.4	79	2.2	32.7	35.9	40.6	2.0	35.6
5.0 – 5.9	86	2.2	34.4	38.6	43.1	94	2.0	35.0	39.0	42.9	2.1	38.8
6.0 – 6.9	98	2.2	36.2	40.7	44.9	92	2.3	37.8	41.6	46.5	2.3	41.1
7.0 – 7.9	106	2.4	38.8	43.3	48.0	93	2.3	38.9	44.2	48.7	2.4	43.7
8.0 – 8.9	96	2.5	40.9	45.6	50.7	95	2.4	40.8	46.0	50.5	2.4	45.8
9.0 – 9.9	122	2.8	43.1	48.5	53.8	122	2.7	43.1	48.3	54.7	2.7	48.4
10.0 – 10.9	134	2.9	45.1	50.5	56.5	136	2.7	47.1	51.6	57.2	2.8	51.1
11.0 – 11.9	143	3.2	47.1	52.6	59.4	151	2.9	48.0	53.3	58.9	3.1	52.9
12.0 – 12.9	78	3.4	48.4	54.6	60.5	79	3.2	50.0	55.5	60.3	3.3	55.1

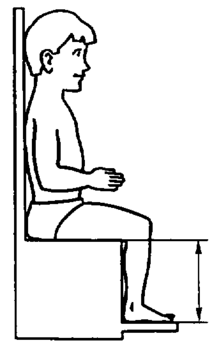


B-28 Popliteal height, seated [cm]

definition: The vertical distance from the footrest surface to the hollow of the knee.

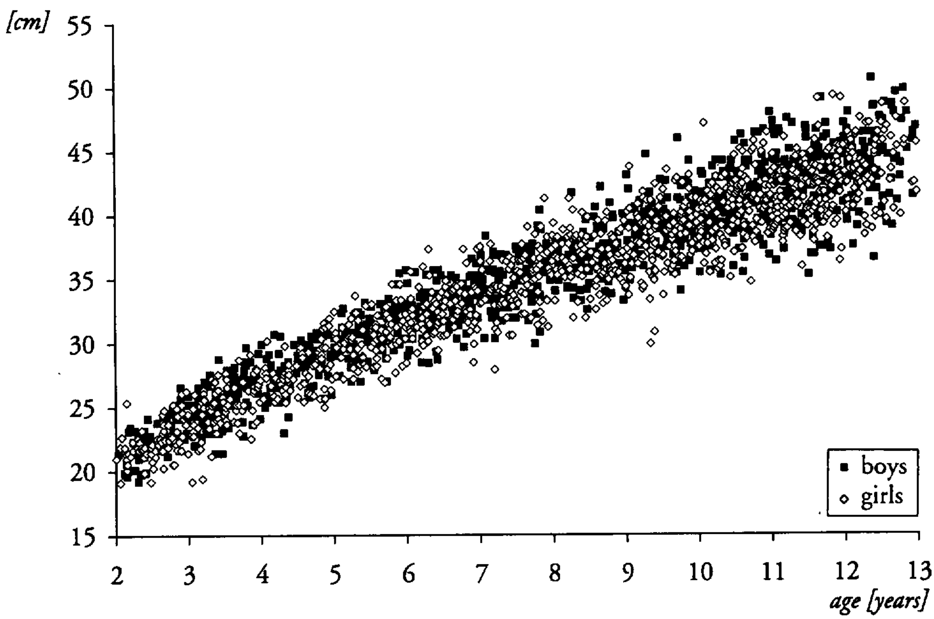
method: The child sits erect, thighs supported and feet resting on a platform adjusted for 90° knee flexion. The distance is measured from the footrest surface to the superior surface of the seat.

device: Automated anthropometer.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	1.6	19.8	22.6	25.7	92	1.5	19.9	22.3	25.4	1.6	22.4
3.0– 3.9	97	1.8	22.0	25.5	28.8	86	1.9	21.2	25.0	28.0	1.8	25.3
4.0– 4.9	85	1.7	25.0	28.1	30.7	79	1.7	25.4	27.7	31.4	1.7	27.9
5.0– 5.9	86	1.8	27.0	30.9	34.6	94	1.7	27.2	30.4	33.7	1.8	30.7
6.0– 6.9	98	1.9	28.7	32.9	36.2	92	1.9	29.5	32.6	37.4	1.9	32.8
7.0– 7.9	106	2.0	30.8	34.9	38.4	93	2.2	30.6	34.7	39.1	2.1	34.8
8.0– 8.9	96	2.0	33.3	36.8	40.9	95	1.9	32.6	36.5	40.2	1.9	36.7
9.0– 9.9	122	2.0	35.5	39.3	43.1	122	2.5	33.7	38.3	42.9	2.3	38.8
10.0–10.9	134	2.5	35.6	40.8	46.4	136	2.4	35.9	40.6	45.2	2.5	40.7
11.0–11.9	143	2.7	37.3	42.4	47.2	151	2.3	37.9	41.8	46.0	2.5	42.1
12.0–12.9	78	3.0	39.1	44.1	49.6	79	2.5	39.1	43.4	47.5	2.8	43.8



B-29 Instep height [cm]

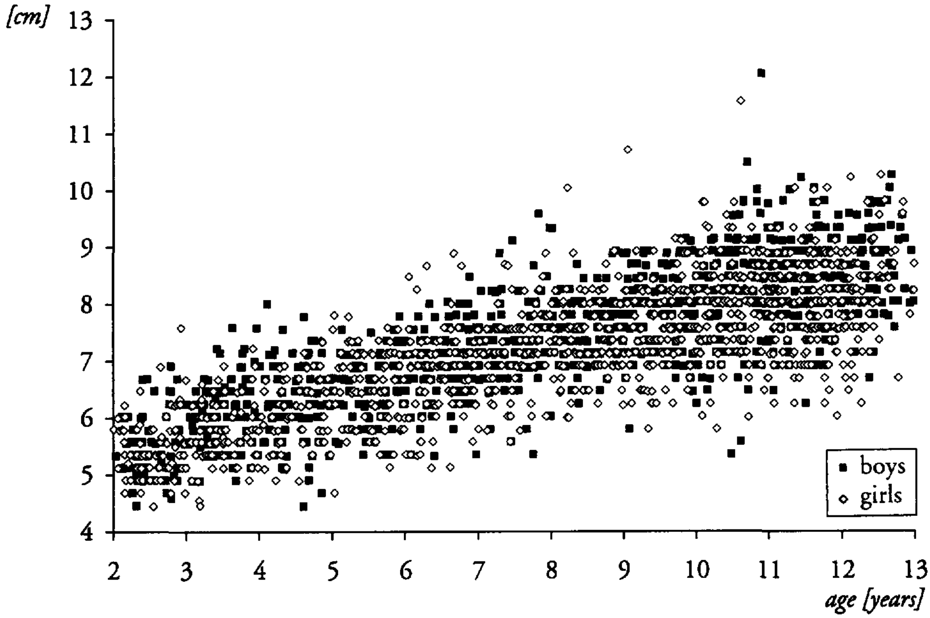
definition: The vertical distance from the footrest surface to the instep (the junction of lower leg and foot).

method: The child sits erect, thighs supported and feet resting on a surface.

device: Automated anthropometer.

results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	0.5	4.7	5.5	6.7	92	0.5	4.7	5.5	6.7	0.5	5.5
3.0– 3.9	97	0.6	4.9	6.0	7.2	86	0.5	4.9	5.8	6.9	0.6	5.9
4.0– 4.9	85	0.7	4.9	6.3	7.6	79	0.6	5.1	6.1	7.3	0.7	6.2
5.0– 5.9	86	0.6	5.4	6.5	7.6	94	0.6	5.4	6.5	7.6	0.6	6.5
6.0– 6.9	98	0.6	5.4	6.9	8.0	92	0.8	5.3	6.8	8.7	0.7	6.9
7.0– 7.9	106	0.7	5.8	7.3	8.9	93	0.7	5.8	7.2	8.7	0.7	7.3
8.0– 8.9	96	0.6	6.5	7.6	8.9	95	0.7	6.2	7.4	8.9	0.6	7.5
9.0– 9.9	122	0.7	6.7	7.9	8.9	122	0.8	6.3	7.6	8.9	0.7	7.7
10.0–10.9	134	1.0	6.5	8.2	9.8	136	0.8	6.5	8.0	9.6	0.9	8.1
11.0–11.9	143	0.8	6.9	8.4	9.8	151	0.8	6.5	8.0	9.3	0.8	8.2
12.0–12.9	78	0.8	7.1	8.6	9.8	79	0.9	6.7	8.2	9.8	0.8	8.4

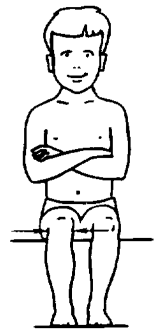


B-30 Knee breadth, seated [cm]

definition: Breadth of the right knee at the condyles of the upper leg.

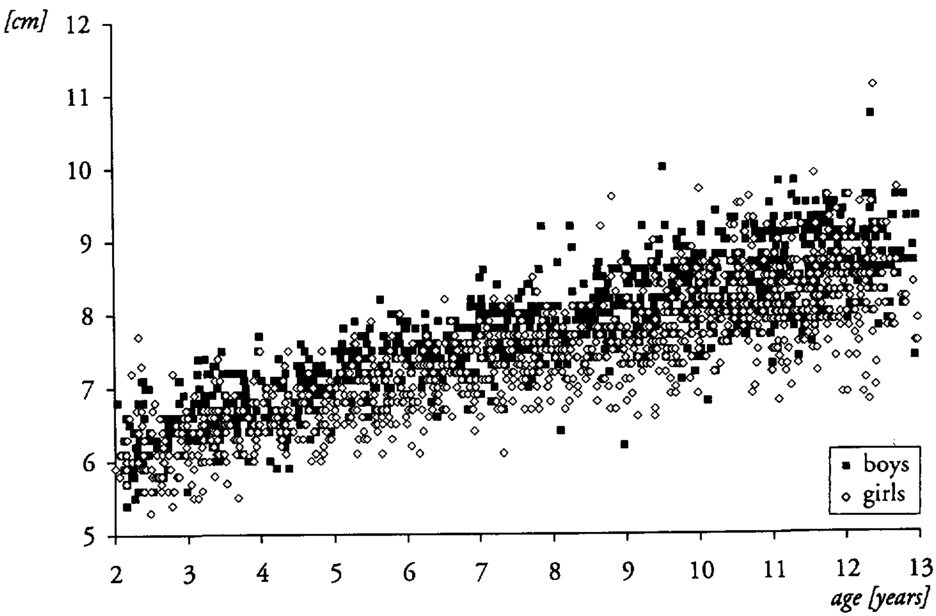
method: The child sits erect with the thighs and feet supported.

device: Sliding calliper.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	0.4	5.6	6.3	7.1	92	0.4	5.6	6.2	7.2	0.4	6.2
3.0– 3.9	97	0.4	6.0	6.7	7.5	86	0.4	5.5	6.4	7.1	0.4	6.6
4.0– 4.9	85	0.4	6.0	6.8	7.4	79	0.3	6.1	6.7	7.3	0.4	6.8
5.0– 5.9	86	0.3	6.7	7.3	8.0	94	0.4	6.3	6.9	7.7	0.4	7.1
6.0– 6.9	98	0.3	6.7	7.4	8.1	92	0.4	6.4	7.1	7.9	0.4	7.3
7.0– 7.9	106	0.4	7.0	7.8	8.5	93	0.4	6.7	7.4	8.2	0.5	7.6
8.0– 8.9	96	0.4	7.2	7.9	8.7	95	0.5	6.7	7.5	8.7	0.5	7.7
9.0– 9.9	122	0.5	7.3	8.2	9.1	122	0.5	6.8	7.8	8.7	0.5	8.0
10.0–10.9	134	0.5	7.4	8.4	9.3	136	0.5	7.2	8.2	9.3	0.5	8.3
11.0–11.9	143	0.5	7.8	8.7	9.5	151	0.5	7.2	8.2	9.2	0.6	8.4
12.0–12.9	78	0.5	7.9	8.8	9.6	79	0.7	6.9	8.3	9.6	0.7	8.6

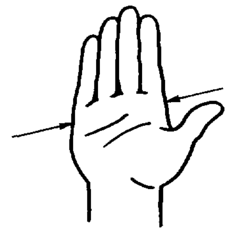


B-31 Hand breadth (without thumb) [cm]

definition: The distance from the radial to ulnar side of the hand, measured at the distal extremities of the metacarpals.

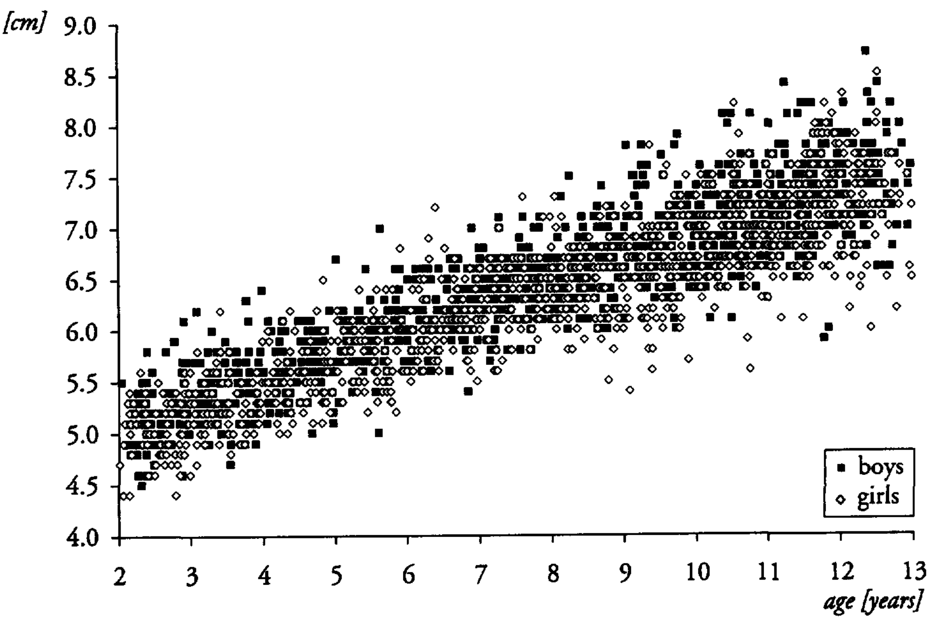
method: The child extends right hand and fingers, palm up and thumb abducted from the hand.

device: Sliding calliper



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	0.3	4.6	5.2	5.9	92	0.3	4.4	5.1	5.6	0.3	5.1
3.0 – 3.9	97	0.3	4.9	5.4	6.3	86	0.3	4.9	5.3	5.8	0.3	5.4
4.0 – 4.9	85	0.3	5.1	5.6	6.1	79	0.3	5.1	5.5	6.2	0.3	5.6
5.0 – 5.9	86	0.3	5.4	6.0	6.6	94	0.3	5.3	5.8	6.4	0.3	5.9
6.0 – 6.9	98	0.3	5.6	6.2	6.7	92	0.3	5.6	6.1	6.8	0.3	6.1
7.0 – 7.9	106	0.3	5.8	6.4	7.0	93	0.3	5.6	6.4	7.1	0.3	6.4
8.0 – 8.9	96	0.3	6.0	6.6	7.3	95	0.3	5.8	6.5	7.1	0.3	6.5
9.0 – 9.9	122	0.4	6.3	6.9	7.8	122	0.4	5.8	6.6	7.5	0.4	6.7
10.0 – 10.9	134	0.4	6.4	7.1	8.0	136	0.4	6.3	6.9	7.6	0.4	7.0
11.0 – 11.9	143	0.4	6.6	7.3	8.1	151	0.4	6.5	7.1	7.9	0.4	7.2
12.0 – 12.9	78	0.4	6.6	7.4	8.3	79	0.5	6.2	7.2	8.1	0.5	7.3

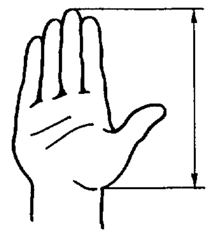


B-32 Hand length [cm]

definition: The distance from the wrist crease to the tip of the middle finger, parallel to the fingers.

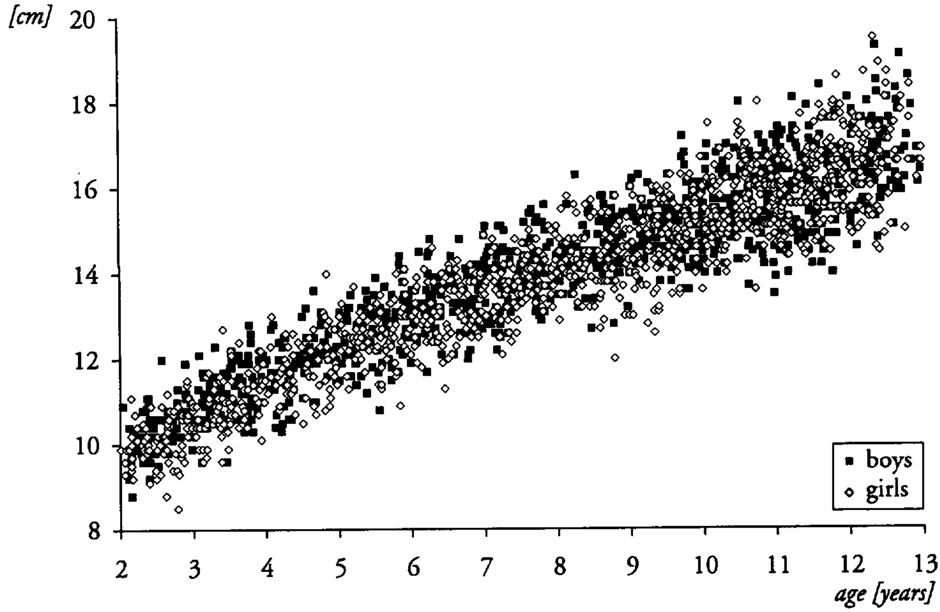
method: The child extends right hand and fingers with palm up.

device: Sliding calliper.



results:

age [years]	boys n	s	P_3	$\bar{x}$	P_{97}	girls n	s	P_3	$\bar{x}$	P_{97}	boys + girls s	$\bar{x}$
2.0– 2.9	81	0.6	9.2	10.4	11.3	92	0.6	9.1	10.2	11.2	0.6	10.3
3.0– 3.9	97	0.6	10.3	11.2	12.4	86	0.7	9.7	11.0	12.2	0.6	11.1
4.0– 4.9	85	0.7	10.5	11.9	13.1	79	0.7	10.7	11.8	13.0	0.7	11.8
5.0– 5.9	86	0.7	11.4	12.7	14.1	94	0.6	11.3	12.6	13.8	0.7	12.6
6.0– 6.9	98	0.6	12.1	13.3	14.8	92	0.7	11.9	13.2	14.3	0.7	13.3
7.0– 7.9	106	0.7	12.6	13.9	15.3	93	0.7	12.5	13.8	15.0	0.7	13.9
8.0– 8.9	96	0.7	13.2	14.5	15.8	95	0.7	12.9	14.3	15.7	0.7	14.4
9.0– 9.9	122	0.7	13.8	15.1	16.5	122	0.8	13.1	14.9	16.3	0.8	15.0
10.0–10.9	134	0.9	14.0	15.6	17.0	136	0.8	14.2	15.6	17.3	0.8	15.6
11.0–11.9	143	0.9	14.5	16.1	17.9	151	0.9	14.5	16.1	17.9	0.9	16.1
12.0–12.9	78	1.0	15.1	16.7	18.6	79	1.1	14.9	16.6	18.7	1.0	16.6

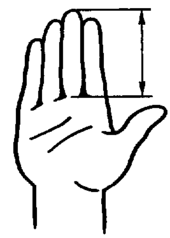


B-33 Middle finger length [cm]

definition: Distance from the skin crease at the base of the middle finger to the tip of the middle finger, parallel to the long axis of the middle finger.

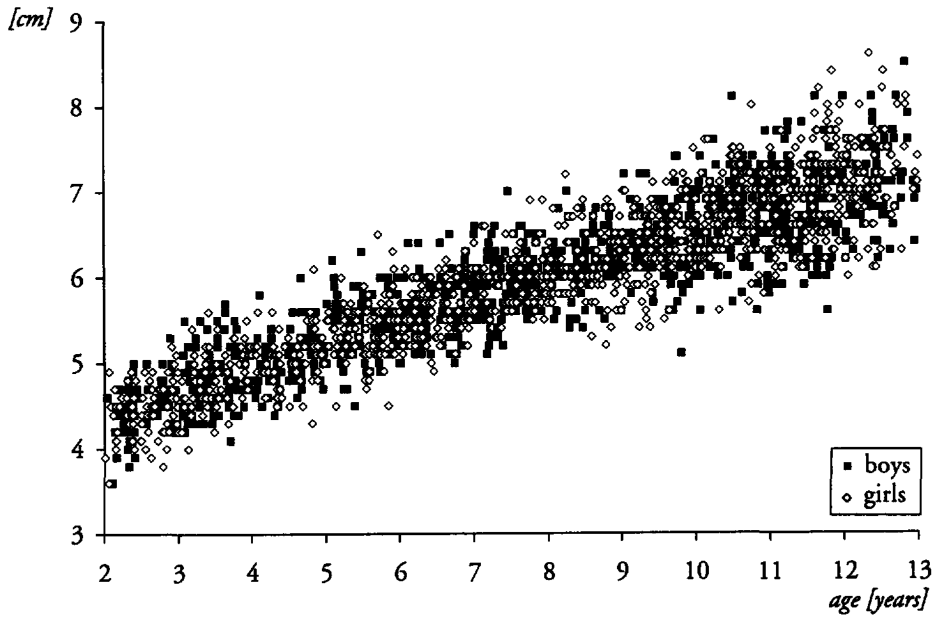
method: The child extends right hand and fingers, with palm up.

device: Sliding calliper.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	0.3	3.9	4.5	5.0	92	0.3	3.9	4.5	5.0	0.3	4.5
3.0– 3.9	97	0.4	4.3	4.9	5.5	86	0.3	4.2	4.8	5.4	0.3	4.8
4.0– 4.9	85	0.3	4.5	5.1	5.6	79	0.3	4.5	5.0	5.6	0.3	5.0
5.0– 5.9	86	0.4	4.7	5.4	6.0	94	0.3	4.7	5.4	6.1	0.4	5.4
6.0– 6.9	98	0.3	5.1	5.7	6.4	92	0.3	5.1	5.6	6.2	0.3	5.6
7.0– 7.9	106	0.4	5.3	5.9	6.6	93	0.3	5.4	5.9	6.6	0.3	5.9
8.0– 8.9	96	0.4	5.5	6.2	6.8	95	0.4	5.4	6.2	6.9	0.4	6.2
9.0– 9.9	122	0.4	5.7	6.4	7.2	122	0.4	5.5	6.4	7.1	0.4	6.4
10.0–10.9	134	0.4	5.8	6.7	7.4	136	0.4	6.0	6.7	7.5	0.4	6.7
11.0–11.9	143	0.5	6.0	6.9	7.7	151	0.5	6.1	6.9	7.9	0.5	6.9
12.0–12.9	78	0.5	6.3	7.1	8.1	79	0.5	6.1	7.1	8.2	0.5	7.1

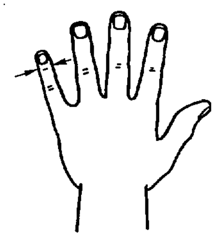


B-34 Little finger breadth [cm]

definition: The maximum distance from the radial to the ulnar side of the little finger at the distal interphalangial joint.

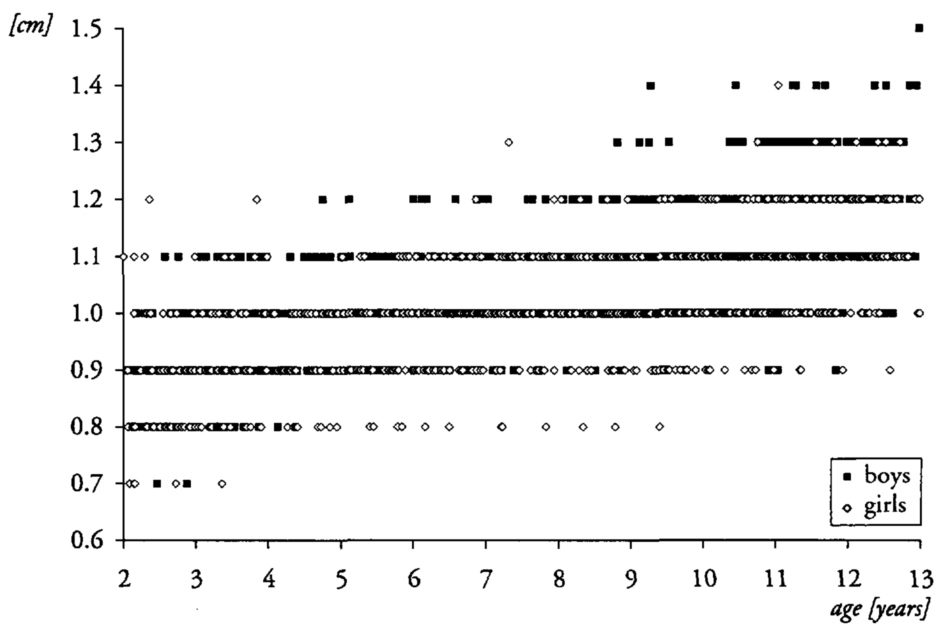
method: The child extends right hand and fingers, with palm up and fingers spread.

device: Sliding calliper.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	0.1	0.8	0.9	1.0	92	0.1	0.7	0.9	1.1	0.1	0.9
3.0– 3.9	97	0.1	0.8	1.0	1.1	86	0.1	0.8	0.9	1.1	0.1	0.9
4.0– 4.9	85	0.1	0.9	1.0	1.1	79	0.1	0.8	0.9	1.0	0.1	0.9
5.0– 5.9	86	0.1	0.9	1.0	1.1	94	0.1	0.8	1.0	1.1	0.1	1.0
6.0– 6.9	98	0.1	0.9	1.0	1.2	92	0.1	0.9	1.0	1.1	0.1	1.0
7.0– 7.9	106	0.1	0.9	1.0	1.2	93	0.1	0.8	1.0	1.1	0.1	1.0
8.0– 8.9	96	0.1	0.9	1.1	1.2	95	0.1	0.9	1.0	1.2	0.1	1.1
9.0– 9.9	122	0.1	1.0	1.1	1.3	122	0.1	0.9	1.0	1.2	0.1	1.1
10.0–10.9	134	0.1	1.0	1.1	1.3	136	0.1	0.9	1.1	1.2	0.1	1.1
11.0–11.9	143	0.1	1.0	1.2	1.3	151	0.1	1.0	1.1	1.2	0.1	1.1
12.0–12.9	78	0.1	1.0	1.2	1.4	79	0.1	1.0	1.1	1.3	0.1	1.2

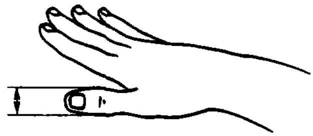


B-35 Thumb breadth [cm]

definition: The maximum distance from the radial to the ulnar side of the thumb at the distal interphalangial joint.

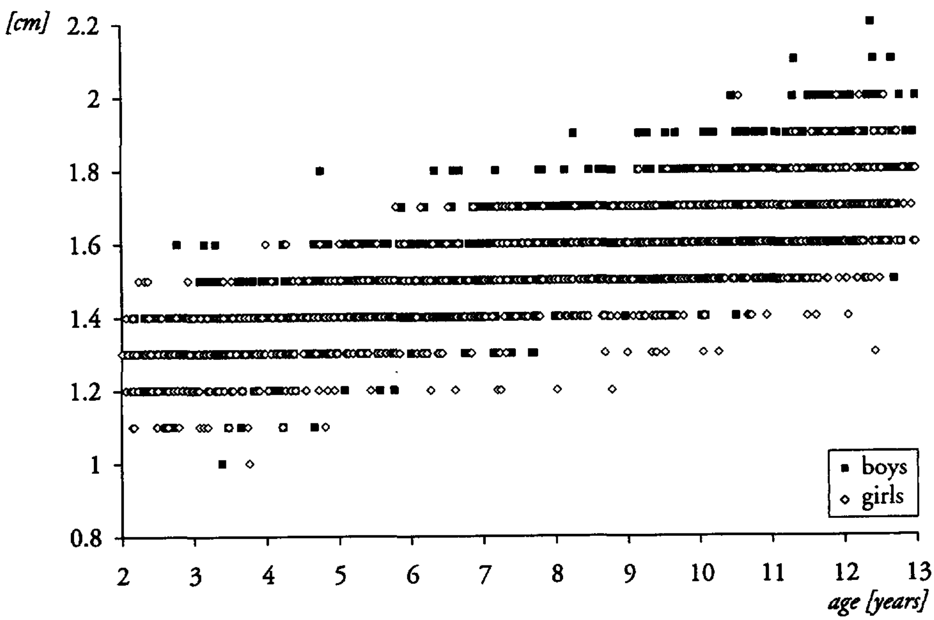
method: The child extends right hand and thumb.

device: Sliding calliper.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	0.1	1.2	1.3	1.4	92	0.1	1.1	1.3	1.5	0.1	1.3
3.0– 3.9	97	0.1	1.1	1.4	1.5	86	0.1	1.1	1.3	1.5	0.1	1.3
4.0– 4.9	85	0.1	1.2	1.4	1.6	79	0.1	1.1	1.3	1.5	0.1	1.4
5.0– 5.9	86	0.1	1.2	1.5	1.6	94	0.1	1.3	1.4	1.6	0.1	1.4
6.0– 6.9	98	0.1	1.3	1.5	1.8	92	0.1	1.3	1.4	1.7	0.1	1.5
7.0– 7.9	106	0.1	1.3	1.6	1.7	93	0.1	1.3	1.5	1.7	0.1	1.5
8.0– 8.9	96	0.1	1.4	1.6	1.8	95	0.1	1.3	1.5	1.7	0.1	1.6
9.0– 9.9	122	0.1	1.4	1.7	1.9	122	0.1	1.3	1.5	1.7	0.1	1.6
10.0–10.9	134	0.1	1.5	1.7	1.9	136	0.1	1.4	1.6	1.8	0.1	1.6
11.0–11.9	143	0.1	1.5	1.7	2.0	151	0.1	1.5	1.6	1.9	0.1	1.7
12.0–12.9	78	0.1	1.6	1.8	2.1	79	0.1	1.5	1.7	1.9	0.2	1.7

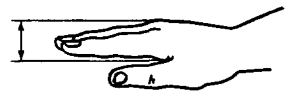


B-36 Hand thickness [cm]

definition: The maximum distance between the palm and the back of the hand at the middle finger joint.

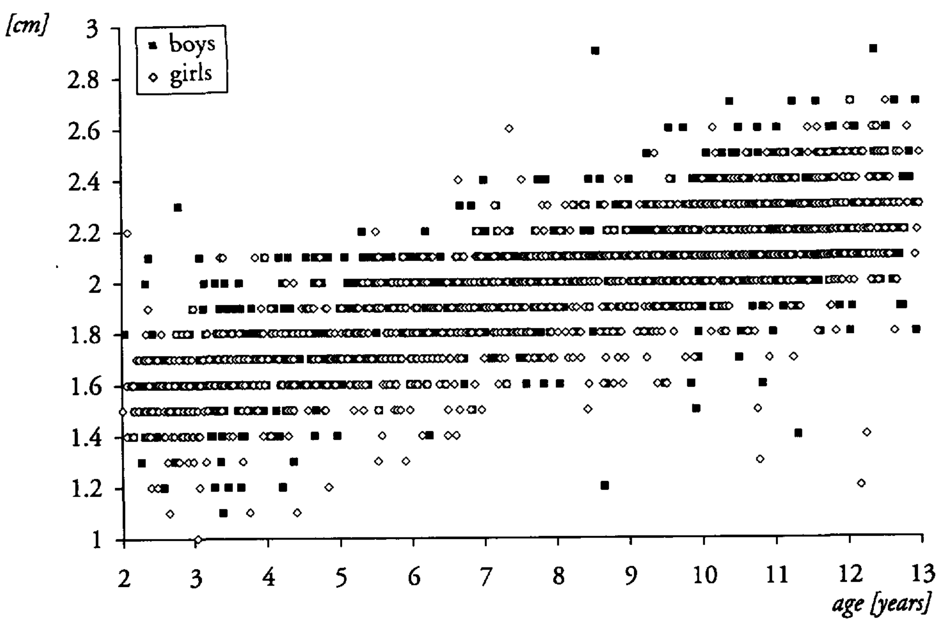
method: The child extends the right hand and fingers.

device: Sliding calliper.



results:

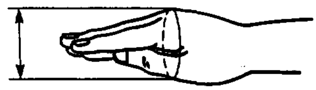
age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	0.2	1.3	1.6	2.0	92	0.2	1.2	1.6	1.9	0.2	1.6
3.0 – 3.9	97	0.2	1.2	1.7	2.0	86	0.2	1.2	1.6	2.1	0.2	1.6
4.0 – 4.9	85	0.2	1.4	1.7	2.1	79	0.2	1.4	1.7	2.0	0.2	1.7
5.0 – 5.9	86	0.2	1.6	1.9	2.1	94	0.2	1.4	1.8	2.1	0.2	1.8
6.0 – 6.9	98	0.2	1.6	1.9	2.3	92	0.2	1.4	1.8	2.1	0.2	1.9
7.0 – 7.9	106	0.2	1.7	2.0	2.3	93	0.2	1.7	2.0	2.3	0.2	2.0
8.0 – 8.9	96	0.2	1.6	2.1	2.4	95	0.2	1.6	2.0	2.3	0.2	2.0
9.0 – 9.9	122	0.2	1.7	2.1	2.4	122	0.2	1.7	2.1	2.3	0.2	2.1
10.0 – 10.9	134	0.2	1.8	2.2	2.5	136	0.2	1.8	2.1	2.4	0.2	2.2
11.0 – 11.9	143	0.2	1.9	2.2	2.6	151	0.2	1.9	2.2	2.5	0.2	2.2
12.0 – 12.9	78	0.2	1.9	2.3	2.7	79	0.2	1.8	2.2	2.6	0.2	2.3



B-37 Hand diameter [cm]

definition: The smallest circular diameter through which the extended hand, reduced to its smallest configuration, can pass without forcing.

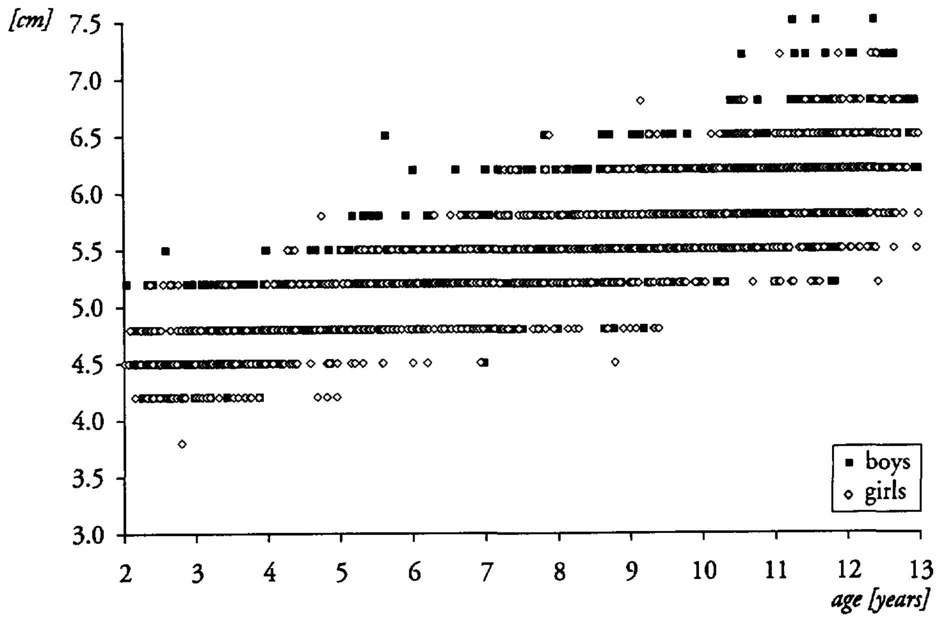
method: The child extends the right hand and reduces it to the smallest configuration.



device: Measurement board with rounds of different diameters.

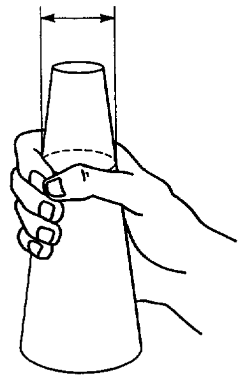
results:

age [years]	boys n	s	P_3	$\bar{x}$	P_{97}	girls n	s	P_3	$\bar{x}$	P_{97}	boys + girls s	$\bar{x}$
2.0 – 2.9	81	0.3	4.2	4.7	5.2	92	0.3	4.2	4.5	5.2	0.3	4.6
3.0 – 3.9	97	0.3	4.2	4.8	5.2	86	0.3	4.2	4.6	5.2	0.3	4.7
4.0 – 4.9	85	0.3	4.5	5.0	5.5	79	0.3	4.2	4.8	5.5	0.3	4.9
5.0 – 5.9	86	0.3	4.8	5.3	5.8	94	0.3	4.5	5.1	5.5	0.3	5.1
6.0 – 6.9	98	0.3	4.8	5.3	6.2	92	0.3	4.8	5.2	5.8	0.3	5.3
7.0 – 7.9	106	0.4	4.8	5.5	6.2	93	0.4	4.8	5.4	6.2	0.4	5.4
8.0 – 8.9	96	0.4	5.2	5.6	6.5	95	0.3	4.8	5.5	6.2	0.4	5.6
9.0 – 9.9	122	0.4	5.2	5.8	6.5	122	0.4	4.8	5.6	6.2	0.4	5.7
10.0 – 10.9	134	0.4	5.5	5.9	6.8	136	0.4	5.2	5.9	6.5	0.4	5.9
11.0 – 11.9	143	0.5	5.5	6.2	7.2	151	0.4	5.2	6.1	6.8	0.4	6.1
12.0 – 12.9	78	0.4	5.8	6.4	7.2	79	0.4	5.5	6.1	6.8	0.4	6.3



B-38 Grip circumference [cm]

definition: The maximum circumferene of the circle, made by thumb and forefinger when enclosing a cone (in accordance with DIN 33402).



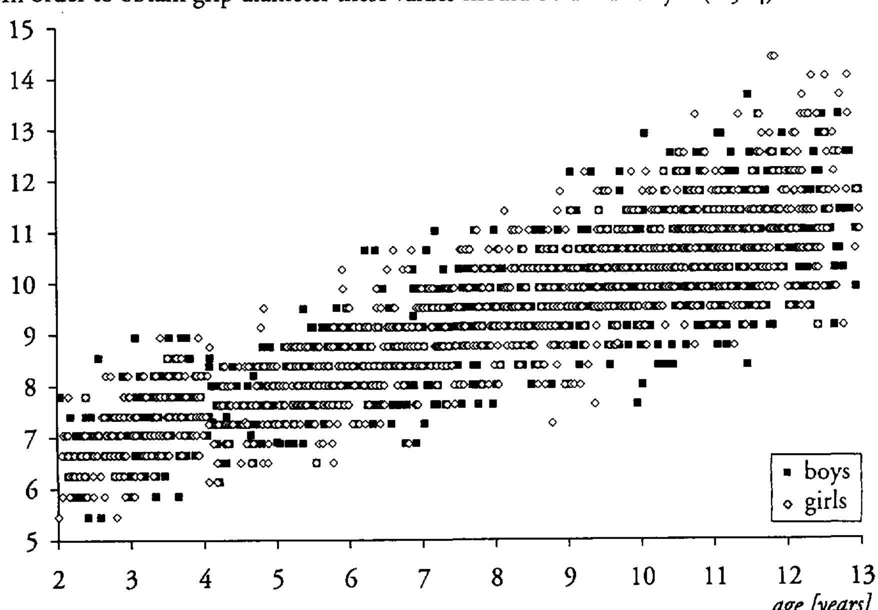
method: The tips of thumb and forefinger are held together and make a circle. This circle is shoved along a cone, while the tips of thumb and forefinger remain together. The maximum value is read at the fold of the skin between thumb and forefinger.

device: Cone.

results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0 – 2.9	81	0.6	5.9	6.8	8.2	92	0.6	5.9	6.8	8.2	0.6	6.8
3.0 – 3.9	97	0.7	6.3	7.5	9.0	86	0.6	6.3	7.4	8.6	0.7	7.5
4.0 – 4.9	85	0.6	6.5	7.6	8.6	79	0.7	6.5	7.6	9.1	0.6	7.6
5.0 – 5.9	86	0.7	6.9	8.2	9.5	94	0.7	6.9	8.1	9.5	0.7	8.1
6.0 – 6.9	98	0.7	7.3	8.6	10.3	92	0.8	7.3	8.7	10.3	0.8	8.6
7.0 – 7.9	106	0.8	7.6	9.1	10.6	93	0.8	8.0	9.2	10.6	0.8	9.2
8.0 – 8.9	96	0.7	8.0	9.6	11.0	95	0.9	8.0	9.6	11.4	0.8	9.6
9.0 – 9.9	122	0.8	8.8	10.1	11.8	122	0.9	8.0	10.1	11.8	0.8	10.1
10.0 – 10.9	134	1.0	8.4	10.5	12.5	136	0.9	9.1	10.6	12.1	0.9	10.6
11.0 – 11.9	143	1.0	9.1	10.9	12.9	151	1.0	9.5	11.0	12.9	1.0	10.9
12.0 – 12.9	78	1.0	9.5	11.1	13.3	79	1.2	9.5	11.5	14.0	1.1	11.3

In order to obtain grip diameter these values should be divided by π (= 3.14)

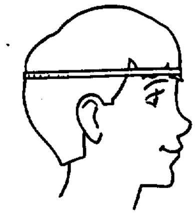


B-39 Head circumference [cm]

definition: The maximum, approximately horizontal, circumference of the head at the level of the plane passing above glabella and through opistocranion, perpendicular to the midsagittal plane.

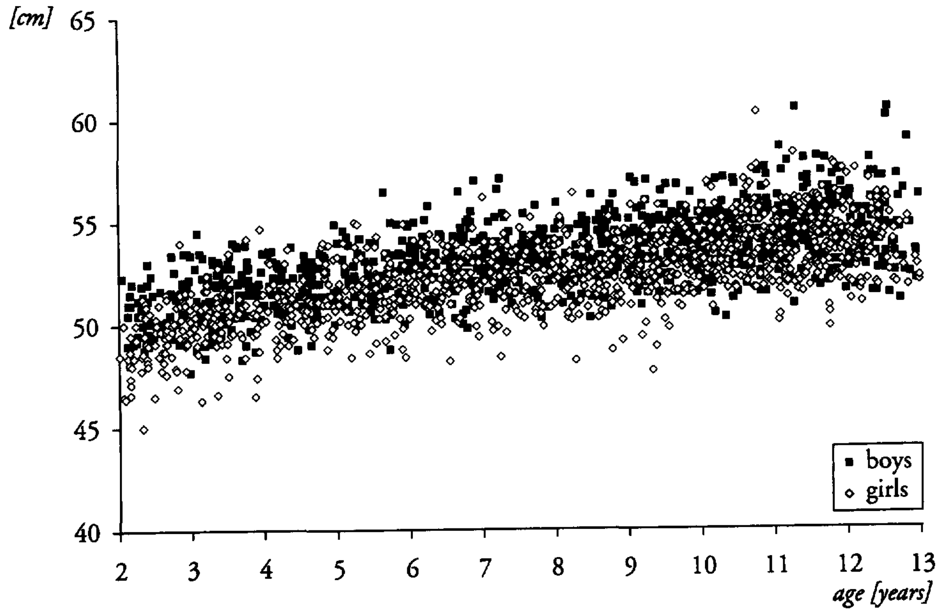
method: The hair is included in the measurement but the tape is pulled snug.

device: Measuring tape.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	1.3	48.8	50.8	53.4	92	1.5	46.5	49.3	51.6	1.6	50.0
3.0– 3.9	97	1.4	48.7	51.5	53.9	86	1.5	46.6	50.4	53.5	1.5	51.0
4.0– 4.9	85	1.2	49.4	51.8	53.8	79	1.3	48.8	51.0	53.8	1.3	51.4
5.0– 5.9	86	1.3	50.3	52.4	54.9	94	1.4	48.6	51.6	54.9	1.4	52.0
6.0– 6.9	98	1.4	50.3	52.9	55.8	92	1.3	49.7	52.2	54.4	1.4	52.6
7.0– 7.9	106	1.2	51.0	53.1	55.4	93	1.4	49.7	52.4	54.7	1.4	52.8
8.0– 8.9	96	1.4	51.0	53.4	55.9	95	1.4	49.2	52.4	55.2	1.5	52.9
9.0– 9.9	122	1.3	51.5	54.0	56.8	122	1.4	49.8	52.9	55.7	1.5	53.4
10.0–10.9	134	1.4	51.4	54.2	57.1	136	1.5	51.7	53.9	56.9	1.5	54.0
11.0–11.9	143	1.5	52.0	54.8	58.0	151	1.6	50.8	53.8	57.2	1.6	54.3
12.0–12.9	78	1.9	51.5	54.6	59.0	79	1.5	51.6	53.9	56.3	1.7	54.2

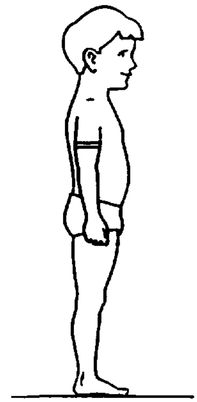


B-40 Upper arm circumference [cm]

definition: The maximum, approximately horizontal, circumference of the upper arm, at the biceps.

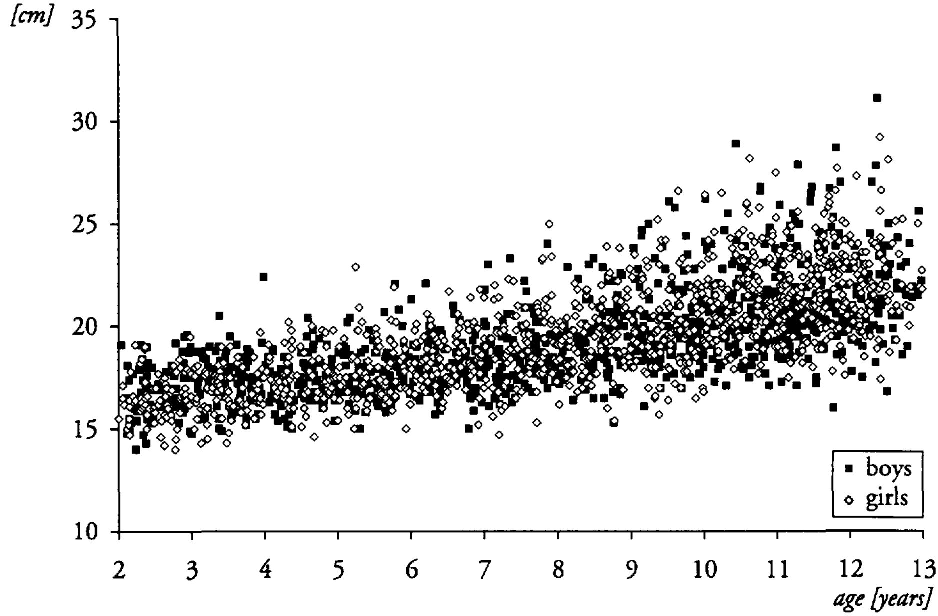
method: The arm hangs down relaxed.

device: Measuring tape.



results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
2.0– 2.9	81	1.3	14.7	16.8	19.2	92	1.1	14.5	16.5	19.0	1.2	16.7
3.0– 3.9	97	1.2	15.2	17.4	19.5	86	1.1	14.5	16.8	19.0	1.2	17.1
4.0– 4.9	85	1.2	15.2	17.3	19.5	79	1.2	15.1	17.5	19.8	1.2	17.4
5.0– 5.9	86	1.2	15.8	17.8	20.7	94	1.5	15.4	17.8	20.9	1.4	17.8
6.0– 6.9	98	1.3	15.9	18.1	21.0	92	1.3	16.3	18.5	21.4	1.3	18.3
7.0– 7.9	106	1.5	16.5	18.6	22.2	93	1.9	15.6	19.1	23.3	1.7	18.8
8.0– 8.9	96	1.7	16.5	19.3	22.9	95	1.7	16.2	19.6	22.8	1.7	19.4
9.0– 9.9	122	1.9	17.5	20.0	24.7	122	2.0	16.5	20.0	24.2	2.0	20.0
10.0–10.9	134	2.1	17.5	20.8	26.2	136	2.1	18.3	21.6	26.0	2.1	21.2
11.0–11.9	143	2.3	17.5	21.4	26.7	151	2.0	18.2	21.8	25.8	2.2	21.6
12.0–12.9	78	2.3	17.8	21.8	27.0	79	2.2	18.7	22.1	27.3	2.2	21.9



C Differences between successive age groups of boys and girls

	boys										girls									
age: / measurements	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12
1 body mass	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
2 stature	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
3 shoulder height standing	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
4 reaching height standing	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
5 step height	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•
6 shoulder breadth	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
7 breadth across the elbows	•	•	•	•	•	•	•	•	•		•	•		•	•		•	•		•
8 hip breadth standing	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
9 breast depth	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•	•	•
10 head length	•		•			•		•	•	•	•	•	•	•				•		
11 chin to crown length	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•		•
12 head breadth	•		•	•			•		•		•	•			•			•		
13 head height	•	•	•		•		•	•	•		•	•	•		•	•		•	•	
14 foot breadth	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
15 foot length	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
16 hip breadth seated	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•		•
17 reaching height seated	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
18 arm length	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
19 reaching depth seated	•		•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•
20 buttock-foot length	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
21 sitting height	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
22 eye height seated	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
23 shoulder height seated	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
24 elbow height seated				•	•		•	•		•		•		•	•	•		•		
25 thigh thickness	•		•	•	•	•	•	•	•		•		•	•	•	•	•	•		•
26 buttock-popliteal length	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
27 buttock-knee length	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
28 popliteal height	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
29 instep height	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
30 knee breadth	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•	•	•		
31 hand breadth	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
32 hand length	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
33 middle finger length	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
34 little finger breadth	•		•	•		•	•		•	•			•	•	•	•		•	•	•
35 thumb breadth	•		•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	
36 hand thickness	•		•	•	•	•		•	•	•	•	•	•	•	•		•	•	•	
37 hand diameter	•	•	•		•	•	•	•	•	•		•	•	•	•		•	•	•	
38 grip circumference	•		•	•	•	•	•	•	•		•		•	•	•	•	•	•	•	•
39 head circumference	•		•	•			•		•		•	•	•	•			•	•		
40 upper arm circumference	•		•	•	•	•	•	•	•			•		•	•	•	•	•		
proportions:																				
41 sitting height/stature	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•
42 shoulder breadth/hip breadth					•	•	•		•									•		•
43 upper leg/lower leg		•									•		•			•		•		
44 head length/stature	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
45 arm length/leg length	•	•		•	•		•					•		•		•	•			

•= *the second age group has a significant larger mean value than the preceding age group* ($p < 0.05$).

D Differences between boys and girls per age group

measurements	2	3	4	5	6	7	8	9	10	11	12
	age [years]										
1 body mass		■							■		
2 stature		■						■			
3 shoulder height standing									■		
4 reaching height standing		■							■		
5 step height											
6 shoulder breadth		■		■							
7 breadth across the elbows		■		■				■			
8 hip breadth standing		■			•		•		•	•	•
9 breast depth		■		•					•	•	•
10 head length	■	■	■	■		■	■	■		■	
11 chin to crown length	■	■	■	■	■	■	■	■	■	■	■
12 head breadth	■	■	■	■	■	■	■	■	■	■	■
13 head height	■	■	■	■	■	■	■	■	■	■	■
14 foot breadth	■	■	■	■		■	■	■		■	■
15 foot length	■	■		■				■		■	■
16 hip breadth seated			•	•	•		•	•	•		
17 reaching height seated								■			
18 arm length		■		■				■			
19 reaching depth seated		■							•		
20 buttock-foot length								■			
21 sitting height	■	■						■			
22 eye height seated		■						■			
23 shoulder height seated		■					•		•	•	
24 elbow height seated							•		•	•	
25 thigh thickness					•	•	•	•	•	•	•
26 buttock-popliteal length	•		•	•	•	•			•	•	•
27 buttock-knee length			•		•	•			•	•	•
28 popliteal height								■			
29 instep height		■					■	■		■	■
30 knee breadth	■	■	■	■	■	■	■	■	■	■	■
31 hand breadth	■	■	■	■	■		■	■	■	■	■
32 hand length	■	■									
33 middle finger length											
34 little finger breadth		■	■	■	■	■	■	■	■	■	■
35 thumb breadth	■	■	■	■	■	■	■	■	■	■	■
36 hand thickness				■	■		■	■	■		
37 hand diameter	■	■	■	■	■		■	■		■	■
38 grip circumference											•
39 head circumference	■	■	■	■	■	■	■	■		■	■
40 upper arm circumference		■			•	•			•		
proportions											
41 sitting height/stature											
42 shoulder breadth/hip breadth	■				■		■	■	■	■	■
43 upper leg/lower leg	•	•	•	•	•	•	•	•	•	•	
44 head length/stature		■	■	■	■	■	■	■	■	■	■
45 arm length/leg length	■		■	■				■			■

■ = *boys significant larger mean values than girls*

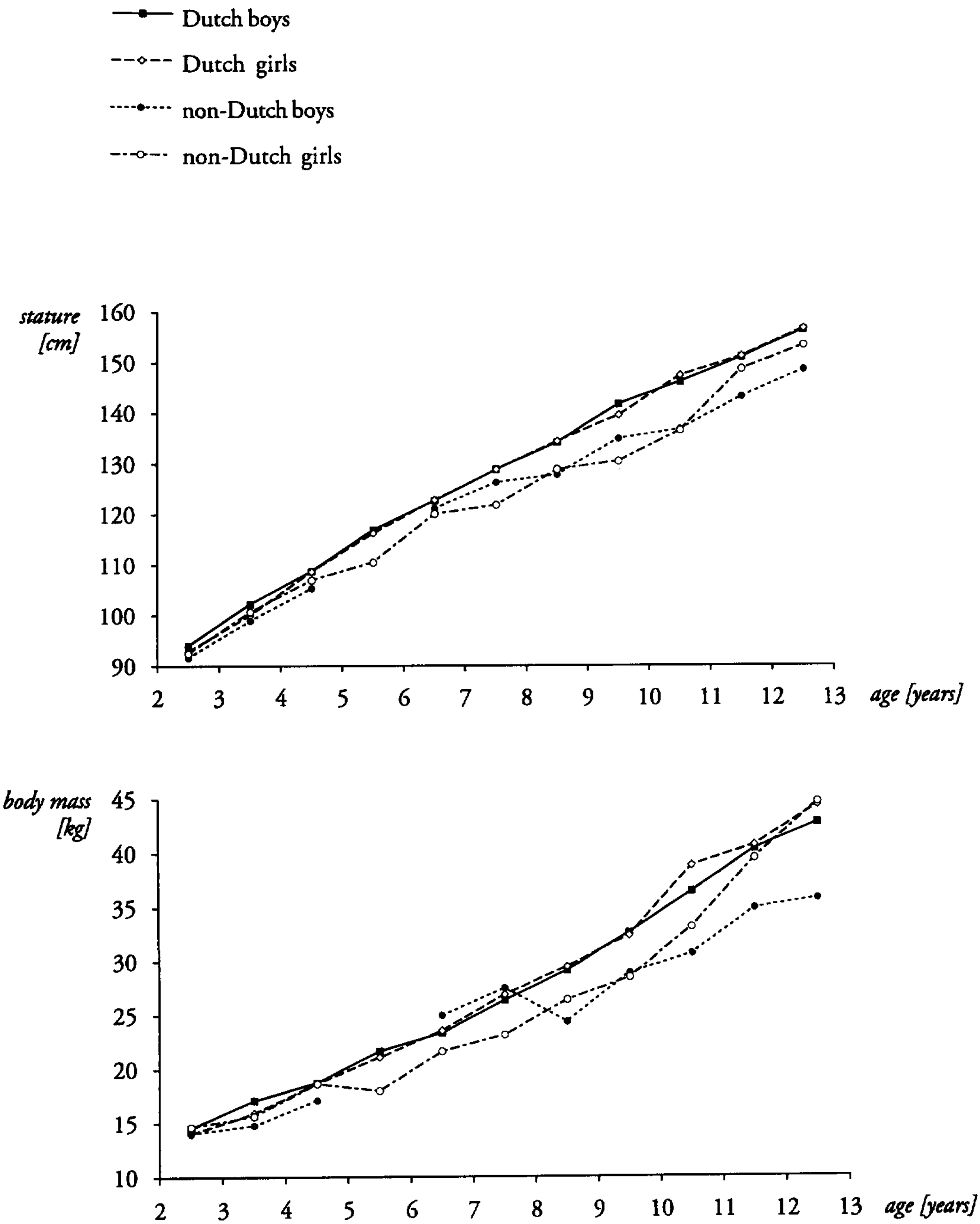
• = *girls significant larger mean values than boys.*

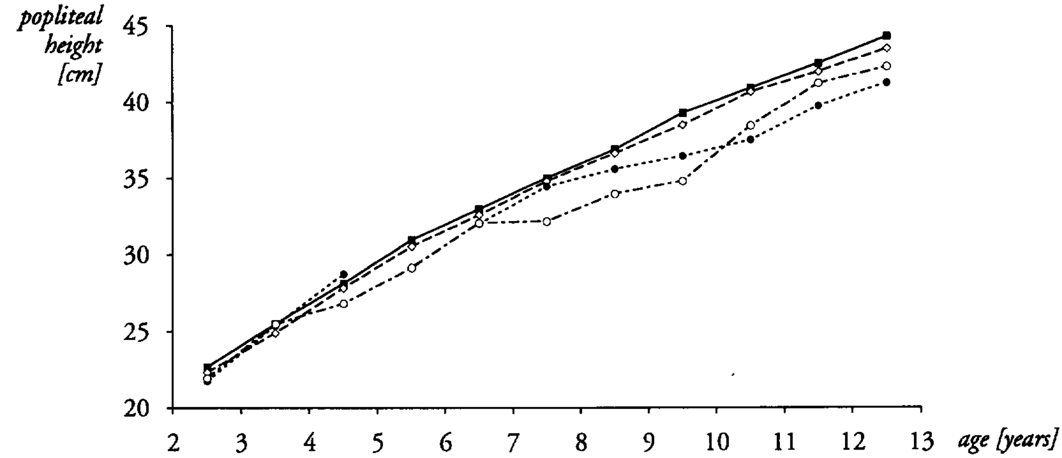
E Partial correlation matrix of the 40 body measurements

variable:	1 body mass	2 stature	3 shoulder height standing	4 reaching height standing	5 step height	6 shoulder breadth	7 breadth across the elbows	8 hip breadth standing	9 breast depth	10 head length	11 chin to crown length	12 head breadth	13 head height	14 foot breadth	15 foot length	16 hip breadth seated	17 reaching height seated
1 body mass		.6310	.6380	.6091	.0488	.7641	.7445	.8544	.7187	.2851	.4607	.2614	.2963	.5523	.5153	.8125	.6044
2 stature	.6310		.9534	.9306	.2836	.6043	.3991	.5683	.4291	.3371	.5336	.1833	.3870	.7825	.5171	.4924	.8089
3 shoulder height standing	.6380	.9534		.9127	.2862	.6004	.4075	.5717	.4253	.3056	.4743	.1658	.3311	.7507	.4858	.5013	.7968
4 reaching height standing	.6091	.9306	.9127		.3499	.6159	.3919	.5487	.4170	.2974	.4700	.1772	.3372	.7484	.4757	.4669	.8693
5 step height	.0488	.2836	.2862	.3499		.1117	.0015	.0572	.0348	.0404	.1205	.0188	.0894	.1694	.0111	.0200	.3542
6 shoulder breadth	.7641	.6043	.6004	.6159	.1117		.6957	.7545	.5643	.2626	.4662	.3184	.3122	.5464	.5059	.7251	.6175
7 breadth across the elbows	.7445	.3991	.4075	.3919	.0015	.6957		.7181	.6007	.2172	.3764	.2349	.2317	.3680	.4146	.7163	.3988
8 hip breadth standing	.8544	.5683	.5717	.5487	.0572	.7545	.7181		.6651	.2467	.4142	.2747	.2916	.5273	.5035	.8849	.5430
9 breast depth	.7187	.4291	.4253	.4170	.0348	.5643	.6007	.6651		.2042	.3180	.2102	.2265	.3992	.3834	.6485	.4091
10 head length	.2851	.3371	.3056	.2974	.0404	.2626	.2172	.2467	.2042		.6195	.1527	.3267	.3003	.2549	.2617	.2444
11 chin to crown length	.4607	.5336	.4743	.4700	.1205	.4662	.3764	.4142	.3180	.6195		.2947	.4649	.4583	.4063	.3930	.4116
12 head breadth	.2614	.1833	.1658	.1772	.0188	.3184	.2349	.2747	.2102	.1527	.2947		.2236	.2019	.2196	.2323	.1874
13 head height	.2963	.3870	.3311	.3372	.0894	.3122	.2317	.2916	.2265	.3267	.4649	.2236		.3367	.2875	.2447	.3291
14 foot breadth	.5523	.7825	.7507	.7484	.1694	.5464	.3680	.5273	.3992	.3003	.4583	.2019	.3367		.5954	.4318	.6628
15 foot length	.5153	.5171	.4858	.4757	.0111	.5059	.4146	.5035	.3834	.2549	.4063	.2196	.2875	.5954		.4842	.4431
16 hip breadth seated	.8125	.4924	.5013	.4669	.0200	.7251	.7163	.8849	.6485	.2617	.3930	.2323	.2447	.4318	.4842		.4707
17 reaching height seated	.6044	.8089	.7968	.8693	.3542	.6175	.3988	.5430	.4091	.2444	.4116	.1874	.3291	.6628	.4431	.4707	
18 arm length	.4456	.6029	.5982	.6208	.2001	.4012	.2977	.3992	.3152	.1606	.3018	.0823	.2351	.4974	.3023	.3509	.5669
19 reaching depth seated	.4699	.5316	.5345	.5612	.2624	.4672	.3249	.4286	.2969	.1735	.3076	.1338	.2357	.4441	.2991	.3876	.5798
20 buttock-foot length	.5639	.8115	.7995	.7871	.2298	.5518	.4072	.5328	.4051	.2796	.4297	.1439	.3394	.6476	.4446	.4741	.6559
21 sitting height	.6046	.8475	.7937	.7522	.2246	.5696	.3745	.5529	.3930	.3022	.4941	.1829	.3692	.6656	.4798	.4918	.7468
22 eye height seated	.5890	.7945	.7595	.7170	.2424	.5478	.3687	.5298	.3904	.2125	.3959	.1476	.2741	.6200	.4493	.4758	.7215
23 shoulder height seated	.5696	.6995	.7460	.6453	.2106	.5229	.3664	.5148	.3708	.1982	.3346	.1263	.2328	.5515	.3903	.4675	.6681
24 elbow height seated	.3039	.3124	.3324	.2225	.0476	.2496	.1879	.2759	.1790	.1002	.1704	.0712	.0935	.2432	.2096	.2724	.2979
25 thigh thickness	.7175	.3702	.3876	.3607	.0206	.6002	.5894	.6466	.5671	.1757	.2991	.2059	.1652	.3620	.3867	.6324	.3922
26 buttock-popliteal length	.5473	.7115	.6984	.6898	.1969	.4853	.3940	.4839	.3720	.2451	.3776	.1488	.2430	.5557	.3724	.4014	.5473
27 buttock-knee length	.6353	.7924	.7834	.7722	.2015	.5798	.4709	.5826	.4473	.2861	.4379	.1774	.3053	.6439	.4586	.5140	.6307
28 popliteal height	.4318	.8434	.8238	.8324	.2728	.4540	.2716	.3896	.2894	.2663	.4072	.1141	.3183	.7149	.4246	.3161	.6833
29 instep height	.2582	.3953	.3889	.3650	.1463	.3440	.2381	.2897	.2644	.1874	.2563	.0623	.2150	.3778	.2795	.3043	.3543
30 knee breadth	.6133	.5451	.5206	.5135	.0700	.5507	.4531	.6011	.4480	.2181	.3858	.2370	.2376	.5446	.5056	.5418	.4847
31 hand breadth	.5538	.5732	.5474	.5488	.1047	.5258	.3979	.4886	.4249	.2371	.3959	.2136	.2618	.6042	.5498	.4397	.5516
32 hand length	.5142	.7418	.7215	.7246	.1523	.5140	.3163	.4638	.3812	.2766	.4311	.2066	.3150	.7708	.4881	.3870	.6561
33 middle finger length	.4577	.6280	.6127	.6158	.1287	.4375	.2723	.4038	.3323	.2300	.3621	.1738	.2837	.6743	.4185	.3328	.5605
34 little finger breadth	.1336	.1115	.1076	.1048	.0284	.1435	.1122	.1222	.0999	.0382	.0756	.0505	.0329	.0976	.0998	.1090	.1228
35 thumb breadth	.3707	.4045	.3836	.3871	.1159	.4154	.3052	.3386	.2898	.1807	.3077	.1521	.1968	.4147	.3758	.3081	.4050
36 hand thickness	.3004	.3443	.3236	.3272	.0792	.3441	.2352	.2888	.2665	.1780	.2843	.1084	.1363	.3452	.3525	.2679	.3007
37 hand diameter	.5633	.4826	.4711	.4522	.0677	.5188	.4166	.4971	.4145	.1793	.3589	.1987	.2839	.4769	.4755	.4591	.4745
38 grip circumference	.3229	.4879	.5083	.5109	.2531	.2720	.1559	.2581	.2028	.1924	.2582	.1015	.1932	.5410	.2461	.1817	.4549
39 head circumference	.4416	.4106	.3761	.3839	.0501	.3913	.3296	.3812	.3126	.7528	.6443	.5025	.3476	.3584	.2891	.3613	.3442
40 upper arm circumference	.8365	.3952	.4093	.3898	.0094	.6761	.7117	.7426	.6120	.2018	.3512	.2560	.2323	.3577	.4267	.7415	.4259

variable:	18 arm length	19 reaching depth seated	20 buttock-foot length	21 sitting height	22 eye height seated	23 shoulder height seated	24 elbow height seated	25 thigh thickness	26 buttock-popliteal length	27 buttock-knee length	28 popliteal height	29 instep height	30 knee breadth	31 hand breadth	32 hand length	33 middle finger length	34 little finger breadth	35 thumb breadth	36 hand thickness	37 hand diameter	38 grip circumference	39 head circumference	40 upper arm circumference
1 body mass	.4456	.4699	.5639	.6046	.5890	.5696	.3039	.7175	.5473	.6353	.4318	.2582	.6133	.5538	.5142	.4577	.1336	.3707	.3004	.5633	.3229	.4416	.8365
2 stature	.6029	.5316	.8115	.8475	.7945	.6995	.3124	.3702	.7115	.7924	.8434	.3953	.5451	.5732	.7418	.6280	.1115	.4045	.3443	.4826	.4879	.4106	.3952
3 shoulder height standing	.5982	.5345	.7995	.7937	.7595	.7460	.3324	.3876	.6984	.7834	.8238	.3889	.5206	.5474	.7215	.6127	.1076	.3836	.3236	.4711	.5083	.3761	.4093
4 reaching height standing	.6208	.5612	.7871	.7522	.7170	.6453	.2225	.3607	.6898	.7722	.8324	.3650	.5135	.5488	.7246	.6158	.1048	.3871	.3272	.4522	.5109	.3839	.3898
5 step height	.2001	.2624	.2298	.2246	.2424	.2106	.0476	.0206	.1969	.2015	.2728	.1463	.0700	.1047	.1523	.1287	.0284	.1159	.0792	.0677	.2531	.0501	.0094
6 shoulder breadth	.4012	.4672	.5518	.5696	.5478	.5229	.2496	.6002	.4853	.5798	.4540	.3440	.5507	.5258	.5140	.4375	.1435	.4154	.3441	.5188	.2720	.3913	.6761
7 breadth across the elbows	.2977	.3249	.4072	.3745	.3687	.3664	.1879	.5894	.3940	.4709	.2716	.2381	.4531	.3979	.3163	.2723	.1122	.3052	.2352	.4166	.1559	.3296	.7117
8 hip breadth standing	.3992	.4286	.5328	.5529	.5298	.5148	.2759	.6466	.4839	.5826	.3896	.2897	.6011	.4886	.4638	.4038	.1222	.3386	.2888	.4971	.2581	.3812	.7426
9 breast depth	.3152	.2969	.4051	.3930	.3904	.3708	.1790	.5671	.3720	.4473	.2894	.2644	.4480	.4249	.3812	.3323	.0999	.2898	.2665	.4145	.2028	.3126	.6120
10 head length	.1606	.1735	.2796	.3022	.2125	.1982	.1002	.1757	.2451	.2861	.2663	.1874	.2181	.2371	.2766	.2300	.0382	.1807	.1780	.1793	.1924	.7528	.2018
11 chin to crown length	.3018	.3076	.4297	.4941	.3959	.3346	.1704	.2991	.3776	.4379	.4072	.2563	.3858	.3959	.4311	.3621	.0756	.3077	.2843	.3589	.2582	.6443	.3512
12 head breadth	.0823	.1338	.1439	.1829	.1476	.1263	.0712	.2059	.1488	.1774	.1141	.0623	.2370	.2136	.2066	.1738	.0505	.1521	.1084	.1987	.1015	.5025	.2560
13 head height	.2351	.2357	.3394	.3692	.2741	.2328	.0935	.1652	.2430	.3053	.3183	.2150	.2376	.2618	.3150	.2837	.0329	.1968	.1363	.2839	.1932	.3476	.2323
14 foot breadth	.4974	.4441	.6476	.6656	.6200	.5515	.2432	.3620	.5557	.6439	.7149	.3778	.5446	.6042	.7708	.6743	.0976	.4147	.3452	.4769	.5410	.3584	.3577
15 foot length	.3023	.2991	.4446	.4798	.4493	.3903	.2096	.3867	.3724	.4586	.4246	.2795	.5056	.5498	.4881	.4185	.0998	.3758	.3525	.4755	.2461	.2891	.4267
16 hip breadth seated	.3509	.3876	.4741	.4918	.4758	.4675	.2724	.6324	.4014	.5140	.3161	.3043	.5418	.4397	.3870	.3328	.1090	.3081	.2679	.4591	.1817	.3613	.7415
17 reaching height seated	.5669	.5798	.6559	.7468	.7215	.6681	.2979	.3922	.5473	.6307	.6833	.3543	.4847	.5516	.6561	.5605	.1228	.4050	.3007	.4745	.4549	.3442	.4259
18 arm length		.4507	.5880	.4761	.4883	.4219	.0962	.2274	.4641	.5432	.5362	.2304	.3160	.3432	.4783	.4119	.0678	.2629	.2039	.3680	.3323	.2175	.2947
19 reaching depth seated	.4507		.5199	.4846	.4765	.4556	.1551	.3353	.4499	.4956	.4415	.2617	.3297	.3395	.4189	.3564	.0823	.2507	.1906	.3232	.3423	.2377	.3511
20 buttock-foot length	.5880	.5199		.5775	.5570	.4984	.0990	.3428	.7082	.8102	.7623	.3994	.4187	.4359	.6207	.5443	.0853	.3108	.2633	.4071	.4019	.3314	.3660
21 sitting height	.4761	.4846	.5775		.9013	.8135	.5474	.4010	.4669	.5485	.6238	.3878	.5181	.5654	.6202	.5307	.1283	.4139	.3331	.5043	.3734	.3647	.4087
22 eye height seated	.4883	.4765	.5570	.9013		.7961	.5303	.3952	.4538	.5329	.5856	.3847	.4705	.5187	.5708	.4833	.1193	.3883	.3017	.4830	.3612	.2849	.4010
23 shoulder height seated	.4219	.4556	.4984	.8135	.7961		.6259	.4066	.3707	.4607	.5093	.3540	.4321	.4842	.5259	.4589	.1160	.3572	.2633	.4406	.3722	.2628	.4090
24 elbow height seated	.0962	.1551	.0990	.5474	.5303	.6259		.2765	.0265	.0861	.1383	.2346	.2112	.2613	.1930	.1600	.0783	.1754	.1285	.2444	.1139	.1219	.2173
25 thigh thickness	.2274	.3353	.3428	.4010	.3952	.4066	.2765		.3858	.4308	.2407	.3108	.4504	.4088	.3144	.2844	.0966	.2707	.2308	.3782	.1694	.3033	.7059
26 buttock-popliteal length	.4641	.4499	.7082	.4669	.4538	.3707	.0265	.3858		.8904	.5641	.2029	.4137	.3803	.5206	.4411	.0455	.2299	.2168	.3442	.3714	.3268	.3992
27 buttock-knee length	.5432	.4956	.8102	.5485	.5329	.4607	.0861	.4308	.8904		.6909	.2978	.4645	.4521	.5971	.5168	.0743	.2904	.2644	.4286	.4035	.3716	.4617
28 popliteal height	.5362	.4415	.7623	.6238	.5856	.5093	.1383	.2407	.5641	.6909		.4459	.3924	.4524	.6793	.5776	.0829	.3228	.2854	.3629	.4679	.2993	.2226
29 instep height	.2304	.2617	.3994	.3878	.3847	.3540	.2346	.3108	.2029	.2978	.4459		.2174	.2947	.3368	.2972	.0832	.2565	.1990	.3109	.1501	.1492	.1635
30 knee breadth	.3160	.3297	.4187	.5181	.4705	.4321	.2112	.4504	.4137	.4645	.3924	.2174		.5284	.4898	.4146	.1322	.4103	.3854	.4894	.2451	.3180	.5069
31 hand breadth	.3432	.3395	.4359	.5654	.5187	.4842	.2613	.4088	.3803	.4521	.4524	.2947	.5284		.6041	.5591	.1637	.5325	.4346	.6127	.3398	.3172	.4712
32 hand length	.4783	.4189	.6207	.6202	.5708	.5259	.1930	.3144	.5206	.5971	.6793	.3368	.4898	.6041		.8227	.1063	.4007	.3420	.4525	.6133	.3479	.3300
33 middle finger length	.4119	.3564	.5443	.5307	.4833	.4589	.1600	.2844	.4411	.5168	.5776	.2972	.4146	.5591	.8227		.0936	.3355	.3266	.4116	.5748	.3016	.2912
34 little finger breadth	.0678	.0823	.0853	.1283	.1193	.1160	.0783	.0966	.0455	.0743	.0829	.0832	.1322	.1637	.1063	.0936		.2154	.1349	.1568	.0273	.0560	.1042
35 thumb breadth	.2629	.2507	.3108	.4139	.3883	.3572	.1754	.2707	.2299	.2904	.3228	.2565	.4103	.5325	.4007	.3355	.2154		.4105	.4379	.1813	.2220	.3172
36 hand thickness	.2039	.1906	.2633	.3331	.3017	.2633	.1285	.2308	.2168	.2644	.2854	.1990	.3854	.4346	.3420	.3266	.1349	.4105		.3866	.1560	.2009	.2486
37 hand diameter	.3680	.3232	.4071	.5043	.4830	.4406	.2444	.3782	.3442	.4286	.3629	.3109	.4894	.6127	.4525	.4116	.1568	.4379	.3866		.1855	.2647	.5122
38 grip circumference	.3323	.3423	.4019	.3734	.3612	.3722	.1139	.1694	.3714	.4035	.4679	.1501	.2451	.3398	.6133	.5748	.0273	.1813	.1560	.1855		.2253	.1500
39 head circumference	.2175	.2377	.3314	.3647	.2849	.2628	.1219	.3033	.3268	.3716	.2993	.1492	.3180	.3172	.3479	.3016	.0560	.2220	.2009	.2647	.2253		.3627
40 upper arm circumference	.2947	.3511	.3660	.4087	.4010	.4090	.2173	.7059	.3992	.4617	.2226	.1635	.5069	.4712	.3300	.2912	.1042	.3172	.2486	.5122	.1500	.3627	

F Anthropometric measurements of boys and girls of different ethnic background





popliteal height [cm]
45
40
35
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25
20
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4
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6
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8
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10
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12
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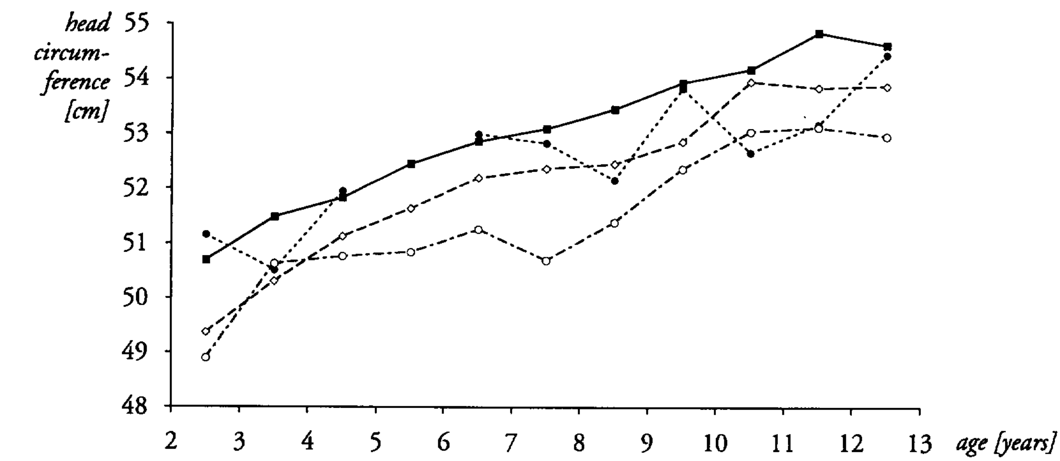
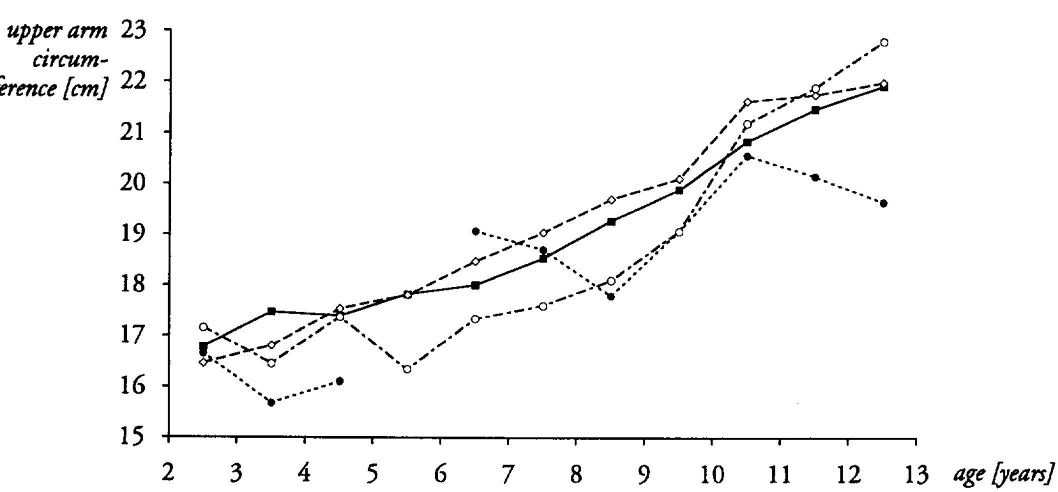
age [years]



head circum-ference [cm]
55
54
53
52
51
50
49
48
2
3
4
5
6
7
8
9
10
11
12
13
age [years]



upper arm circum-ference [cm]
23
22
21
20
19
18
17
16
15
2
3
4
5
6
7
8
9
10
11
12
13
age [years]

G Results of force exertion (children between 4 and 13 years of age)

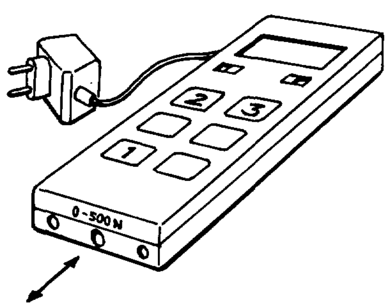


Figure G-1 Erichsen push/pull device

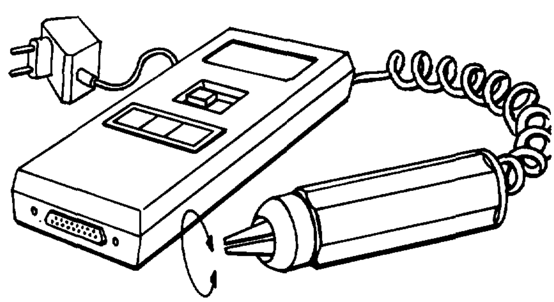
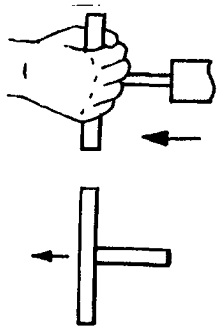


Figure G-2 Metek torque device

G-1 Pulling force of the hand [N]

description: Maximum pulling force of the hand, exerted for 3 seconds.

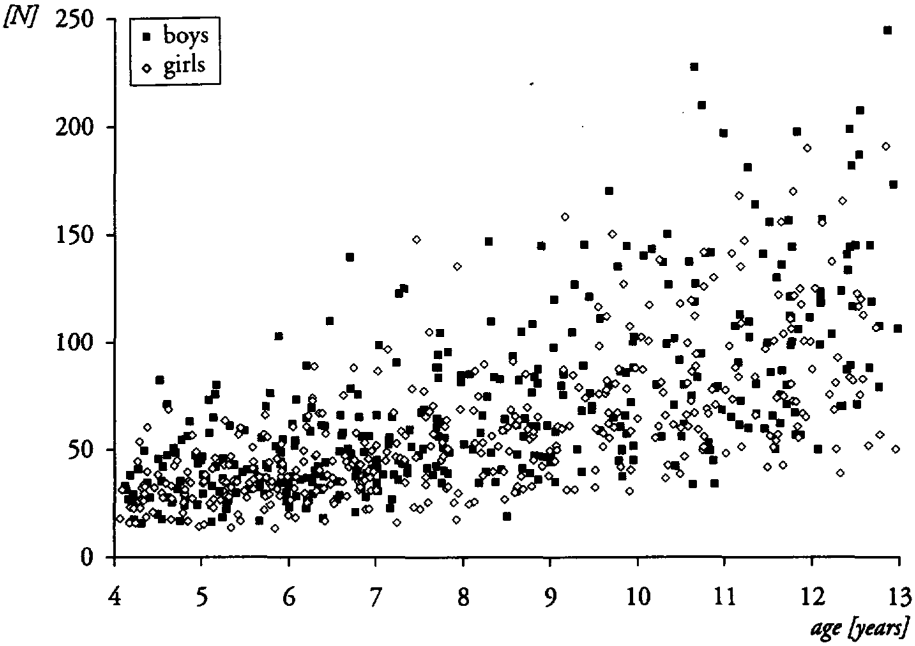
method: The child sits upright before the measuring device, which is in front of the forearm. The forearm is horizontal, in a sagittal plane. Upper arm and forearm are at an angle of about 150 degrees. The legs hang down freely or are directed forward. The bar is placed vertically, its axis between middle finger and ringfinger.



device: Erichsen push/pull device, with a vertical bar, diameter 1.1 cm.

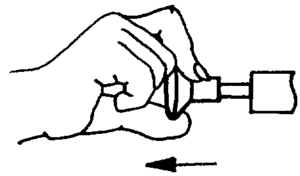
results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0 – 4.9	41	15.1	16.9	36.9	71.4	46	12.5	15.9	31.2	60.6	14.0	33.9
5.0 – 5.9	53	17.7	16.9	43.3	80.2	59	12.1	13.7	36.3	63.7	15.3	39.6
6.0 – 6.9	59	21.7	21.0	48.1	110.3	57	16.4	18.6	44.0	88.3	19.3	46.1
7.0 – 7.9	50	24.5	27.0	59.0	122.9	42	28.5	17.6	55.0	135.7	26.3	57.2
8.0 – 8.9	41	28.6	30.6	66.3	145.1	40	17.7	25.9	53.8	90.1	24.5	60.1
9.0 – 9.9	41	32.9	37.8	81.3	145.6	42	29.8	31.4	72.2	150.6	31.5	76.7
10.0 – 10.9	35	49.7	34.3	99.7	210.2	39	28.5	38.9	80.6	138.6	40.8	89.7
11.0 – 11.9	40	37.2	57.0	100.6	181.5	44	36.8	42.9	93.5	170.3	36.9	96.9
12.0 – 12.9	30	45.9	50.2	127.0	244.9	23	40.0	39.2	97.8	191.2	45.5	114.3

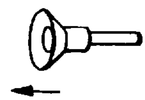


G-2 Pulling force of thumb and forefinger [N]

description: Maximum pulling force of the thumb and forefinger, exerted for 3 seconds.



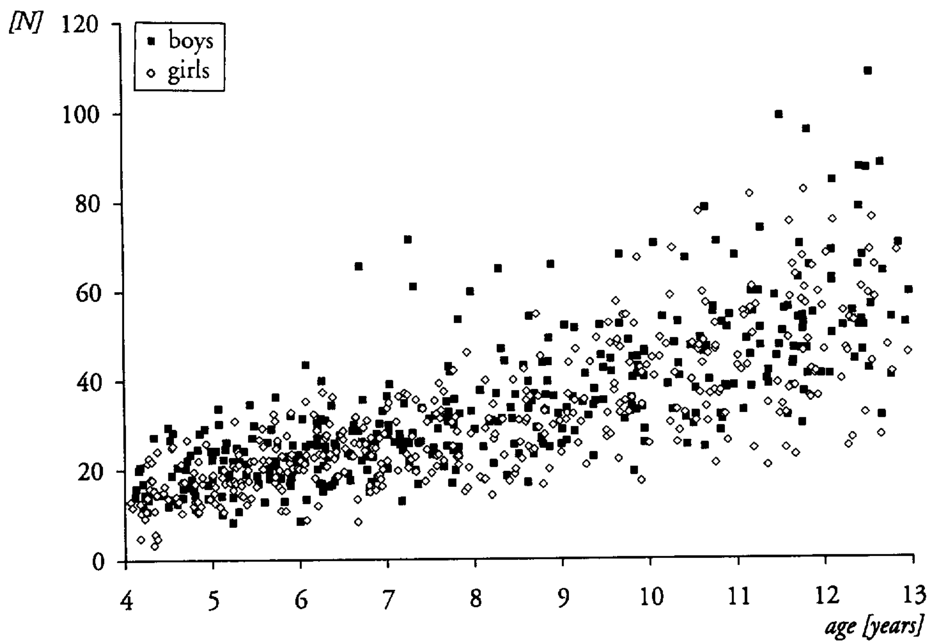
method: The child sits upright before the measuring device, which is in front of the forearm. The forearm is horizontal and in a sagittal plane. Upper arm and forearm are at an angle of about 150 degrees. The legs hang down freely or are directed forward. The finger is placed on top of a round knob, the thumb is on the bottom of the knob. The other fingers are flexed into a fist.



device: Erichsen push/pull device, with a round concave knob, diameter 2 cm.

results:

age [years]	boys n	boys s	boys P_3	boys $\bar{x}$	boys P_{97}	girls n	girls s	girls P_3	girls $\bar{x}$	girls P_{97}	boys + girls s	boys + girls $\bar{x}$
4.0– 4.9	41	5.5	11.4	18.3	29.3	46	5.7	4.8	15.3	25.9	5.8	16.7
5.0– 5.9	53	6.0	10.1	21.6	34.7	59	5.3	10.9	20.0	32.6	5.7	20.7
6.0– 6.9	59	8.5	13.5	25.3	43.6	57	6.4	8.8	23.7	36.3	7.5	24.5
7.0– 7.9	50	11.2	16.8	30.5	61.0	42	7.6	15.9	27.7	42.1	9.8	29.2
8.0– 8.9	41	10.9	18.5	34.7	64.9	40	8.7	16.6	28.9	45.3	10.2	31.8
9.0– 9.9	41	9.6	22.8	39.0	52.3	42	10.8	20.9	38.7	57.4	10.2	38.9
10.0–10.9	35	13.9	25.4	45.7	70.8	39	11.8	25.9	42.0	69.2	12.9	43.7
11.0–11.9	40	14.5	31.8	51.3	95.5	44	14.9	23.0	48.1	81.2	14.7	49.6
12.0–12.9	30	17.2	31.7	60.9	108.2	23	15.2	24.8	51.4	75.9	16.9	56.8

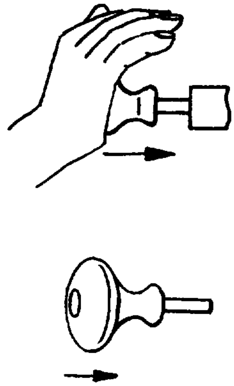


G-3 Pushing force of the hand [N]

description: Maximum pushing force of the hand, exerted for 3 seconds.

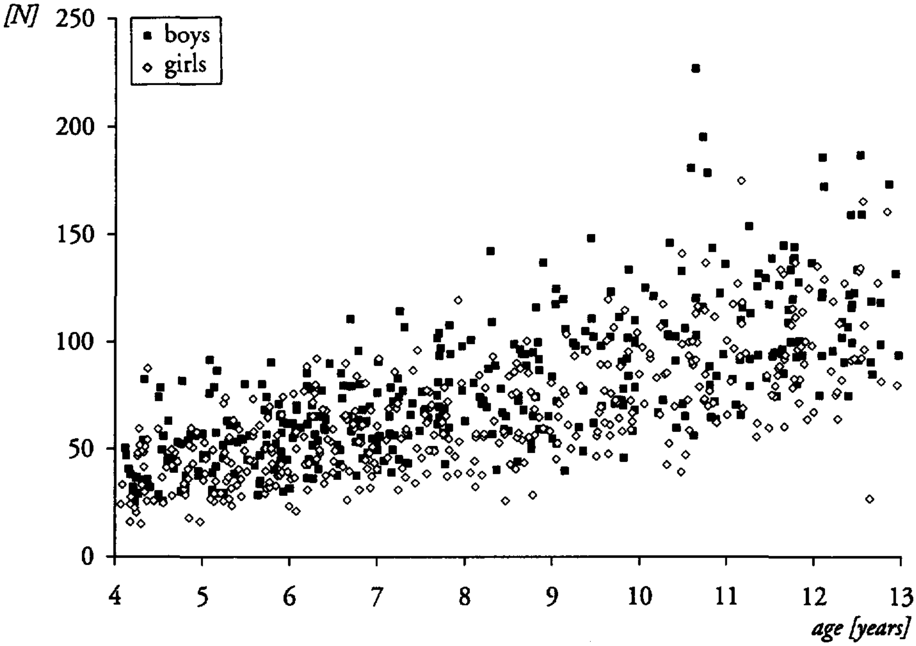
method: The child sits upright before the measuring device, which is in front of the forearm. The forearm is horizontal and in a sagittal plane, the wrist is flexed. Upper arm and forearm are at an angle of about 150 degrees. The legs hang down freely or are directed forward. Force is exerted with the palm of the hand.

device: Erichsen push/pull device, with a round convex knob, diameter 4 cm.

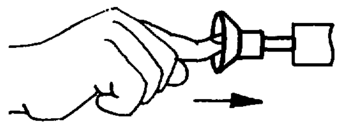


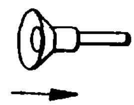
results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0– 4.9	41	15.0	25.7	45.9	81.7	46	15.0	16.1	38.7	60.0	15.3	42.1
5.0– 5.9	53	16.6	28.8	54.2	90.4	59	13.8	23.8	44.4	73.9	15.9	49.0
6.0– 6.9	59	15.6	36.5	61.9	95.7	57	16.9	26.3	55.0	90.1	16.6	58.5
7.0– 7.9	50	19.6	40.4	69.7	108.0	42	18.9	34.3	60.9	96.2	19.7	65.6
8.0– 8.9	41	22.5	44.3	79.4	136.9	40	18.8	28.6	62.4	93.2	22.3	71.0
9.0– 9.9	41	25.6	46.2	88.6	133.6	42	19.3	46.6	74.5	114.9	23.6	81.5
10.0–10.9	35	40.6	59.9	108.9	195.5	39	23.6	42.8	86.4	136.7	34.4	97.0
11.0–11.9	40	23.3	70.6	108.5	144.9	44	24.8	59.9	94.3	137.0	25.0	101.1
12.0–12.9	30	31.7	74.8	118.9	186.9	23	32.5	27.0	104.0	165.5	32.6	112.5



G-4 Pushing force of the forefinger [N]





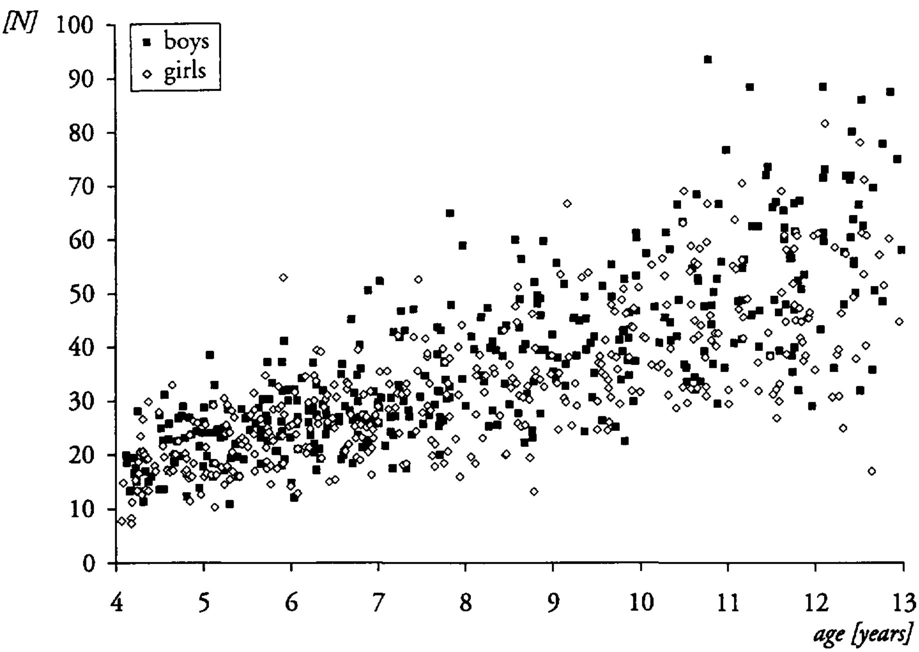
description: Maximum pushing force of the forefinger, exerted for 3 seconds.

method: The child sits upright before the measuring device, which is in front of the forearm. The forearm and hand are horizontal and in a sagittal plane. Upper arm and forearm are at an angle of about 150 degrees. The legs hang down freely or are directed forward. The finger is placed in the middle of a round concave knob. The other fingers and the thumb are flexed into a fist.

device: Erichsen push/pull device, with a round concave knob, diameter 2 cm.

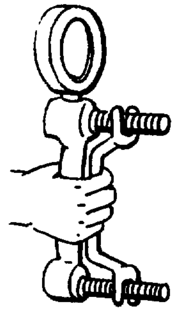
results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0– 4.9	41	5.3	12.3	20.0	29.0	46	5.5	7.8	18.3	29.9	5.4	19.1
5.0– 5.9	53	6.1	16.0	25.2	38.6	59	6.7	14.2	22.8	34.7	6.5	24.0
6.0– 6.9	59	6.8	14.8	27.5	45.2	57	6.0	15.0	26.3	39.4	6.5	26.9
7.0– 7.9	50	9.9	17.6	33.1	59.0	42	8.4	17.9	30.8	44.2	9.3	32.1
8.0– 8.9	41	9.8	23.2	39.1	59.7	40	8.4	18.4	32.3	47.6	9.7	35.7
9.0– 9.9	41	9.6	24.3	41.2	60.4	42	9.7	24.6	38.1	53.9	9.7	39.6
10.0–10.9	35	14.0	32.1	49.4	76.8	39	11.0	29.7	44.7	66.7	12.7	46.9
11.0–11.9	40	12.7	31.9	52.8	73.5	44	11.3	29.5	45.7	69.1	12.5	49.1
12.0–12.9	30	15.1	31.9	62.3	88.4	23	16.4	16.9	50.1	81.6	16.7	57.0



G-5 Gripping force [N]

description: Maximum gripping force of the hand, exerted for 3 seconds.

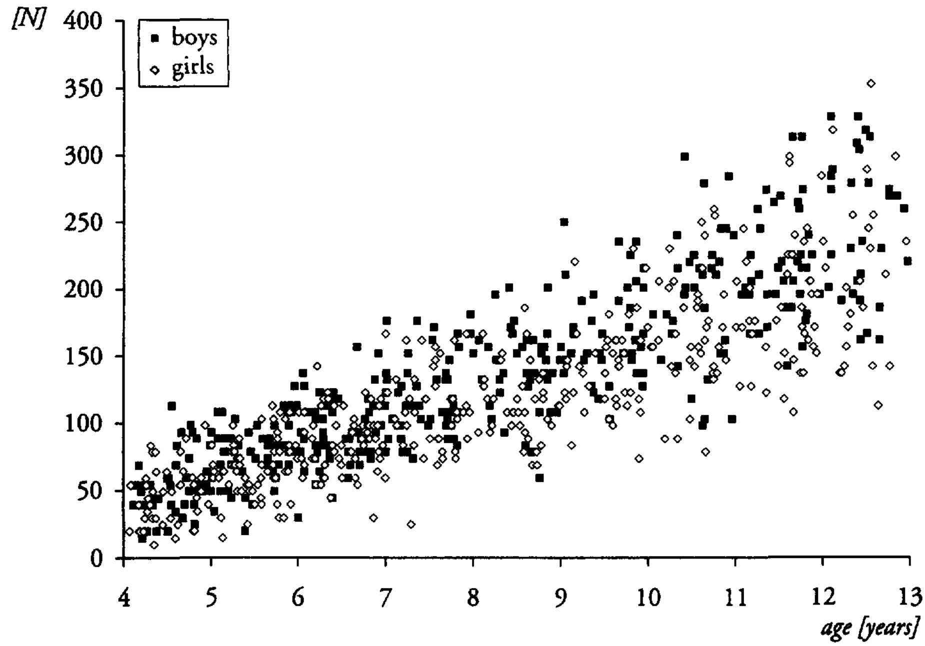


method: The child sits upright before the measuring device, which is in front of the forearm. The forearm is almost horizontal, in a sagittal plane, and rests on the table. Upper arm and forearm are at an angle of about 150 degrees. The legs hang down freely or are directed forward.

device: Jamar dynamometer, position 1 or 2, the distance between the bars 3.3 cm and 4.6 cm, respectively.

results:

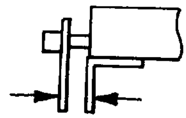
age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0– 4.9	41	23.0	19.6	53.7	98.0	46	21.0	14.7	45.8	88.2	22.2	49.5
5.0– 5.9	53	22.4	34.3	79.2	112.7	59	22.2	24.5	66.1	107.8	23.1	72.3
6.0– 6.9	59	24.4	44.1	93.1	151.9	57	25.3	44.1	88.0	142.1	24.8	90.6
7.0– 7.9	50	28.5	78.4	120.2	176.4	42	31.5	58.8	108.4	161.7	30.3	114.8
8.0– 8.9	41	31.3	78.4	140.3	200.9	40	26.5	68.6	114.0	166.6	31.7	127.3
9.0– 9.9	41	35.2	117.6	167.6	235.2	42	34.3	83.3	142.8	220.5	36.7	155.0
10.0–10.9	35	51.0	102.9	194.6	284.2	39	44.1	88.2	168.9	254.8	48.9	181.0
11.0–11.9	40	40.0	156.8	217.7	313.6	44	46.3	117.6	186.4	294.0	45.9	201.3
12.0–12.9	30	52.0	161.7	246.5	328.3	23	64.8	112.7	209.6	352.8	60.2	230.5

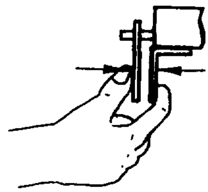


G-6 Pinch grip of forefinger and thumb [N]

description: Maximum pinch grip of the forefinger and the thumb, exerted for 3 seconds.

method: The child sits upright before the measuring device, which is in front of the forearm. The forearm is horizontal and in a sagittal plane. Upper arm and forearm are at an angle of about 150 degrees. The legs hang down freely or are directed forward. The thumb and finger are placed before and behind the plates of the device, respectively. The other fingers and the thumb are flexed into a fist.

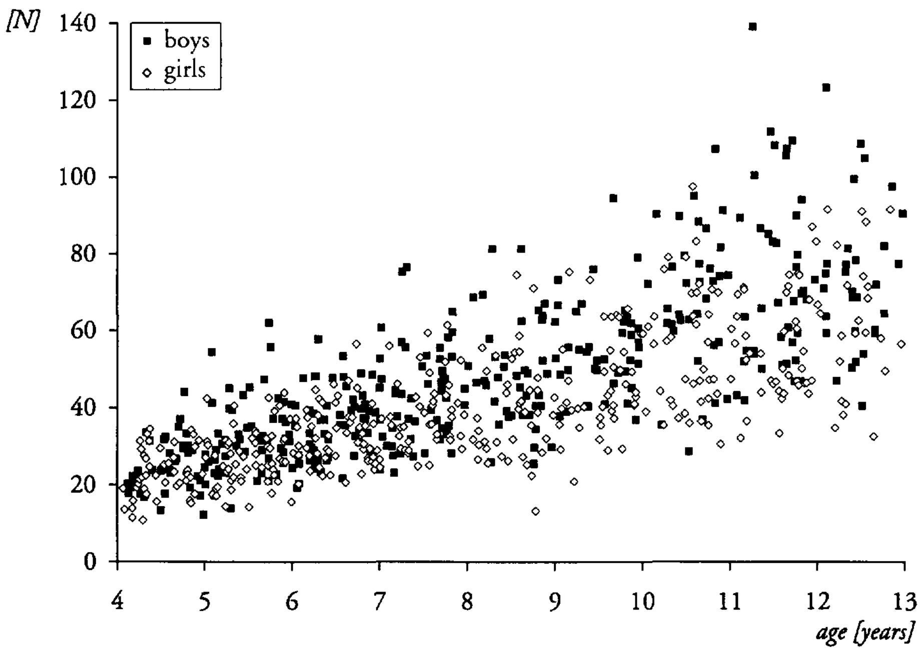




device: Erichsen push/pull device with plates, 2.1 cm apart, to measure pinch grip force.

results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0 – 4.9	41	6.8	13.5	24.7	37.1	46	6.3	11.6	23.1	34.3	6.6	23.9
5.0 – 5.9	53	9.7	17.4	32.6	55.9	59	7.2	14.5	27.5	42.7	8.8	29.9
6.0 – 6.9	59	8.8	20.4	35.8	53.6	57	7.6	20.8	32.8	47.2	8.3	34.4
7.0 – 7.9	50	12.5	24.1	43.6	75.5	42	9.3	24.9	38.6	59.5	11.4	41.3
8.0 – 8.9	41	13.7	26.0	49.2	81.4	40	13.1	22.6	39.6	71.2	14.2	44.4
9.0 – 9.9	41	12.0	38.0	55.7	79.2	42	12.5	29.2	46.4	73.4	13.1	51.0
10.0 – 10.9	35	18.0	35.7	68.7	95.2	39	16.2	35.6	54.9	83.4	18.3	61.4
11.0 – 11.9	40	23.1	43.3	73.4	112.1	44	13.3	33.5	56.1	83.4	20.5	64.4
12.0 – 12.9	30	19.2	40.6	73.8	123.6	23	18.4	32.7	62.7	91.7	19.5	69.0



G-7 Static torque of the hand [N]

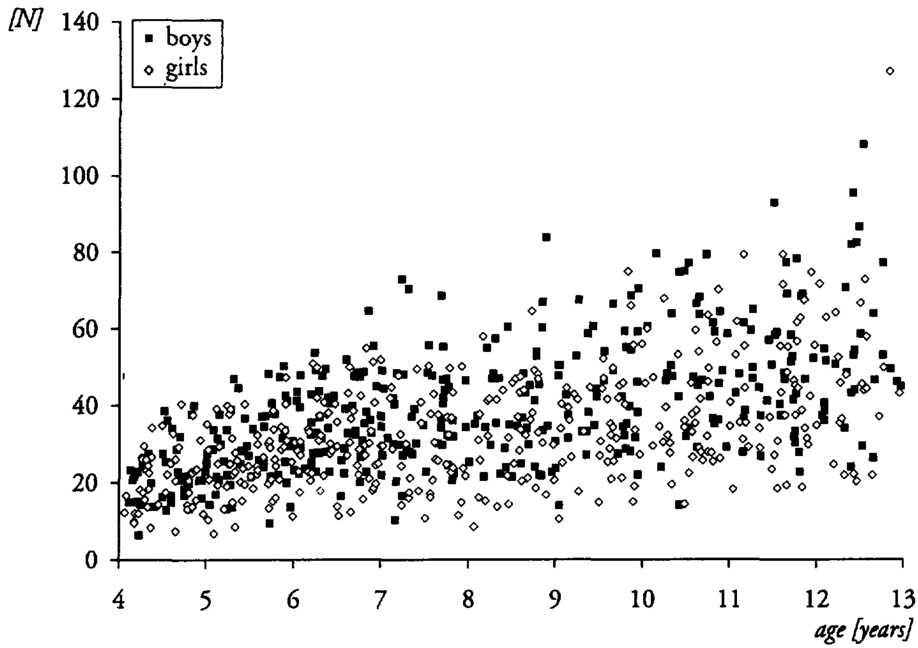
description: Maximum static torque of the preferred hand, exerted for 3 seconds.

method: The child sits upright before the measuring device, which is in front of the forearm. The forearm is almost horizontal, in a sagittal plane, and rests on the table. Upper arm and forearm are at an angle of about 150 degrees. The legs hang down freely or are directed forward.

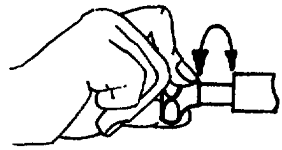
device: Metek torque device with a round form-closed knob, diameter 4 cm.

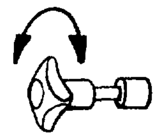
results:

age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0– 4.9	41	7.6	12.9	22.1	38.5	46	8.1	8.3	20.7	37.6	7.9	21.3
5.0– 5.9	53	9.8	13.3	29.1	48.3	59	8.8	8.5	25.5	40.3	9.4	27.2
6.0– 6.9	59	10.4	20.1	35.8	55.3	57	10.7	12.2	30.7	51.9	10.8	33.3
7.0– 7.9	50	13.2	16.6	37.4	70.3	42	11.6	11.6	30.0	50.2	12.9	34.0
8.0– 8.9	41	14.3	21.6	39.0	66.9	40	13.1	13.7	33.3	58.1	13.9	36.2
9.0– 9.9	41	14.0	21.9	43.4	68.7	42	13.7	14.9	36.2	66.1	14.2	39.8
10.0–10.9	35	17.4	23.9	51.8	79.4	39	13.9	19.6	38.6	68.0	16.9	44.9
11.0–11.9	40	15.6	26.8	49.4	78.4	44	16.5	18.5	43.5	79.4	16.2	46.3
12.0–12.9	30	20.7	24.0	54.5	108.2	23	23.6	20.4	48.6	127.1	22.0	51.9



G-8 Static torque of forefinger and thumb [N]





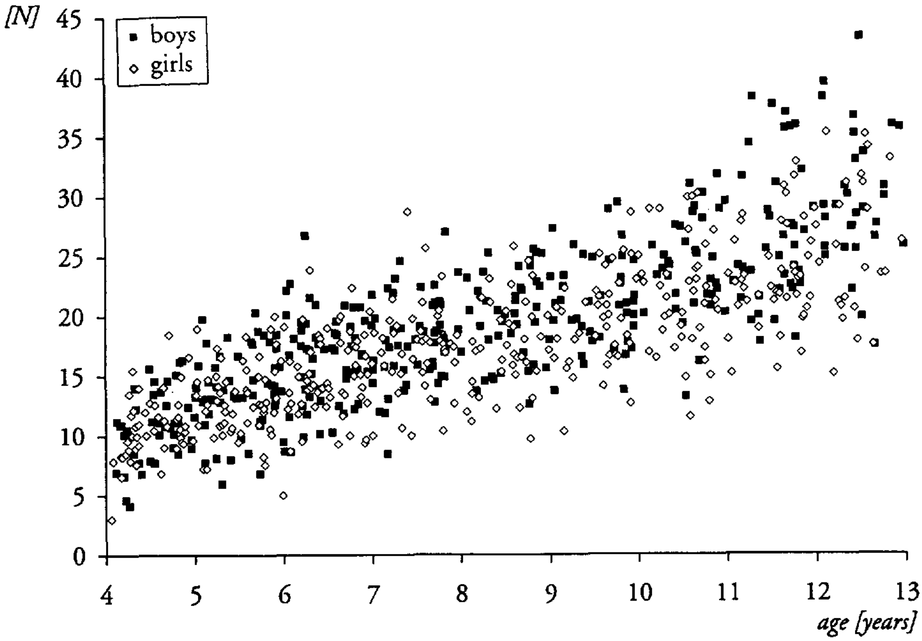
description: Maximum static torque of the forefinger and thumb, exerted for 3 seconds.

method: The child sits upright before the measuring device, which is in front of the forearm. The forearm is horizontal and in a sagittal plane. Upper arm and forearm are at an angle of about 150 degrees. The legs hang down freely or are directed forward. The thumb and finger are positioned on the knop opposite one another. The other fingers are flexed into a fist.

device: Metek torque device with a star knob, maximum diameter 2.5 cm.

results:

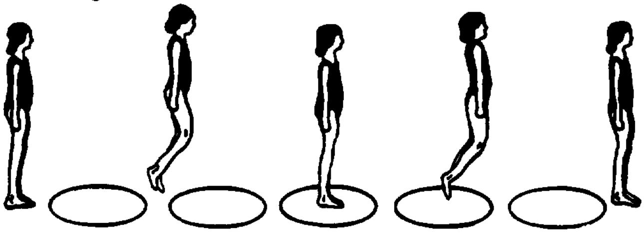
age	boys					girls					boys + girls	
[years]	n	s	P_3	$\bar{x}$	P_{97}	n	s	P_3	$\bar{x}$	P_{97}	s	$\bar{x}$
4.0– 4.9	41	3.0	4.6	10.8	16.2	46	2.8	6.6	10.6	16.6	2.8	10.7
5.0– 5.9	53	3.4	6.8	13.9	19.8	59	3.1	7.2	13.0	19.0	3.3	13.4
6.0– 6.9	59	3.8	8.7	16.5	22.7	57	3.4	9.3	15.2	22.4	3.6	15.9
7.0– 7.9	50	3.6	12.0	17.7	24.7	42	3.8	10.0	17.3	25.7	3.7	17.6
8.0– 8.9	41	3.6	13.8	19.9	25.4	40	3.8	11.2	17.6	24.7	3.9	18.8
9.0– 9.9	41	3.8	13.8	21.2	29.0	42	3.8	12.7	19.7	25.5	3.8	20.4
10.0–10.9	35	4.2	16.2	24.3	31.1	39	4.8	12.9	21.4	30.0	4.7	22.8
11.0–11.9	40	5.7	18.2	26.5	37.7	44	4.2	15.6	23.6	31.7	5.2	25.0
12.0–12.9	30	5.7	17.5	29.8	43.4	23	6.0	15.2	25.7	35.3	6.2	28.0



H Descriptions of the items of MOT '87k

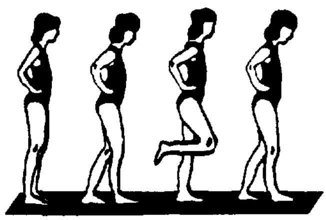
item 1 *Jump in and out a hoop*

From a standing position jump in and out of a hoop (diameter 64 centimetres) lying on the ground, with the feet together. Two attempts are allowed.



item 2 *Walk along a straight line (200 by 10 cm) foot by foot with the hands on the hips*

The distance between toe and heel may not exceed 5 centimetres. The child stands at the beginning of the line with both feet together and starts when the observer gives the signal. This task is performed a second time. This time the child has to stop at the middle of the line and stand –for 10 seconds– on one leg; the other leg is bent at the knee with the lower leg parallel to the ground (stand like a stork). During the second 5 seconds the child also has to close its eyes. At the end of the 10 seconds, the child opens its eyes and continues walking along the line.

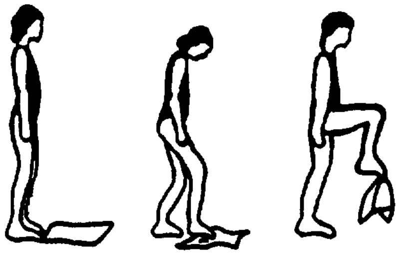


item 3 *Dotting.*

The child has to try to put as many dots on a piece of paper as possible in 10 seconds. While dotting, the elbow and the lower arm have to remain in the same position on the table.
To achieve this position it appears best to put the elbow on the table first and then place the lower arm on the table. The paper is positioned with its long side parallel to the edge of the table. The pencil lies with its point directed away from the child in the middle of the piece of paper. The child picks up the pencil. The dots may be placed in any order, as long as they remain distinguishable.

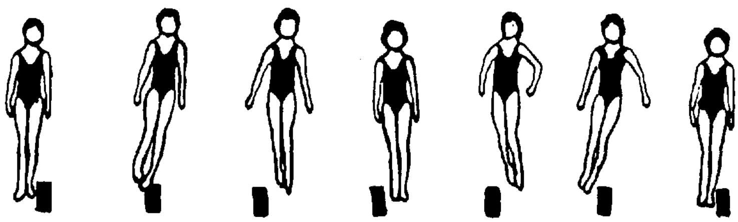
item 4 *Pick up a handkerchief with the toes.*

A handkerchief has to be taken between the toes (i.e. the foot is placed on the handkerchief and the toes are used to pick it up) and given to the observer. The unfolded handkerchief lies about 20 cm in front of the child on the ground. This item has to be performed twice. The first time the child chooses the foot he/she wants to use. The second time the other foot has to be used. The handkerchief has to be lifted to the height of the knee of the leg on which the child is standing.



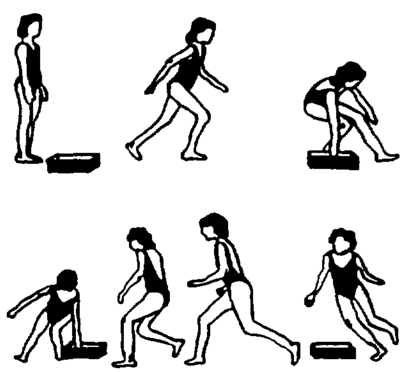
item 5 *Jump sideways over a line.*

The child has to jump as often as possible sideways over a line (10 by 100 cm), with its feet together, in 10 seconds. The child starts on the right side and in the middle of the line. It starts when the observer gives a signal. It is not allowed to touch the line. Take-off and landing have to be performed with the feet together, otherwise the jump is not included in the number of jumps performed.



item 6 *Run with tennis balls.*

Three tennis balls have to be taken in succession from one box and put in second box as fast as possible. The distance between the boxes is 4 meters. The child starts at an empty box. The task is completed when the last ball is in the second box (the distance is covered 6 times, being 24 meters). The child starts at the observer's signal.

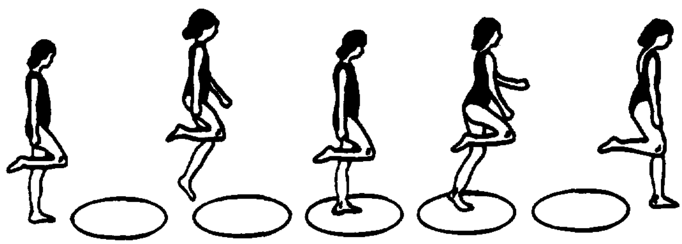


item 7. *Pick up 40 matches.*

The matches lie in 4 piles of 10 matches, each in a corner of the table, parallel to the front of the table. In the middle is a matchbox in which the matches have to be put. Neither the piles of matches nor the box are allowed to be moved. The matches are picked up one by one; both hands may be used at the same time. The time needed to perform this task is recorded.

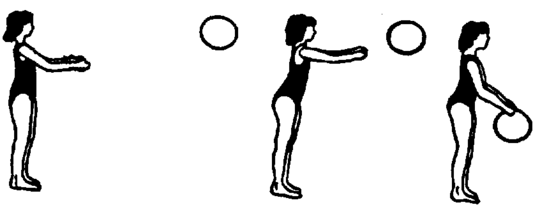
item 8 *Jump in and out of a hoop on one leg.*

While standing on one leg, the child jumps into a hoop (diameter 64 cm); it keeps on standing on this leg for 5 seconds and then jumps out of the hoop. The beginning position is 15 centimetres in front of the hoop. The first time the child chooses the leg it wants to use; the second time the other leg has to be used. Children in the lower classes perform this item as described above; children in the upper classes have to jump in the hoop three times –without stopping– stand still for 5 seconds and then jump out of the hoop.



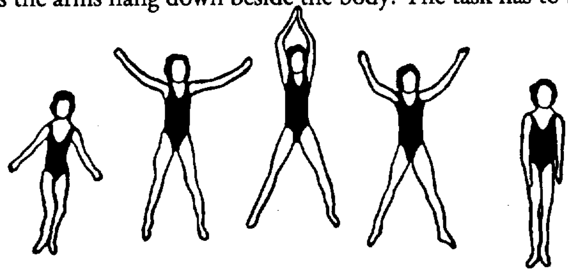
item 9 *Catch a ring (diameter 17 cm) with both hands.*

The observer throws the ring at chest height in vertical position from a distance of 4 meters. The ring may not touch the chest or stomach of the child. The child stands with both feet together and with the arms stretched forward. The task is performed twice.



item 10 *'Hampelmann' jump.*

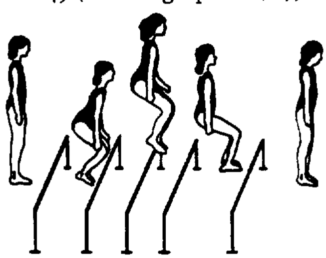
For 10 seconds the arms and legs are spread open and closed alternately. While the legs are spread open, the arms are closed above the head and the hands are clapped. While closing the legs the arms hang down beside the body. The task has to be performed rhythmically.



item 11 *Standing high jump.*

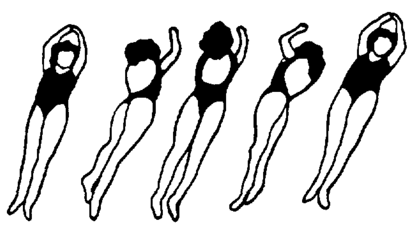
The jump is performed without running, i.e. from a standing position, with both feet together. The child stands with its toes against a line, 35 cm in front of the cord. During the jump the cord may not be touched. Two attempts are allowed.

The height of the cord for children in the lower classes is 35 cm and later 45 cm; for children in the upper classes it is 45 (warming-up item), 55 and 65 centimetres.

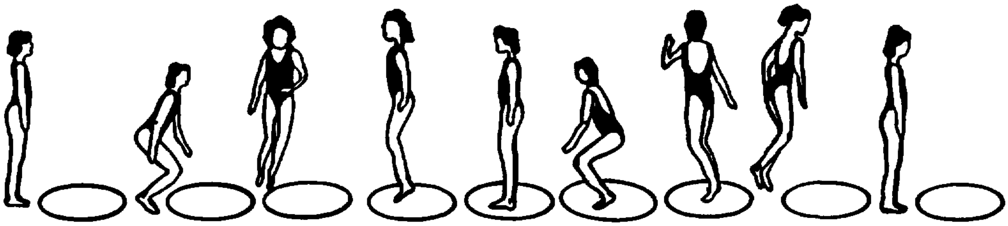


item 12 *Roll along the long axis of the body.*

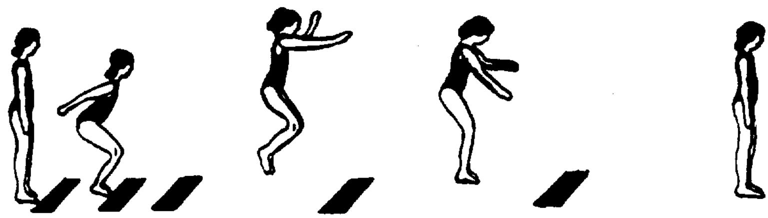
Starting point: lie on the ground on the back, the arms stretched up along the head; the muscles of the body are tensed. In this position, roll from the back to the belly and then to the back. The second roll is from belly to back and further to belly. It is important that the muscles remain tense during the rolls. Arms and legs are not allowed to bend while rolling. Two attempts are allowed.



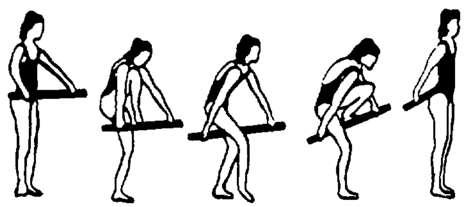
item 13. *Turn while jumping in and out of a hoop (diameter 64 centimetres).*
From a standing position with the feet together jump into and out of the hoop. Each jump is accompanied by a rotation of 180 degrees, such that the child faces the same direction at the beginning and the end. The task is performed twice.



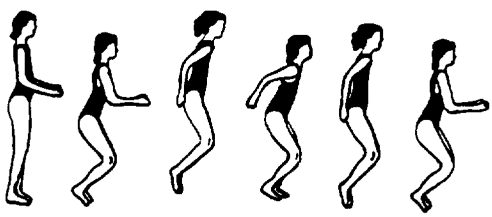
item 14 *Standing broad jump.*
From a standing position behind a line, with both feet together, the child jumps as far as possible. Take-off with the feet together is necessary and the child should land on both feet. Two attempts are allowed.



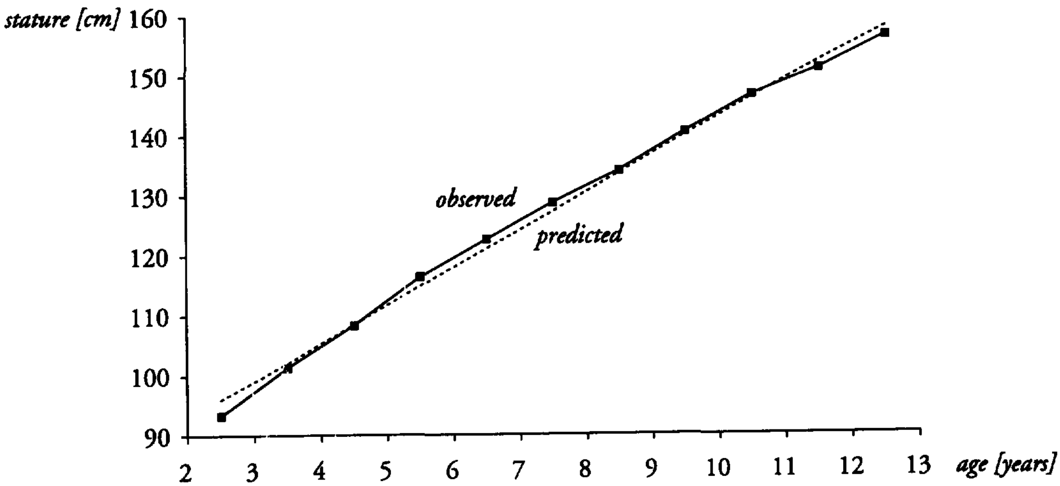
item 15 *Step over a stick (100 centimetres length).*
Step over a stick which is held with both hands, the arms are stretched. Step first with one leg, then with the other. The hands have to be kept as far apart as possible. The distance between the hands is measured.

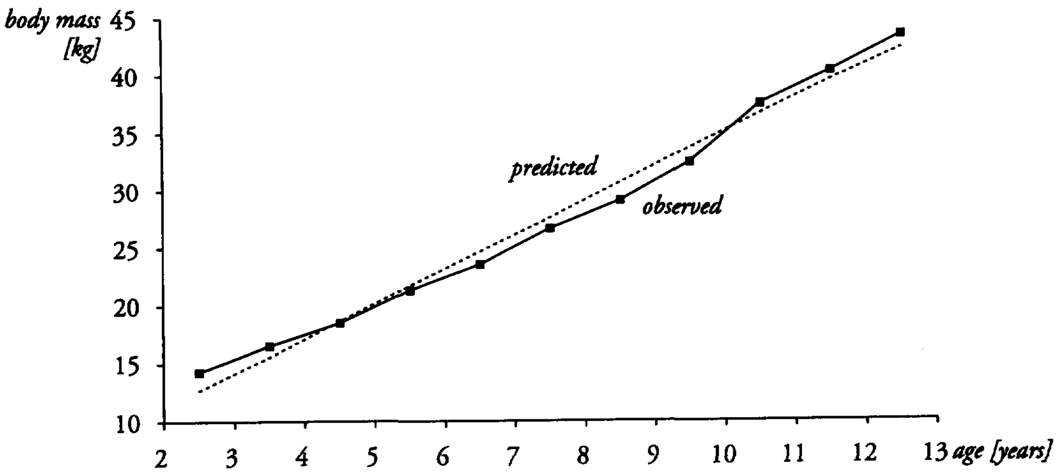


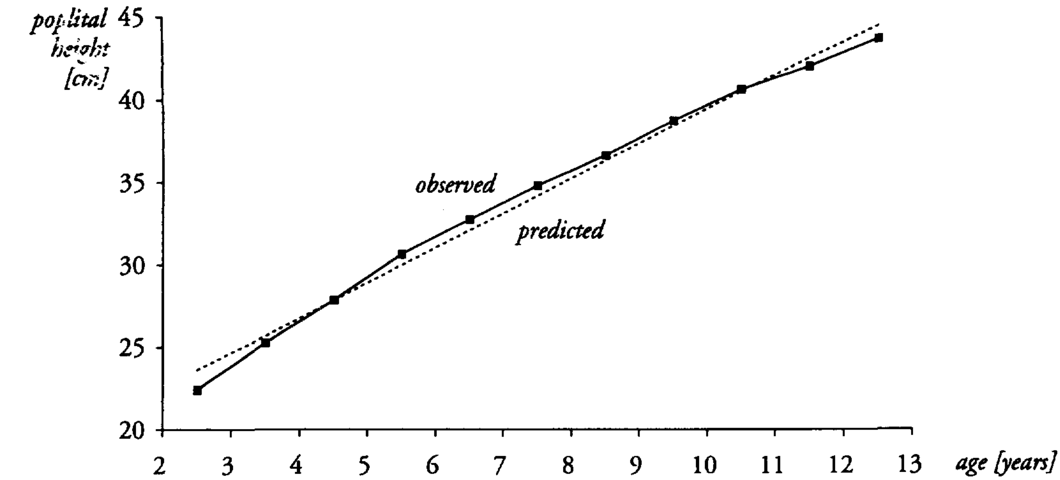
item 16 *Clap in front of and behind the body while skipping.*
The first time rhythmic clapping in front of and behind the body is performed for 10 seconds. The second time the child has to skip while clapping.

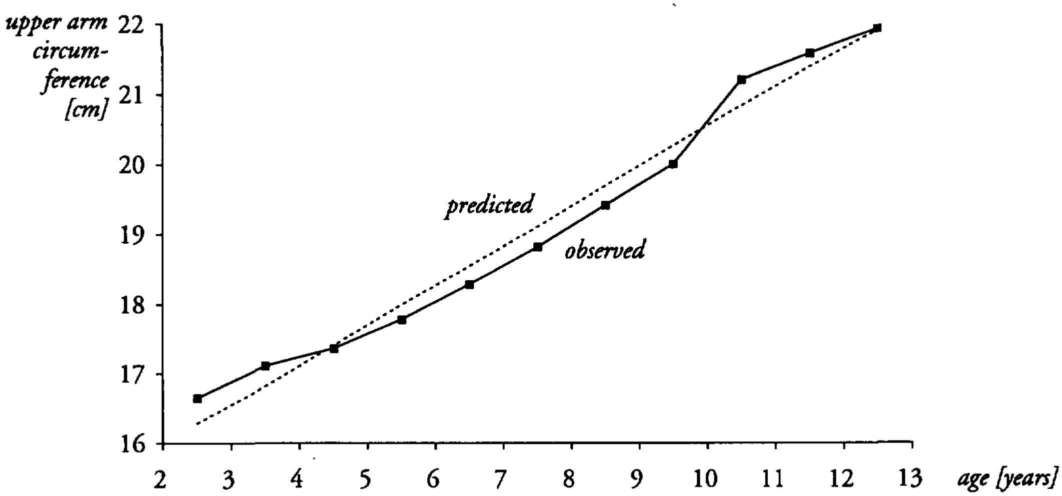


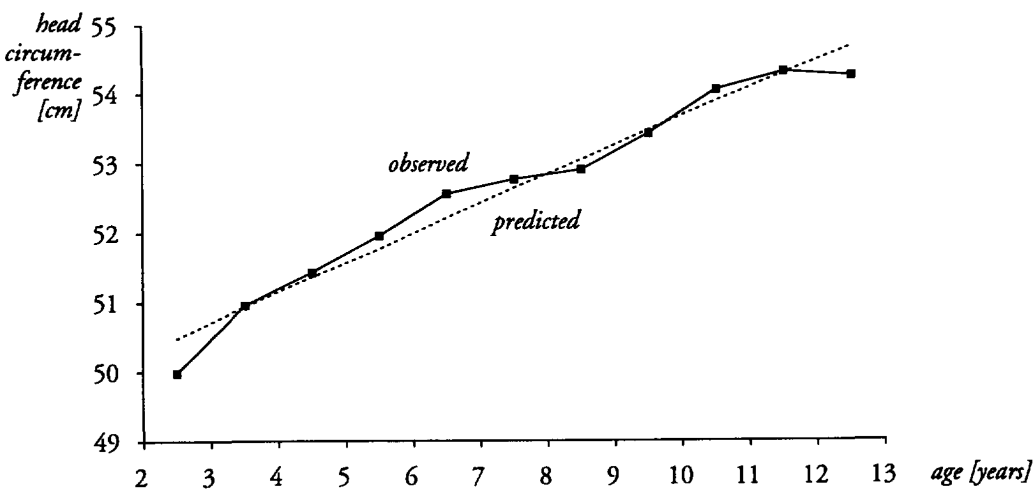
J Plots of predicted and observed mean values

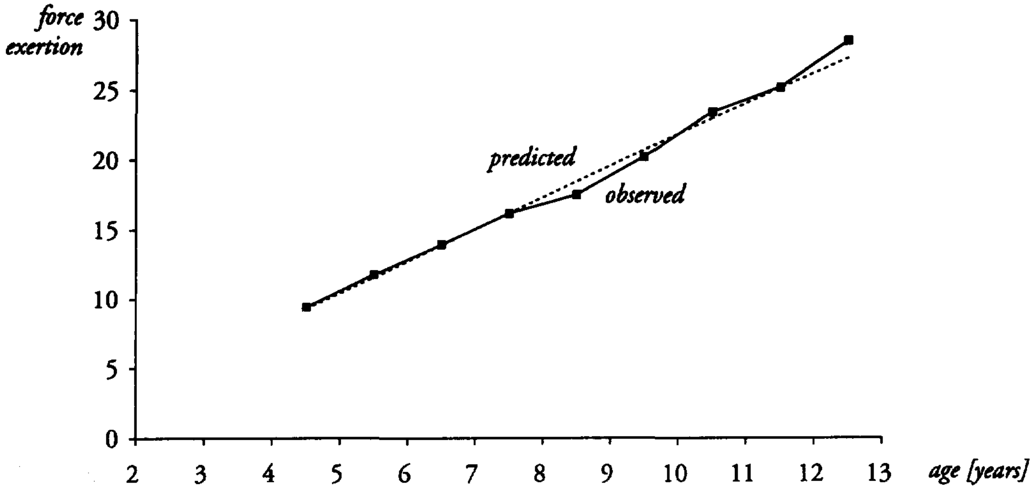


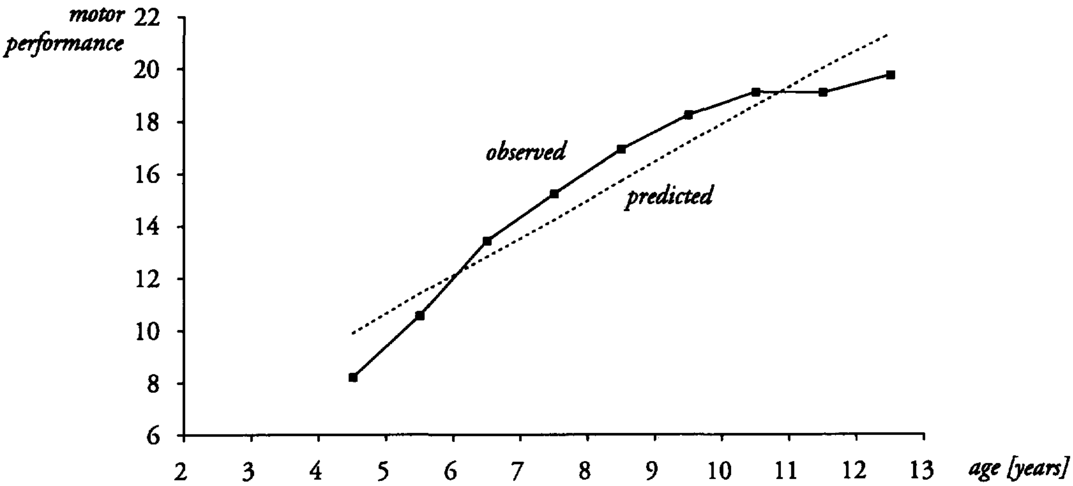


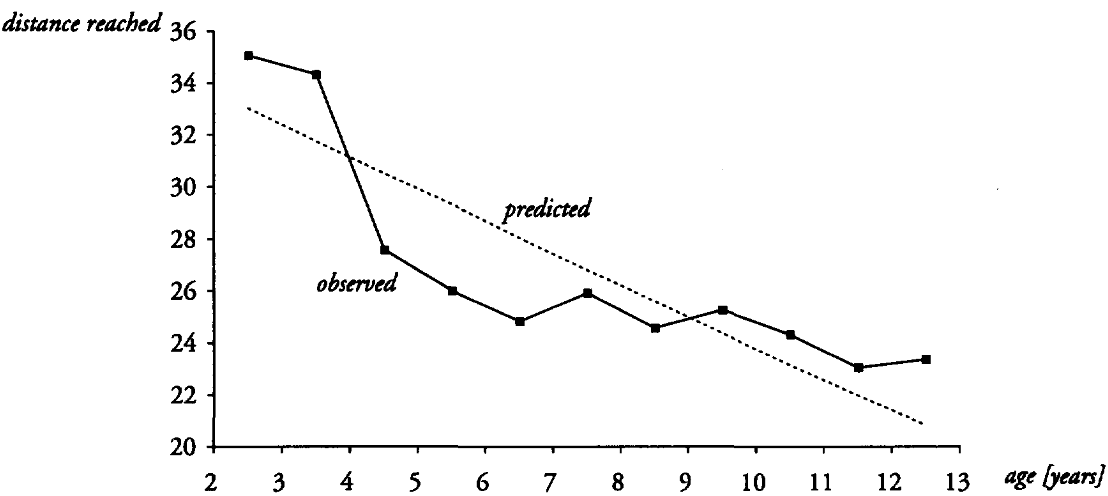

popliteal height [cm]
45
40
35
30
25
20
observed
predicted
2
3
4
5
6
7
8
9
10
11
12
13
age [years]

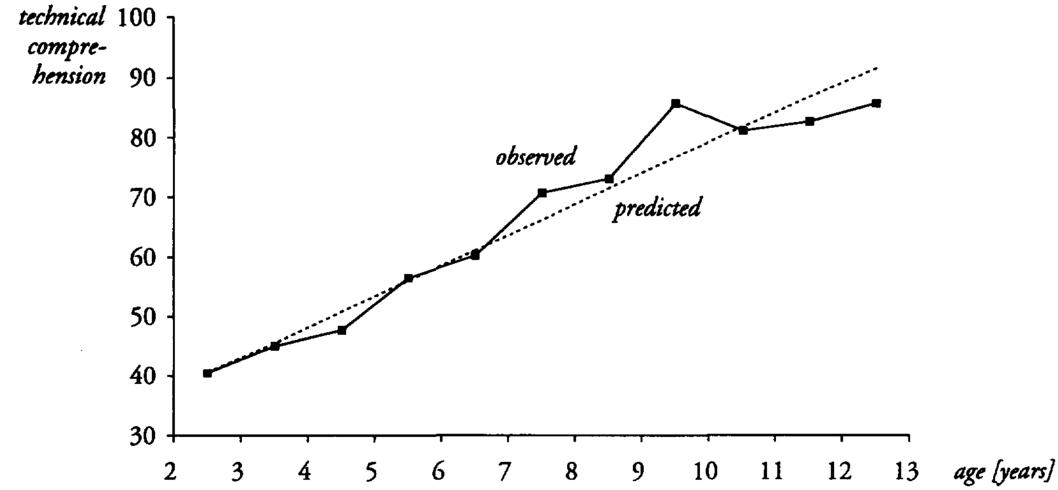

upper arm circum-ference [cm]
22
21
20
19
18
17
16
predicted
observed
2
3
4
5
6
7
8
9
10
11
12
13
age [years]

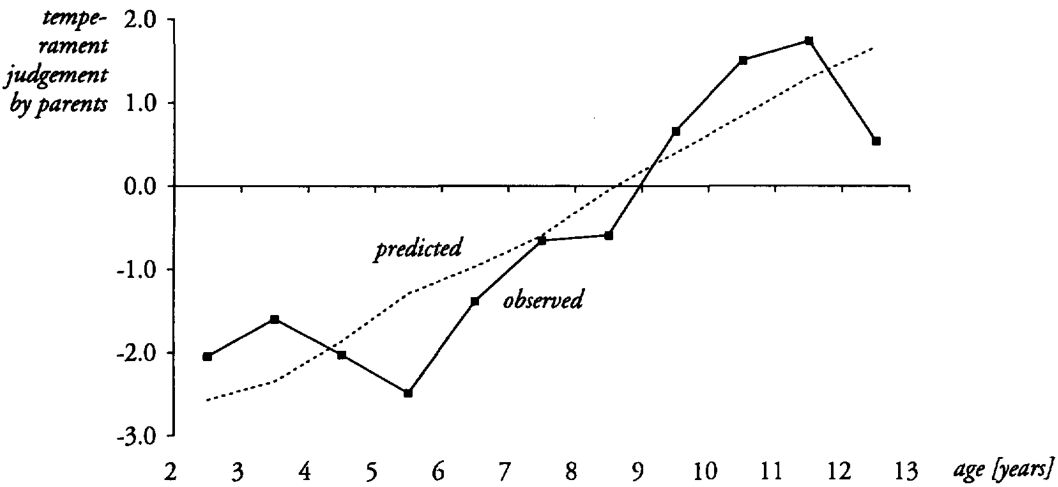

head circum-ference [cm]
55
54
53
52
51
50
49
observed
predicted
2
3
4
5
6
7
8
9
10
11
12
13
age [years]

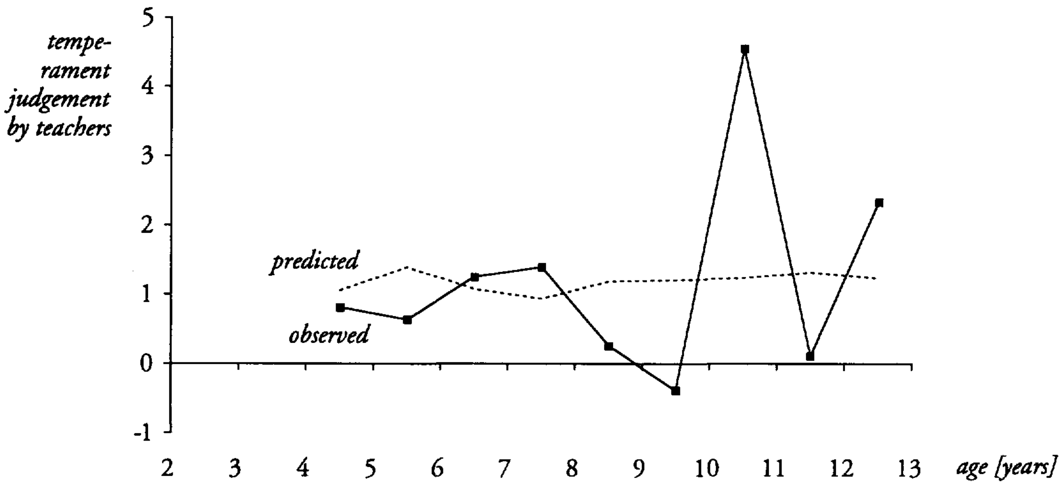

force exertion
30
25
20
15
10
5
0
predicted
observed
2
3
4
5
6
7
8
9
10
11
12
13
age [years]


motor performance
22
20
18
16
14
12
10
8
6
observed
predicted
2
3
4
5
6
7
8
9
10
11
12
13
age [years]


distance reached
36
34
32
30
28
26
24
22
20
predicted
observed
2
3
4
5
6
7
8
9
10
11
12
13
age [years]


technical comprehension
100
90
80
70
60
50
40
30
2
3
4
5
6
7
8
9
10
11
12
13
age [years]
observed
predicted


temperament judgement by parents
2.0
1.0
0.0
-1.0
-2.0
-3.0
2
3
4
5
6
7
8
9
10
11
12
13
age [years]
predicted
observed


temperament judgement by teachers
5
4
3
2
1
0
-1
2
3
4
5
6
7
8
9
10
11
12
13
age [years]
predicted
observed

K-1 Corr. coeff. between observed and predicted values and t-tests for boys

age [years]	stature r	stature p	stature t	stature p	body mass r	body mass p	body mass t	body mass p	popliteal height r	popliteal height p	popliteal height t	popliteal height p
2.0– 2.9	0.69	0.000	-6.86	0.000	0.52	0.000	7.36	0.000	0.70	0.000	-8.05	0.000
3.0– 3.9	0.45	0.000	-1.28	0.205	0.22	0.030	5.27	0.000	0.49	0.000	-2.40	0.018
4.0– 4.9	0.36	0.001	-0.86	0.395	0.29	0.010	-1.28	0.204	0.32	0.005	0.08	0.936
5.0– 5.9	0.34	0.002	3.44	0.001	0.25	0.023	-0.64	0.525	0.46	0.000	3.91	0.000
6.0– 6.9	0.35	0.001	2.29	0.024	0.20	0.052	-4.73	0.000	0.37	0.000	3.25	0.002
7.0– 7.9	0.22	0.022	2.77	0.077	0.15	0.138	-2.78	0.006	0.26	0.007	3.07	0.003
8.0– 8.9	0.27	0.007	0.38	0.706	0.22	0.035	-3.63	0.000	0.19	0.069	0.92	0.359
9.0– 9.9	0.13	0.171	3.38	0.001	-0.03	0.747	-1.04	0.299	0.13	0.171	2.79	0.006
10.0–10.9	0.20	0.021	-0.32	0.746	0.11	0.229	0.34	0.734	0.23	0.007	-0.31	0.758
11.0–11.9	0.17	0.042	-2.02	0.045	0.17	0.046	1.87	0.064	0.12	0.167	-1.92	0.057
12.0–12.9	0.31	0.006	-1.88	0.065	0.17	0.148	1.08	0.284	0.31	0.006	-2.30	0.024

age [years]	head cirumference r	p	t	p	upper arm circumference r	p	t	p	force exertion r	p	t	p
2.0– 2.9	0.30	0.011	-2.18	0.032	0.19	0.110	2.64	0.010	no measurements			
3.0– 3.9	0.11	0.284	-0.06	0.952	0.03	0.784	3.83	0.000	no measurements			
4.0– 4.9	-0.06	0.607	-0.36	0.723	0.16	0.152	-1.20	0.235	0.38	0.014	0.59	0.559
5.0– 5.9	0.02	0.853	0.65	0.518	0.11	0.318	-1.33	0.186	0.23	0.093	1.36	0.181
6.0– 6.9	0.02	0.873	1.86	0.065	-0.03	0.791	-3.21	0.002	0.26	0.051	-0.15	0.885
7.0– 7.9	0.01	0.946	0.63	0.527	0.07	0.502	-2.86	0.005	0.30	0.036	-0.33	0.740
8.0– 8.9	0.20	0.049	-0.41	0.684	0.17	0.097	-1.79	0.076	0.10	0.548	-1.16	0.253
9.0– 9.9	-0.05	0.626	0.89	0.377	-0.06	0.531	-0.56	0.574	0.07	0.645	-1.39	0.173
10.0–10.9	0.07	0.419	-0.71	0.481	0.01	0.906	1.19	0.237	0.02	0.893	0.67	0.506
11.0–11.9	0.07	0.442	1.29	0.198	0.11	0.179	1.24	0.219	0.12	0.470	-0.33	0.743
12.0–12.9	0.01	0.966	-1.97	0.052	0.12	0.316	0.71	0.482	0.08	0.667	0.95	0.349

age [years]	motor performance r	p	t	p	distance reached r	p	t	p	technical comprehension r	p	t	p
2.0– 2.9	*no measurements*				0.16	0.159	5.42	0.000	-0.15	0.199	-0.22	0.824
3.0– 3.9	no measurements				0.11	0.282	5.98	0.000	0.05	0.600	-0.17	0.863
4.0– 4.9	0.53	0.014	-3.11	0.006	0.22	0.135	-3.18	0.003	-0.05	0.766	-0.99	0.326
5.0– 5.9	0.48	0.002	-1.30	0.203	0.04	0.760	-5.26	0.000	0.30	0.039	0.61	0.543
6.0– 6.9	0.17	0.289	-0.18	0.860	0.08	0.542	-4.47	0.000	0.14	0.335	-0.05	0.961
7.0– 7.9	0.25	0.121	2.26	0.030	0.05	0.738	-1.04	0.303	-0.29	0.095	0.40	0.691
8.0– 8.9	0.00	0.989	4.64	0.000	0.12	0.455	-0.47	0.643	0.16	0.430	0.62	0.541
9.0– 9.9	0.29	0.127	2.09	0.045	-0.01	0.934	0.15	0.885	0.18	0.355	2.26	0.032
10.0–10.9	0.27	0.201	2.03	0.054	0.03	0.857	1.27	0.213	-0.28	0.156	-0.08	0.935
11.0–11.9	0.25	0.181	-2.55	0.016	-0.07	0.972	0.68	0.498	0.03	0.884	-0.98	0.337
12.0–12.9	-0.03	0.893	-3.26	0.003	-0.18	0.332	3.38	0.002	-0.04	0.899	-1.45	0.168

age [years]	temperament judgement by parents r	p	t	p	temperament judgement by teachers r	p	t	p
2.0– 2.9	0.22	0.052	1.35	0.182	no measurements			
3.0– 3.9	-0.14	0.183	0.94	0.352	no measurements			
4.0– 4.9	0.03	0.804	0.52	0.603	0.33	0.038	0.29	0.772
5.0– 5.9	-0.09	0.407	-1.90	0.061	0.49	0.001	-1.00	0.324
6.0– 6.9	0.18	0.073	-1.25	0.214	0.56	0.000	0.64	0.523
7.0– 7.9	0.03	0.737	0.08	0.935	0.66	0.000	0.12	0.903
8.0– 8.9	0.15	0.139	0.05	0.958	0.50	0.005	0.69	0.495
9.0– 9.9	0.02	0.848	-0.29	0.771	0.54	0.001	-0.70	0.487
10.0–10.9	0.20	0.023	-0.60	0.548	0.67	0.000	0.80	0.432
11.0–11.9	0.12	0.156	0.85	0.397	0.67	0.000	-1.46	0.156
12.0–12.9	0.10	0.405	0.50	0.622	0.61	0.001	0.52	0.608

K-2 Corr. coeff. between observed and predicted values and t-tests for girls

age	stature				body mass				popliteal height			
[years]	r	p	t	p	r	p	t	p	r	p	t	p
2.0– 2.9	0.67	0.000	-6.52	0.000	0.44	0.000	11.52	0.000	0.55	0.000	-8.50	0.000
3.0– 3.9	0.52	0.000	-2.35	0.021	0.37	0.001	4.53	0.000	0.46	0.000	-2.43	0.017
4.0– 4.9	0.44	0.000	0.47	0.637	0.16	0.188	0.06	0.955	0.40	0.001	0.15	0.879
5.0– 5.9	0.30	0.004	3.03	0.003	0.10	0.331	-1.74	0.086	0.26	0.014	3.71	0.000
6.0– 6.9	0.32	0.002	4.28	0.000	0.25	0.010	-3.78	0.000	0.25	0.019	3.86	0.000
7.0– 7.9	0.42	0.000	2.76	0.007	0.28	0.007	-2.09	0.039	0.34	0.001	3.10	0.003
8.0– 8.9	0.06	0.585	1.16	0.249	0.23	0.027	-4.00	0.000	-0.10	0.341	2.17	0.032
9.0– 9.9	0.27	0.003	-1.06	0.294	0.18	0.055	-4.13	0.000	0.24	0.009	0.51	0.610
10.0–10.9	0.34	0.000	1.99	0.049	0.20	0.023	2.51	0.013	0.32	0.000	1.51	0.133
11.0–11.9	0.35	0.000	-2.62	0.010	0.36	0.000	0.81	0.419	0.25	0.002	-3.19	0.002
12.0–12.9	0.18	0.113	-1.54	0.127	0.17	0.130	1.54	0.128	0.19	0.094	-2.84	0.006

	head cirumference				upper arm circumference				force exertion				he
2.0– 2.9	0.40	0.000	-4.15	0.000	0.14	0.197	2.88	0.005	no measurements				
3.0– 3.9	0.06	0.594	0.10	0.919	0.07	0.518	0.39	0.700	no measurements				
4.0– 4.9	1.33	0.267	1.23	0.223	-0.07	0.586	0.49	0.626	0.32	0.028	0.25	0.807	
5.0– 5.9	-0.08	0.465	1.91	0.059	0.03	0.795	-1.49	0.139	0.27	0.037	0.33	0.744	
6.0– 6.9	0.03	0.817	3.14	0.002	0.14	0.197	-0.70	0.488	0.01	0.954	0.84	0.402	
7.0– 7.9	0.09	0.416	1.26	0.211	0.23	0.031	-0.72	0.473	0.03	0.837	0.32	0.754	
8.0– 8.9	-0.01	0.913	-1.58	0.118	0.21	0.037	-1.47	0.145	0.16	0.335	-2.42	0.020	
9.0– 9.9	0.11	0.252	-1.69	0.093	0.03	0.784	-2.35	0.021	0.28	0.078	-0.41	0.682	
10.0–10.9	0.11	0.194	3.22	0.002	0.12	0.163	2.87	0.005	-0.02	0.928	0.39	0.702	
11.0–11.9	0.18	0.025	-0.87	0.385	0.22	0.006	0.79	0.430	0.11	0.489	0.21	0.837	
12.0–12.9	-0.01	0.925	-2.57	0.012	0.10	0.363	-0.54	0.593	0.06	0.780	0.38	0.711	

	motor performance				distance reached				technical comprehension			
2.0– 2.9	no measurements				-0.08	0.455	6.13	0.000	-0.09	0.419	0.13	0.899
3.0– 3.9	no measurements				0.08	0.462	6.26	0.000	-0.06	0.576	-0.03	0.748
4.0– 4.9	0.58	0.002	-3.84	0.001	0.12	0.414	-4.30	0.000	0.00	0.993	-0.83	0.409
5.0– 5.9	0.34	0.038	-3.07	0.004	0.02	0.887	-4.53	0.000	0.08	0.592	-0.35	0.726
6.0– 6.9	0.04	0.784	3.58	0.001	-0.28	0.037	-4.15	0.000	0.21	0.177	-0.54	0.592
7.0– 7.9	0.15	0.425	3.07	0.005	0.08	0.613	-1.24	0.221	0.18	0.315	1.79	0.083
8.0– 8.9	0.02	0.909	2.38	0.025	-0.25	0.122	-1.68	0.102	-0.05	0.801	0.02	0.982
9.0– 9.9	0.01	0.981	4.65	0.000	-0.07	0.656	1.93	0.061	0.46	0.008	4.24	0.000
10.0–10.9	-0.04	0.836	0.83	0.411	0.06	0.719	0.94	0.355	-0.04	0.828	-0.42	0.674
11.0–11.9	0.25	0.176	-4.11	0.000	0.11	0.496	1.30	0.200	-0.04	0.840	-1.09	0.283
12.0–12.9	0.21	0.425	-5.94	0.000	-0.35	0.105	1.45	0.162	0.04	0.884	-1.46	0.169

	temperament judgement by parents				temperament judgement by teachers			
2.0– 2.9	0.00	0.987	-0.23	0.817	no measurements			
3.0– 3.9	0.15	0.169	0.48	0.633	no measurements			
4.0– 4.9	0.39	0.000	-1.04	0.301	0.41	0.010	-0.26	0.800
5.0– 5.9	-0.03	0.759	-0.18	0.857	0.49	0.000	1.25	0.219
6.0– 6.9	-0.07	0.517	0.47	0.641	0.35	0.022	1.00	0.323
7.0– 7.9	0.05	0.672	-0.21	0.835	0.61	0.000	0.43	0.671
8.0– 8.9	0.05	0.630	-1.12	0.266	0.27	0.130	-1.28	0.209
9.0– 9.9	-0.12	0.179	0.98	0.329	0.61	0.000	-1.41	0.169
10.0–10.9	-0.04	0.609	2.27	0.025	0.49	0.004	1.47	0.151
11.0–11.9	-0.04	0.622	0.19	0.852	0.45	0.010	-0.84	0.405
12.0–12.9	0.14	0.212	-2.73	0.008	0.70	0.000	-1.13	0.271

L Differences in proportions

age [years]	head t	head p	trunk t	trunk p	legs t	legs p
2.0 – 2.9	1.21	0.227	0.21	0.833	-1.23	0.220
3.0 – 3.9	2.21	0.028	0.37	0.709	-1.78	0.078
4.0 – 4.9	2.47	0.015	-1.04	0.300	-2.33	0.021
5.0 – 5.9	1.94	0.054	-1.12	0.263	-0.67	0.502
6.0 – 6.9	4.63	0	1.07	0.285	-0.97	0.334
7.0 – 7.9	4.47	0	-0.97	0.331	-1.24	0.217
8.0 – 8.9	3.72	0	-2.83	0.005	0.59	0.554
9.0 – 9.9	2.56	0.011	-1.52	0.130	0.61	0.541
10.0 – 10.9	5.83	0	-1.27	0.207	-0.63	0.531
11.0 – 11.9	5.95	0	-3.69	0	1.02	0.310
12.0 – 12.9	4.40	0	-1.15	0.251	0.25	0.800

T-tests, testing the differences between mean values of boys and girls

age groups [years]	head t	head p	trunk t	trunk p	legs t	legs p
2 – 3	3.68	0	4.90	0	-9.16	0
3 – 4	3.35	0.001	6.29	0	-3.85	0
4 – 5	3.97	0	2.74	0.007	-6.83	0
5 – 6	4.75	0	-1.34	0.181	-1.80	0.074
6 – 7	3.74	0	1.06	0.293	-3.50	0.001
7 – 8	4.12	0	1.84	0.067	-4.08	0
8 – 9	6.19	0	0.74	0.458	-3.39	0.001
9 – 10	1.60	0.012	-0.48	0.628	-2.58	0.011
10 – 11	3.31	0.011	1.15	0.249	-2.82	0.005
11 – 12	4.15	0	-1.06	0.291	-1.59	0.113

T-tests, testing differences between successive age groups of boys

age groups [years]	head t	head p	trunk t	trunk p	legs t	legs p
2 – 3	4.09	0	4.61	0	-10.10	0
3 – 4	3.83	0	5.12	0	-4.51	0
4 – 5	3.46	0.001	2.98	0.003	-4.99	0
5 – 6	6.77	0	0.84	0.401	-2.03	0.044
6 – 7	3.46	0.001	-1.00	0.319	-3.48	0.001
7 – 8	3.15	0.002	0.04	0.968	-2.37	0.019
8 – 9	4.44	0	2.29	0.023	-3.62	0
9 – 10	4.46	0	-0.20	0.842	-3.88	0
10 – 11	2.75	0.006	0.96	0.336	-1.39	0.166
11 – 12	4.19	0	0.57	0.566	-2.25	0.025

T-tests, testing differences between successive age groups of girls

M-1 Correlation coefficients (alle ages)

	correlation between different variables for all ages together									
	stature	body mass	popliteal height	head circum-ference	upper arm circum-ference	force exertion	technical compre-hension	distance reached	motor perfor-mance	temperament judgement by parents
body mass	.9284 n = 2209 p = .000									
popliteal height	.9850 n = 2200 p = .000	.8974 n = 2200 p = .000	→ *correlation coefficient* → *number of cases* → *one-tailed significance*							
head circumference	**.7098** n = 2201 p = .000	**.7193** n = 2202 p = .000	**.6914** n = 2198 p = .000							
upper arm circumference	**.7527** n = 2200 p = .000	**.9005** n = 2201 p = .000	**.7140** n = 2197 p = .000	**.6321** n = 2201 p = .000						
force exertion	**.8267** n = 772 p = .000	**.7938** n = 772 p = .000	**.8224** n = 772 p = .000	**.5254** n = 772 p = .000	**.6416** n = 772 p = .000					
technical comprehension	**.5841** n = 926 p = .000	**.5461** n = 927 p = .000	**.5793** n = 918 p = .000	**.4003** n = 920 p = .000	**.4500** n = 919 p = .000	**.4265** n = 547 p = .000				
distance reached	**-.5719** n = 1115 p = .000	**-.4865** n = 1116 p = .000	**-.5824** n = 1110 p = .000	**-.4409** n = 1112 p = .000	**-.3855** n = 1111 p = .000	**-.0962** n = 781 p = .004	**-.3120** n = 898 p = .000			
motor performance	**.7946** n = 550 p = .000	**.6816** n = 550 p = .000	**.7801** n = 550 p = .000	**.4379** n = 550 p = .000	**.5083** n = 550 p = .000	**.6954** n = 549 p = .000	**.5364** n = 340 p = .000	**-.0710** n = 551 p = .048		
temperament judgement by parents	**.1257** n = 2200 p = .000	**.1086** n = 2201 p = .000	**.1181** n = 2191 p = .000	**.0973** n = 2193 p = .000	**.0757** n = 2192 p = .000	.0082 n = 783 p = .410	.0016 n = 957 p = .481	-.0405 n = 1132 p = .086	**.1762** n = 552 p = .000	
temperament judgement by teachers	.0586 n = 616 p = .073	.0394 n = 616 p = .165	.0359 n = 616 p = .187	-.0143 n = 616 p = .362	.0038 n = 616 p = .462	**-.1093** n = 569 p = .005	-.0022 n = 522 p = .480	**.0805** n = 569 p = .027	**.1347** n = 355 p = .006	**.5558** n = 633 p = .000

bold: $p < 0.05$ (one-tailed significance)

M-2 Correlation coefficients (2 - 5 years)

	correlation between different variables for children aged 2 to 5 years									
	stature	body mass	popliteal height	head circumference	upper arm circumference	force exertion	technical comprehension	distance reached	motor performance	temperament judgement by parents
body mass	**.9044** n = 670 p = .000									
popliteal height	**.9550** n = 661 p = .000	**.8406** n = 661 p = .000	→ *correlation coefficient* → *number of cases* → *one-tailed significance*							
head circumference	**.5289** n = 662 p = .000	**.5759** n = 663 p = .000	**.4860** n = 659 p = .000							
upper arm circumference	**.4766** n = 661 p = .000	**.7211** n = 662 p = .000	**.3991** n = 658 p = .000	**.3830** n = 662 p = .000						
force exertion	**.5358** n = 189 p = .000	**.4761** n = 189 p = .000	**.4924** n = 189 p = .000	**.2099** n = 189 p = .002	**.2856** n = 189 p = .000					
technical comprehension	**.2532** n = 503 p = .000	**.2412** n = 504 p = .000	**.2244** n = 495 p = .000	**.0873** n = 497 p = .026	**.1353** n = 496 p = .001	**.2400** n = 150 p = .002				
distance reached	**-.5820** n = 531 p = .000	**-.4909** n = 532 p = .000	**-.5985** n = 526 p = .000	**-.3162** n = 528 p = .000	**-.2093** n = 527 p = .000	.0796 n = 199 p = .132	**-.0838** n = 498 p = .031			
motor performance	**.5199** n = 123 p = .000	**.3711** n = 123 p = .000	**.4987** n = 123 p = .000	.1363 n = 123 p = .066	**.1741** n = 123 p = .027	**.5002** n = 124 p = .000	**.3436** n = 81 p = .001	.0378 n = 124 p = .338		
temperament judgement by parents	-.0485 n = 667 p = .105	**-.0788** n = 668 p = .021	-.0538 n = 658 p = .084	.0274 n = 660 p = .241	**-.0862** n = 659 p = .013	**-.1564** n = 200 p = .014	**-.0897** n = 528 p = .020	.0103 n = 547 p = .405	-.0234 n = 124 p = .398	
temperament judgement by teachers	-.1174 n = 156 p = .072	**-.1846** n = 156 p = .011	-.0764 n = 156 p = .172	-.1253 n = 156 p = .060	**-.1947** n = 156 p = .007	**-.2353** n = 153 p = .002	.0681 n = 147 p = .206	**.1554** n = 152 p = .028	.0659 n = 81 p = .280	**.4915** n = 168 p = .000

bold: $p < 0.05$ (one-tailed significance)

M-3 Correlation coefficients (6 - 8 years)

	correlation between different variables for children aged 6 to 8 years									
	stature	body mass	popliteal height	head circumference	upper arm circumference	force exertion	technical comprehension	distance reached	motor performance	temperament judgement by parents
body mass	**.8082** n = 577 p = .000									
popliteal height	**.8993** n = 577 p = .000	**.6747** n = 577 p = .000	*→ correlation coefficient* *→ number of cases* *→ one-tailed significance*							
head circumference	**.3474** n = 577 p = .000	**.4280** n = 577 p = .000	**.2763** n = 577 p = .000							
upper arm circumference	**.4902** n = 577 p = .000	**.8296** n = 577 p = .000	**.3690** n = 577 p = .000	**.3318** n = 577 p = .000						
force exertion	**.4781** n = 289 p = .000	**.4867** n = 289 p = .000	**.4709** n = 289 p = .000	**.2419** n = 289 p = .000	**.3527** n = 289 p = .000					
technical comprehension	**.1704** n = 217 p = .006	**.2019** n = 217 p = .001	**.2132** n = 217 p = .001	.0511 n = 217 p = .227	**.1288** n = 217 p = .029	**.1488** n = 206 p = .016				
distance reached	-.0770 n = 290 p = .095	-.0153 n = 290 p = .397	**-.1103** n = 290 p = .030	-.0440 n = 290 p = .228	-.0057 n = 290 p = .461	.0377 n = 289 p = .262	.0618 n = 208 p = .188			
motor performance	**.3892** n = 208 p = .000	**.3105** n = 208 p = .000	**.3496** n = 208 p = .000	.0940 n = 208 p = .088	**.1773** n = 208 p = .005	**.2645** n = 207 p = .000	**.1616** n = 134 p = .031	**.1748** n = 208 p = .006		
temperament judgement by parents	.0421 n = 574 p = .157	-.0386 n = 574 p = .178	.0204 n = 574 p = .313	.0582 n = 574 p = .082	-.0511 n = 574 p = .111	**-.1014** n = 289 p = .043	-.0152 n = 220 p = .411	-.0496 n = 291 p = .200	**.1466** n = 209 p = .017	
temperament judgement by teachers	.0539 n = 228 p = .209	.0216 n = 228 p = .373	.0107 n = 228 p = .436	-.0165 n = 228 p = .402	.0319 n = 228 p = .316	**-.1339** n = 212 p = .026	-.0859 n = 200 p = .113	.0678 n = 213 p = .162	**.1896** n = 136 p = .014	**.5297** n = 231 p = .000

bold: $p < 0.05$ (one-tailed significance)

M-4 Correlation coefficients (9 - 13 years)

correlation between different variables for children aged 9 to 13 years

	stature	body mass	popliteal height	head circumference	upper arm circumference	force exertion	technical comprehension	distance reached	motor performance	temperament judgement by parents
body mass	**.7938** n = 962 p = .000									
popliteal height	**.9045** n = 962 p = .000	**.6517** n = 962 p = .000	→ *correlation coefficient* → *number of cases* → *one-tailed significance*							
head circumference	**.4467** n = 962 p = .000	**.5177** n = 962 p = .000	**.3917** n = 962 p = .000							
upper arm circumference	**.5026** n = 962 p = .000	**.8600** n = 962 p = .000	**.3697** n = 962 p = .000	**.4194** n = 962 p = .000						
force exertion	**.5537** n = 294 p = .000	**.4905** n = 294 p = .000	**.5580** n = 294 p = .000	**.2800** n = 294 p = .000	**.3577** n = 294 p = .000					
technical comprehension	-.0495 n = 206 p = .240	-.0328 n = 206 p = .320	-.0252 n = 206 p = .360	-.0261 n = 206 p = .355	-.0184 n = 206 p = .396	-.0120 n = 191 p = .434				
distance reached	**-.1586** n = 294 p = .003	-.0808 n = 294 p = .084	**-.1882** n = 294 p = .001	-.0928 n = 294 p = .056	-.0578 n = 294 p = .162	.0082 n = 293 p = .444	.0049 n = 192 p = .473			
motor performance	**.1692** n = 219 p = .006	.0884 n = 219 p = .096	**.1301** n = 219 p = .027	-.0005 n = 219 p = .497	.0032 n = 219 p = .481	**.2371** n = 218 p = .000	.0515 n = 125 p = .284	**.1537** n = 219 p = .011		
temperament judgement by parents	.0000 n = 959 p = .499	-.0034 n = 959 p = .458	-.0213 n = 959 p = .255	-.0237 n = 959 p = .231	.0001 n = 959 p = .498	**-.1493** n = 294 p = .005	-.0506 n = 209 p = .234	.0509 n = 294 p = .192	.1024 n = 219 p = .065	
temperament judgement by teachers	.1208 n = 232 p = .033	.0583 n = 232 p = .188	.0277 n = 232 p = .337	-.0137 n = 232 p = .418	-.0005 n = 232 p = .497	**-.2533** n = 204 p = .000	.0008 n = 175 p = .496	.0609 n = 204 p = .193	**.2292** n = 138 p = .003	**.6337** n = 234 p = .000

bold: *$p < 0.05$ (one-tailed significance)*

N-1 Partial correlations (controlling for age)

	partial correlations, controlling for age stature	body mass	popliteal height	head circum-ference	upper arm circum-ference	force exertion	technical compre-hension	distance reached	motor perfor-mance	temperament judgement by parents
body mass	**.6229** n = 2206 p = .000									
popliteal height	**.8368** n = 2197 p = .000	**.4095** n = 2197 p = .000	→ *correlation coefficient* → *number of cases* → *one-tailed significance*							
head circumference	**.4006** n = 2198 p = .000	**.4066** n = 2199 p = .000	**.3090** n = 2195 p = .000							
upper arm circumference	**.3841** n = 2197 p = .000	**.8336** n = 2198 p = .000	**.2029** n = 2194 p = .000	**.3225** n = 2198 p = .000						
force exertion	**.2737** n = 769 p = .000	**.2759** n = 769 p = .000	**.2675** n = 769 p = .000	-.0109 n = 769 p = .381	**.1640** n = 769 p = .000					
technical comprehension	**-.0390** n = 547 p = .181	**-.2052** n = 547 p = .000	**-.0679** n = 547 p = .056	-.2504 n = 547 p = .000	-.2028 n = 547 p = .000	**.0487** n = 546 p = .128				
distance reached	**-.1757** n = 1112 p = .000	.0022 n = 1113 p = .471	**-.2191** n = 1107 p = .000	**-.1281** n = 1109 p = .000	.0070 n = 1108 p = .408	**.7345** n = 778 p = .000	.8498 n = 548 p = .000			
motor performance	.0442 n = 923 p = .089	**.0501** n = 924 p = .064	**.0453** n = 915 p = .085	**.0182** n = 917 p = .291	**.0502** n = 916 p = .064	-.1315 n = 544 p = .001	**.0846** n = 337 p = .060	**.0283** n = 895 p = .198		
temperament judgement by parents	**-.0312** n = 2197 p = .072	**-.0315** n = 2198 p = .070	**-.0476** n = 2188 p = .013	.0083 n = 2190 p = .350	**-.0326** n = 2189 p = .064	**-.1847** n = 780 p = .000	**.1088** n = 549 p = .005	**.0447** n = 1129 p = .066	-.1036 n = 954 p = .001	
temperament judgement by teachers	**.0889** n = 613 p = .014	.0180 n = 613 p = .328	.0084 n = 613 p = .418	-.0489 n = 613 p = .113	-.0294 n = 613 p = .234	**-.2380** n = 566 p = .000	.1914 n = 352 p = .000	**.1200** n = 566 p = .002	**-.0290** n = 519 p = .255	**.5568** n = 630 p = .000

***bold:** significant ($p < 0.05$)*

N-2 Partial correlations (controlling age and sex)

	partial correlations, controlling for age and sex									
	stature	body mass	popliteal height	head circum-ference	upper arm circum-ference	force exertion	technical compre-hension	distance reached	motor perfor-mance	temperament judgement by parents
body mass	**.6246** n = 2205 p = .000									
popliteal height	**.8393** n = 2196 p = .000	**.4164** n = 2196 p = .000	→ *correlation coefficient* → *number of cases* → *one-tailed significance*							
head circumference	**.4107** n = 2197 p = .000	**.4362** n = 2198 p = .000	**.2918** n = 2194 p = .000							
upper arm circumference	**.3867** n = 2196 p = .000	**.8334** n = 2197 p = .000	**.2115** n = 2193 p = .000	**.3566** n = 2197 p = .000						
force exertion	**.2807** n = 768 p = .000	**.3051** n = 768 p = .000	**.2471** n = 768 p = .000	**-.1148** n = 768 p = .001	**.1959** n = 768 p = .000					
technical comprehension	**-.0358** n = 546 p = .202	**-.2129** n = 546 p = .000	-.0534 n = 546 p = .106	-.2211 n = 546 p = .000	-.2146 n = 546 p = .000	**.1012** n = 545 p = .009	n = 0 .			
distance reached	**-.1740** n = 1111 p = .000	-.0045 n = 1112 p = .440	**-.2046** n = 1106 p = .000	**-.0834** n = 1108 p = .003	-.0042 n = 1107 p = .445	**.8485** n = 777 p = .000	.8465 n = 547 p = .000	.		
motor performance	.0429 n = 922 p = .096	**.0524** n = 923 p = .055	.0395 n = 914 p = .116	**.0020** n = 916 p = .476	**.0541** n = 915 p = .051	**-.1588** n = 543 p = .000	**.0938** n = 336 p = .043	**.0388** n = 894 p = .123	.	
temperament judgement by parents	**-.0274** n = 2196 p = .100	**-.0384** n = 2197 p = .036	**-.0304** n = 2187 p = .077	**.0584** n = 2189 p = .003	**-.0438** n = 2188 p = .020	**-.1409** n = 779 p = .000	**.0877** n = 548 p = .020	**.0169** n = 1128 p = .285	-.0957 n = 953 p = .002	.
temperament judgement by teachers	**.1044** n = 612 p = .005	.0048 n = 612 p = .453	**.0498** n = 612 p = .109	.0575 n = 612 p = .077	-.0556 n = 612 p = .084	**-.1403** n = 565 p = .000	.1528 n = 351 p = .002	.0645 n = 565 p = .062	**-.0097** n = 518 p = .413	**.5405** n = 629 p = .000

bold: significant ($p < 0.05$)

P Results of different variables according to age and accident liability

	age [years]	absolutely not n	absolutely not s	absolutely not x̄	doubtful n	doubtful s	doubtful x̄	absolutely n	absolutely s	absolutely x̄
		liable to have accidents								
stature [cm]	4.0– 4.9	70	4.2	108.9	14	4.8	110.8	8	5.8	110.7
	5.0– 5.9	71	5.0	116.5	22	4.6	117.7	5	3.9	114.8
	6.0– 6.9	73	4.0	122.2	18	5.7	119.2	7	6.4	126.7
	7.0– 7.9	60	6.1	129.5	17	5.1	128.6	15	5.2	127.0
	8.0– 8.9	49	5.4	134.3	24	6.5	133.8	7	4.5	134.8
	9.0– 9.9	52	5.4	141.4	22	5.8	140.0	7	5.8	140.1
	10.0–10.9	55	6.7	148.7	18	6.1	145.4	6	9.3	148.7
	11.0–11.9	47	6.2	151.9	18	6.5	150.1	9	10.2	153.0
	12.0–12.9	35	8.0	158.5	8	2.7	158.1		-	-
body mass [kg]	4.0– 4.9	70	2.3	18.6	14	2.3	19.3	8	3.1	20.0
	5.0– 5.9	71	3.1	21.5	22	2.9	21.9	5	1.4	20.9
	6.0– 6.9	73	2.5	23.3	18	3.2	22.3	7	3.0	24.8
	7.0– 7.9	60	4.3	27.9	17	3.1	26.9	15	3.4	25.1
	8.0– 8.9	49	4.2	29.5	24	3.9	28.8	7	3.5	29.0
	9.0– 9.9	52	5.1	33.0	22	5.5	32.2	7	3.9	31.8
	10.0–10.9	55	7.2	38.7	18	7.8	38.5	6	9.9	42.2
	11.0–11.9	47	7.0	41.4	18	7.8	40.8	9	8.6	40.5
	12.0–12.9	35	8.7	45.1	8	4.1	43.5		-	-
popliteal height [cm]	4.0– 4.9	70	1.6	27.9	14	1.5	29.0	8	1.5	29.0
	5.0– 5.9	71	1.8	30.7	22	1.7	30.6	5	1.2	31.1
	6.0– 6.9	73	1.6	32.6	18	2.0	31.8	7	2.7	33.6
	7.0– 7.9	60	2.3	35.1	17	1.6	34.6	15	1.5	33.9
	8.0– 8.9	49	2.2	36.8	24	2.6	36.7	7	2.1	37.4
	9.0– 9.9	52	2.0	39.0	22	2.1	38.2	7	2.4	38.1
	10.0–10.9	55	2.4	41.3	18	2.4	40.5	6	2.7	41.0
	11.0–11.9	47	2.6	42.5	18	3.0	41.6	9	3.9	43.6
	12.0–12.9	35	2.7	44.4	8	1.2	45.1		-	-
head circumference [cm]	4.0– 4.9	70	1.3	51.4	14	1.2	51.9	8	1.2	51.8
	5.0– 5.9	71	1.4	52.0	22	1.4	52.2	5	0.8	52.9
	6.0– 6.9	73	1.4	52.7	18	1.2	52.2	7	1.2	52.4
	7.0– 7.9	60	1.2	53.1	17	1.2	52.8	15	1.7	52.3
	8.0– 8.9	49	1.6	52.9	24	1.2	52.2	7	0.9	53.0
	9.0– 9.9	52	1.4	53.5	22	1.4	53.4	7	1.0	54.0
	10.0–10.9	55	1.7	54.1	18	1.0	53.8	6	1.5	54.4
	11.0–11.9	47	1.4	54.2	18	1.8	54.2	9	1.7	53.9
	12.0–12.9	35	1.6	54.3	8	1.2	54.4		-	-

	age [years]	absolutely not n	s	x̄	doubtful n	s	x̄	absolutely n	s	x̄
		liable to have accidents								
upper arm circumference [cm]	4.0– 4.9	70	1.3	17.3	14	1.5	17.7	8	1.6	18.0
	5.0– 5.9	71	1.5	17.9	22	1.5	17.9	5	0.9	17.7
	6.0– 6.9	73	1.4	18.3	18	1.7	18.1	7	1.7	18.8
	7.0– 7.9	60	1.8	19.4	17	1.4	18.8	15	1.5	18.2
	8.0– 8.9	49	1.8	19.7	24	1.5	19.2	7	1.5	18.8
	9.0– 9.9	52	1.9	20.0	22	2.4	19.9	7	1.8	20.2
	10.0–10.9	55	2.2	21.4	18	2.4	21.6	6	2.4	22.8
	11.0–11.9	47	2.4	21.7	18	2.2	22.0	9	2.4	21.4
	12.0–12.9	35	2.3	22.2	8	1.8	22.2		-	-
total score on force exertion	4.0– 4.9	70	2.5	9.8	14	2.2	10.0	8	2.8	10.5
	5.0– 5.9	71	2.3	11.9	22	2.4	12.4	5	3.6	13.3
	6.0– 6.9	73	2.6	14.4	18	2.6	14.0	7	3.7	14.0
	7.0– 7.9	60	3.5	17.2	17	3.9	17.9	15	2.6	15.4
	8.0– 8.9	49	4.4	17.6	24	3.9	18.2	7	2.5	19.5
	9.0– 9.9	52	4.4	21.1	22	2.7	21.9	7	4.9	19.6
	10.0–10.9	55	5.5	23.9	18	5.8	25.5	6	13.1	28.5
	11.0–11.9	47	5.7	26.0	18	4.7	27.1	9	4.4	23.1
	12.0–12.9	35	6.2	28.2	8	7.8	34.2		-	-
total score on motor performance	4.0– 4.9	70	2.8	8.7	14	2.7	6.5	8	0.8	6.6
	5.0– 5.9	71	2.5	10.8	22	2.3	10.8	1	0.0	11.3
	6.0– 6.9	73	2.5	13.9	18	3.4	12.8	7	4.2	14.1
	7.0– 7.9	60	2.6	15.6	17	2.3	13.9	15	2.6	14.8
	8.0– 8.9	49	1.2	17.1	24	2.1	16.7	7	1.9	15.0
	9.0– 9.9	52	1.7	18.4	22	2.1	17.9	7	0.7	19.7
	10.0–10.9	55	1.4	19.3	18	1.4	18.4	6	1.6	19.2
	11.0–11.9	47	1.9	19.3	18	1.8	18.7	9	1.7	19.3
	12.0–12.9	35	1.5	20.0	8	3.1	19.8		-	-
distance reached [cm]	4.0– 4.9	70	4.7	26.5	14	6.4	25.5	8	2.1	31.2
	5.0– 5.9	71	5.1	26.1	22	5.4	25.9	5	4.3	31.2
	6.0– 6.9	73	5.4	24.6	18	4.1	27.3	7	9.6	25.4
	7.0– 7.9	60	5.3	26.3	17	5.6	23.0	15	5.2	25.8
	8.0– 8.9	49	6.4	24.4	24	6.7	25.1	7	5.8	23.6
	9.0– 9.9	52	6.1	25.6	22	4.9	24.4	7	9.8	21.5
	10.0–10.9	55	6.8	25.2	18	5.2	23.4	6	5.4	26.4
	11.0–11.9	47	7.7	23.7	18	6.0	21.6	9	8.8	27.3
	12.0–12.9	35	7.1	23.4	8	4.2	21.9		-	-

	age [years]	liable to have accidents: absolutely not n	s	x̄	doubtful n	s	x̄	absolutely n	s	x̄
score on physical flexibility	4.0– 4.9	70	0.2	-0.3	14	0.2	-0.4	8	0.3	-0.2
	5.0– 5.9	71	0.2	-0.3	22	0.2	-0.3	5	0.1	-0.1
	6.0– 6.9	73	0.2	-0.2	18	0.2	-0.2	7	0.2	-0.3
	7.0– 7.9	60	0.2	-0.1	17	0.3	-0.2	15	0.2	-0.2
	8.0– 8.9	49	0.3	-0.1	24	0.2	-0.1	7	0.2	0.0
	9.0– 9.9	52	0.2	-0.1	22	0.2	-0.1	7	0.2	-0.2
	10.0–10.9	55	0.2	0.0	18	0.2	-0.1	6	0.4	0.2
	11.0–11.9	47	0.3	0.0	18	0.2	0.0	9	0.2	0.1
	12.0–12.9	35	0.3	0.1	8	0.4	0.1		-	-
total score on technical comprehension	4.0– 4.9	70	21.3	46.0	14	20.9	48.7	8	23.6	50.0
	5.0– 5.9	71	27.2	56.1	22	25.1	57.8	5	19.0	56.7
	6.0– 6.9	73	25.4	58.6	18	17.0	62.0	7	24.9	61.9
	7.0– 7.9	60	22.2	69.9	17	20.4	81.8	15	22.6	58.3
	8.0– 8.9	49	21.6	77.4	24	24.4	60.8	7	11.8	83.3
	9.0– 9.9	52	14.3	86.6	22	16.5	78.2	7	15.1	78.3
	10.0–10.9	55	19.2	81.3	18	18.3	81.6	6	5.9	95.8
	11.0–11.9	47	23.0	83.1	18	17.8	78.9	9	24.6	79.2
	12.0–12.9	35	19.1	84.5	8	16.7	91.7		-	-
temperament judgement by parents	4.0– 4.9	70	8.8	-1.2	14	9.5	-10.1	8	5.9	-17.0
	5.0– 5.9	71	9.8	0.4	22	11.9	-11.9	5	9.7	-13.3
	6.0– 6.9	73	9.2	-0.4	18	9.3	-11.3	7	6.5	-12.0
	7.0– 7.9	60	10.2	-0.2	17	11.4	-10.2	15	8.4	-13.6
	8.0– 8.9	49	10.6	-0.9	24	10.6	-7.1	7	15.0	-8.0
	9.0– 9.9	52	10.1	-0.4	22	13.1	-8.9	7	13.1	-5.1
	10.0–10.9	55	10.4	3.2	18	8.6	-8.9	6	11.7	-7.3
	11.0–11.9	47	9.3	0.4	18	11.9	-6.2	9	13.0	-4.2
	12.0–12.9	35	9.1	2.0	8	8.0	-2.2		-	-
temperament judgement by teachers	4.0– 4.9	70	10.6	1.6	14	13.0	-9.4	8	10.6	-14.2
	5.0– 5.9	71	11.8	2.7	22	13.5	-5.9	5	10.9	-10.5
	6.0– 6.9	73	10.4	3.3	18	10.8	-7.1	7	8.6	-14.4
	7.0– 7.9	60	12.4	3.9	17	9.3	-11.7	15	11.2	-9.5
	8.0– 8.9	49	10.2	-0.6	24	12.2	-1.1	7	14.1	-7.5
	9.0– 9.9	52	10.5	1.6	22	10.2	-10.3	7	10.6	-10.7
	10.0–10.9	55	11.9	5.8	18	12.7	-7.4	6	6.5	-16.6
	11.0–11.9	47	10.7	1.4	18	13.5	-6.0	9	16.7	-7.8
	12.0–12.9	35	9.2	3.6	8	12.0	-5.2		-	-

Q Correlations with accident liability

	accident liability (p < 0.05, 2-tailed)			
	all ages	2.0 – 5.9	6.0 – 8.9	9.0 – 12.9
stature	.0105 n = 721 p = .779	.0607 n = 178 p = .421	.0357 n = 267 p = .562	-.1142 n = 276 p = .058
body mass	-.0037 n = 721 p = .922	.0729 n = 178 p = .333	-.0355 n = 267 p = .564	-.0584 n = 276 p = .334
popliteal height	.0150 n = 721 p = .687	.1095 n = 178 p = .146	.0213 n = 267 p = .728	-.0978 n = 276 p = .105
head circumference	-.0116 n = 721 p = .755	.1365 n = 178 p = .069	-.1358 n = 267 p = .027	-.0193 n = 276 p = .749
upper arm circumference	-.0002 n = 721 p = .996	.0716 n = 178 p = .342	-.0970 n = 267 p = .114	.0114 n = 276 p = .851
force exertion	.0400 n = 668 p = .302	.1062 n = 174 p = .163	.0228 n = 250 p = .720	.0168 n = 244 p = .794
motor performance	-.0069 n = 416 p = .889	-.0917 n = 93 p = .382	-.0992 n = 161 p = .211	-.0640 n = 162 p = .418
distance reached	.0055 n = 669 p = .888	.1303 n = 173 p = .087	.0067 n = 251 p = .915	-.0409 n = 245 p = .524
technical comprehension	-.0037 n = 604 p = .927	.0330 n = 166 p = .673	-.0261 n = 228 p = .695	-.0644 n = 210 p = .353
temperament judgement by parents	**-.3809** n = 737 p = .000	**-.4804** n = 190 p = .000	**-.4054** n = 270 p = .000	**-.3006** n = 277 p = .000
temperament judgement by teachers	**-.3932** n = 723 p = .000	**-.3904** n = 189 p = .000	**-.3793** n = 263 p = .000	**-.4130** n = 271 p = .000

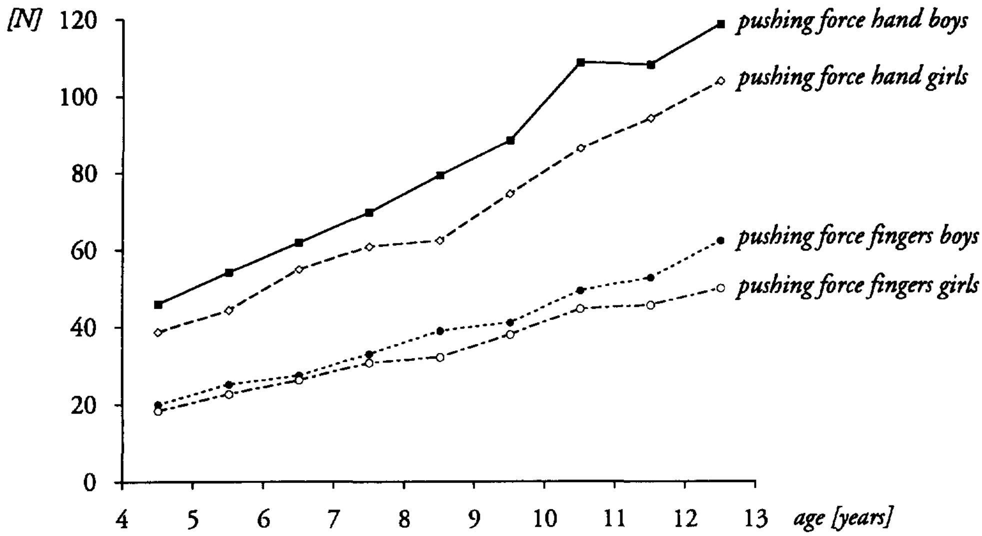
R-1 Correlations between different variables and education of parents

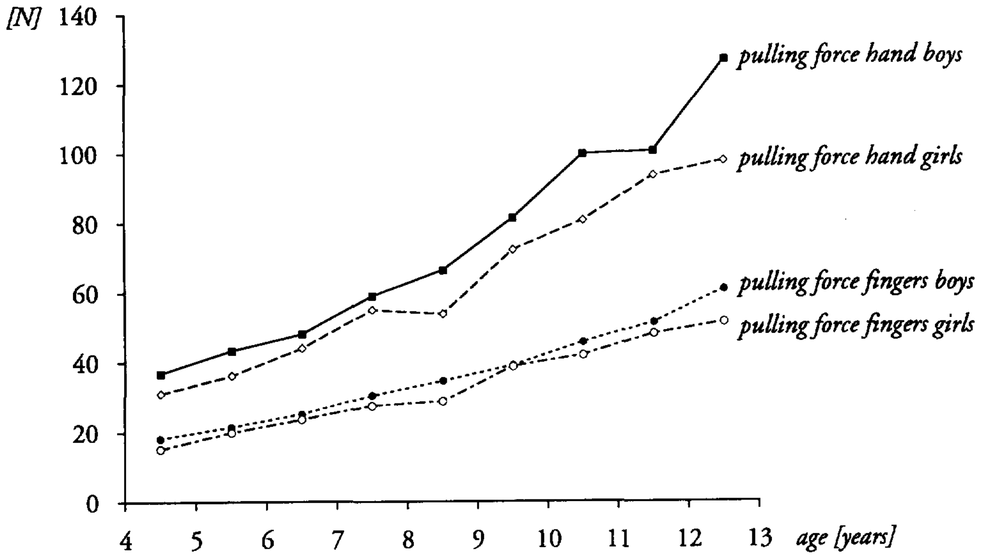
	education parents (p < 0.05, 2-tailed)							
	regular sample				regular + extra added sample			
	all ages	2.0–5.9	6.0–8.9	9.0–12.9	all ages	2.0–5.9	6.0–8.9	9.0–12.9
accident	.0388	-.0393	.0642	.0640	.0298	.0055	.0563	.0278
liability	n = 612	n = 160	n = 229	n = 223	n = 717	n = 184	n = 267	n = 266
	p = .338	p = .622	p = .334	p = .341	p = .425	p = .941	p = .360	p = .651
stature	-.0326	-.0051	.0423	-.0031	-.0368	.0016	.0367	-.0018
	n = 2133	n = 646	n = 561	n = 926	n = 2243	n = 670	n = 601	n = 972
	p = .132	p = .897	p = .318	p = .925	p = .081	p = .967	p = .369	p = .956
body mass	**-.0509**	-.0195	-.0064	-.0573	**-.0549**	-.0122	-.0073	-.0586
	n = 2134	n = 647	n = 561	n = 926	n = 2244	n = 671	n = 601	n = 972
	p = .019	p = .621	p = .879	p = .081	p = .009	p = .753	p = .858	p = .068
popliteal	-.0308	-.0227	.0513	.0159	-.0350	-.0163	.0452	.0169
height	n = 2125	n = 638	n = 561	n = 926	n = 2235	n = 662	n = 601	n = 972
	p = .156	p = .567	p = .225	p = .629	p = .098	p = .676	p = .269	p = .599
head	.0323	.0722	**.0929**	.0632	.0331	**.0805**	**.0917**	**.0681**
circumference	n = 2126	n = 639	n = 561	n = 926	n = 2236	n = 663	n = 601	n = 972
	p = .137	p = .068	p = .028	p = .055	p = .117	p = .038	p = .025	p = .034
upper arm	**-.0713**	-.0548	-.0283	**-.0839**	**-.0728**	-.0507	-.0210	**-.0844**
circumference	n = 2125	n = 638	n = 561	n = 926	n = 2235	n = 662	n = 601	n = 972
	p = .001	p = .167	p = .504	p = .011	p = .001	p = .193	p = .607	p = .008
force exertion	**.0782**	-.0765	.0230	**.1396**	.0657	-.0424	.0036	**.1536**
	n = 758	n = 191	n = 283	n = 284	n = 860	n = 214	n = 322	n = 324
	p = .031	p = .293	p = .700	p = .019	p = .054	p = .537	p = .948	p = .006
motor	.0830	.0491	.0652	.1235	.0605	.0382	.0721	.1218
performance	n = 534	n = 117	n = 206	n = 211	n = 592	n = 129	n = 228	n = 235
	p = .055	p = .599	p = .352	p = .073	p = .141	p = .668	p = .278	p = .062
distance	.0434	.0729	.0452	-.0245	.0452	.0682	.0123	.0006
reached	n = 1101	n = 532	n = 285	n = 284	n = 1204	n = 555	n = 324	n = 325
	p = .150	p = .093	p = .447	p = .681	p = .117	p = .108	p = .826	p = .992
technical	-.0282	-.0559	.1089	-.0097	-.0251	-.0541	.0883	.0408
comprehension	n = 932	n = 516	n = 215	n = 201	n = 1026	n = 537	n = 251	n = 238
	p = .390	p = .205	p = .111	p = .891	p = .423	p = .211	p = .163	p = .531
temperament	**.0989**	**.1637**	**.1335**	.0452	**.0913**	**.1477**	**.1394**	.0346
judgement	n = 2162	n = 674	n = 562	n = 926	n = 2273	n = 699	n = 602	n = 972
by parents	p = .000	p = .000	p = .002	p = .170	p = .000	p = .000	p = .001	p = .281
temperament	**.0960**	.1127	.0729	.1078	.0917	.0770	.1233	.0732
judgement	n = 610	n = 162	n = 226	n = 222	n = 716	n = 186	n = 265	n = 265
by teachers	p = .018	p = .153	p = .275	p = .109	p = .014	p = .296	p = .045	p = .235

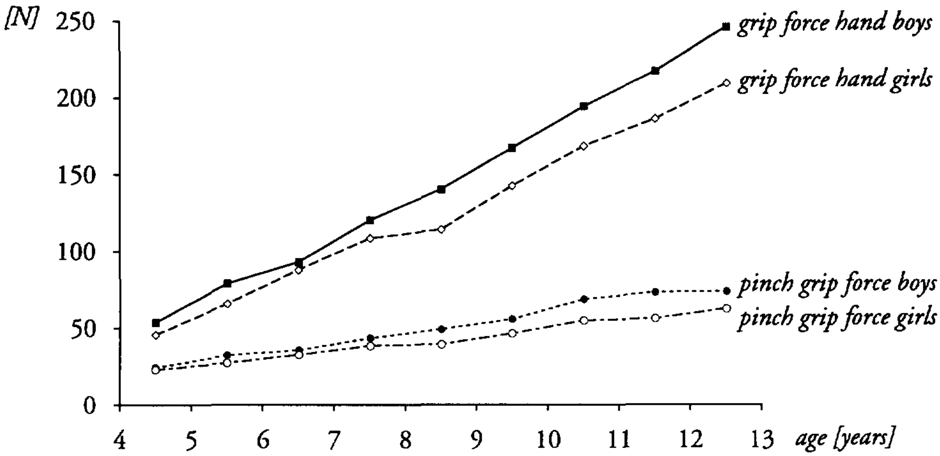
R-2 Correlations between different variables and degree of urbanization

	degree of urbanization (p < 0.05, 2-tailed)							
	regular sample				regular + extra added sample			
	all ages	2.0–5.9	6.0–8.9	9.0–12.9	all ages	2.0–5.9	6.0–8.9	9.0–12.9
accident	**.1179**	.0277	**.1392**	**.1346**	.0672	-.0265	.1107	.0702
liability	n = 630	n = 165	n = 232	n = 233	n = 737	n = 190	n = 270	n = 277
	p = .003	p = .724	p = .034	p = .040	p = .068	p = .716	p = .069	p = .244
stature	.0184	.0221	-.0583	**-.0900**	.0164	.0153	-.0610	**-.0850**
	n = 2209	n = 670	n = 577	n = 962	n = 2326	n = 699	n = 618	n = 1009
	p = .387	p = .568	p = .162	p = .005	p = .430	p = .686	p = .130	p = .007
body mass	.0049	.0131	-.0387	**-.0819**	.0009	.0046	-.0503	**-.0834**
	n = 2210	n = 671	n = 577	n = 962	n = 2327	n = 700	n = 618	n = 1009
	p = .816	p = .735	p = .354	p = .011	p = .966	p = .902	p = .212	p = .008
popliteal	.0268	.0557	-.0533	-.0560	.0250	.0444	-.0476	-.0472
height	n = 2200	n = 661	n = 577	n = 962	n = 2316	n = 689	n = 618	n = 1009
	p = .209	p = .152	p = .201	p = .083	p = .228	p = .245	p = .238	p = .134
head	.0340	.0345	.0142	-.0048	.0297	.0234	-.0028	.0030
circumference	n = 2202	n = 663	n = 577	n = 962	n = 2319	n = 692	n = 618	n = 1009
	p = .110	p = .375	p = .733	p = .881	p = .152	p = .539	p = .944	p = .924
upper arm	-.0284	-.0695	**-.0841**	**-.0730**	-.0379	**-.0801**	**-.1054**	**-.0794**
circumference	n = 2201	n = 662	n = 577	n = 962	n = 2317	n = 690	n = 618	n = 1009
	p = .184	p = .074	p = .043	p = .023	p = .068	p = .035	p = .009	p = .012
force exertion	-.0157	-.0834	**-.1454**	-.0599	-.0129	-.0601	**-.1214**	-.0462
	n = 783	n = 200	n = 289	n = 294	n = 887	n = 224	n = 328	n = 335
	p = .660	p = .240	p = .013	p = .306	p = .701	p = .370	p = .028	p = .399
motor	-.0136	-.0651	-.0959	.0015	-.0186	-.0216	-.1226	-.0055
performance	n = 552	n = 124	n = 209	n = 219	n = 612	n = 137	n = 231	n = 244
	p = .750	p = .472	p = .167	p = .983	p = .646	p = .802	p = .063	p = .932
distance	-.0398	-.0072	-.0219	-.0561	-.0371	-.0027	-.0286	-.0736
reached	n = 1134	n = 549	n = 291	n = 294	n = 1241	n = 575	n = 330	n = 336
	p = .180	p = .866	p = .710	p = .338	p = .192	p = .949	p = .604	p = .178
technical	-.0330	-.0669	**.1663**	.1130	-.0325	-.0653	**.1561**	.1195
comprehension	n = 959	n = 530	n = 220	n = 209	n = 1058	n = 555	n = 256	n = 247
	p = .307	p = .124	p = .014	p = .103	p = .291	p = .125	p = .012	p = .061
temperament	-.0054	-.0480	-.0144	.0172	.0139	-.0200	-.0011	.0355
judgement	n = 2236	n = 697	n = 577	n = 962	n = 2349	n = 723	n = 617	n = 1009
by parents	p = .798	p = .205	p = .729	p = .595	p = .499	p = .591	p = .977	p = .260
temperament	.0120	.1879	-.0370	-.0639	.0014	.1937	-.0754	-.0562
judgement	n = 633	n = 168	n = 231	n = 234	n = 741	n = 193	n = 270	n = 278
by teachers	p = .763	p = .015	p = .575	p = .330	p = .969	p = .007	p = .217	p = .350

S Mean values of diffferent kinds of force exertion according to age and sex



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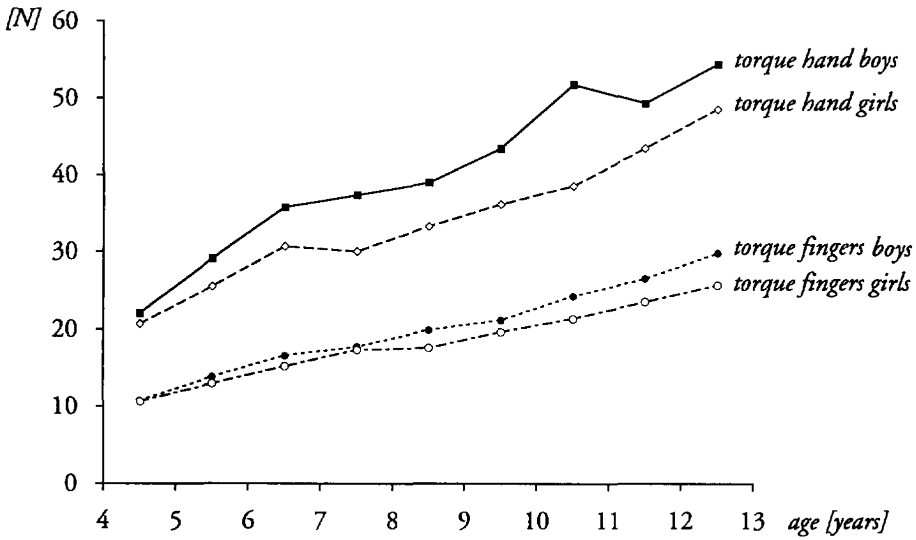
pinch grip force boys
pinch grip force girls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torque hand girls
torque fingers boys
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