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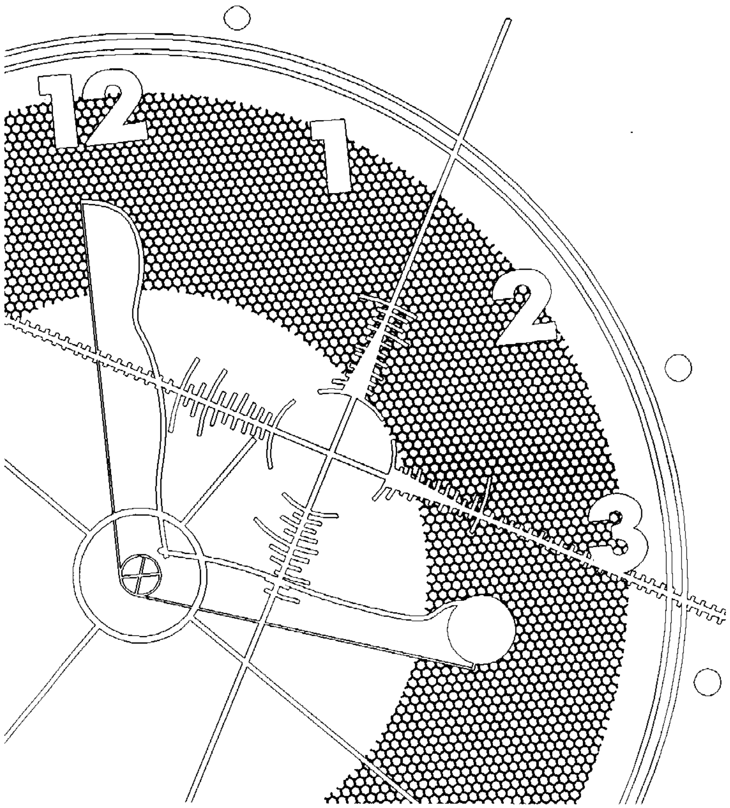
SERIES PHYSCAL ERGONOMICS

Isometric and isoinertial force exertion in product handling

A.I.M. Voorbij



Faculty of Design, Engineering and Production
Delft University of Technology

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Proefschrift

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Contents

1 General introduction

1.1 Object of the study

During the process of evolution humans developed the ability to design and use artefacts that would ease and improve the performance of certain biological and psychological functions. At first these artefacts were existing objects, which were hardly changed at all but were used with only minor adaptations. At this stage the human more often adapted to the product. However, as evolution progressed humans began to adapt products in order to attain ease of use. Today we have evolved to a stage where we place higher and more diverse demands on the comfort, efficiency and safety of the products we use. We have even begun to do scientific research into these aspects of product design and use.

One of the reasons why primitive man sought for alternative equipment was that with good equipment less effort was required to perform tasks. To primitive man this effort usually meant force exertion. Although today the forces required to operate products are, in most cases, far less than in earlier times, for the weaker members of the population they may still be too high.

As humans have evolved, lifespans have increased, and, a growing part of the present population is over 70 years of age. Although health has also improved, we still have to cope with a decrease of force after a certain age. A few generations ago, when most societies had only a small number of old people, the young took care of the old. The capacities of the elderly were then less critical for product design. However, because society has changed and the proportion of old people in society is so much greater, old people now need to be able to manage with as little help as possible. This means that they should be able to live independently up to a very old age.

This places a great demand on the designers and manufacturers of products in everyday use. The target group of their product has expanded to include much older people and force requirements in product use need to be lowered. For designers and manufacturers it is vital that products live up to the ergonomic criteria of comfort, efficiency and safety. To achieve this they need adequate information on the force capacities of the users of their products. The more adequate the information, the better the design can be.

Because information on force capacities helps to improve comfort, efficiency and safety, this information is valuable to designers and manufacturers. It can be applied not only to products for use in the home but also to working conditions.

The problem is that the information on forces that is required by designers and manufacturers is often not readily available. Many forces have not yet been measured and studied and nor have many groups of users.

The objective of this study was to assess some of the forces and force types that are relevant and necessary to the work of product designers.

In the study done by Daams (1994) a number of the shortcomings of the present information sources available to designers are categorised. After a thorough survey of the literature, she pinpointed several fields that are of interest for product development, and which have not been sufficiently studied. Among these are 'dynamic force exertion' and 'forces of different populations'.

Because there is still a lack of information on force exertion, the fields she mentioned continue to be of special interest for research and development. In certain aspects this study is a continuation of Daams' investigation: it focuses on dynamic force exertion and the gerontechnology of force exertion.

1.2 Basic muscle mechanics

Human force is derived from the contraction or higher internal tension of one or more muscles. To understand how such contractions or tension variations occur, it is necessary to have a basic knowledge of the structural elements of a muscle and its functions. The functional components are presented in figure 1.2.1.

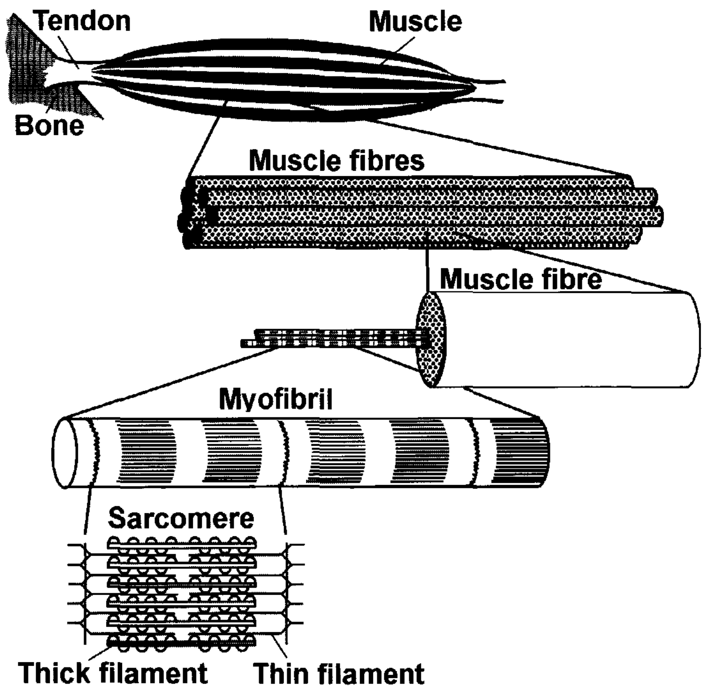


Figure 1.2.1 Structural elements of a muscle. The muscle consists of muscle fibres. These fibres are constructed as series of sarcomeres. The sarcomeres can shorten themselves by means of a chemical reaction between actin and myosin molecules, which are the elements of the thin and thick filaments respectively.

The muscle belly, the fleshy part of the muscle, consists of fibres. These fibres are constructed from myofibrils. In general, one myofibril consists of thousands of sarcomeres in series.

Sarcomeres are the basic, force-producing units. This force arises from the interaction between actin and myosin molecules, which are bound into separate filaments. The interaction between actin and myosin molecules is based on the hydrolysis of ATP (Adenosin-Tri-Phosphate) by the myosin ATPase. This so-called cross-bridge cycle is presented in figure 1.2.2.

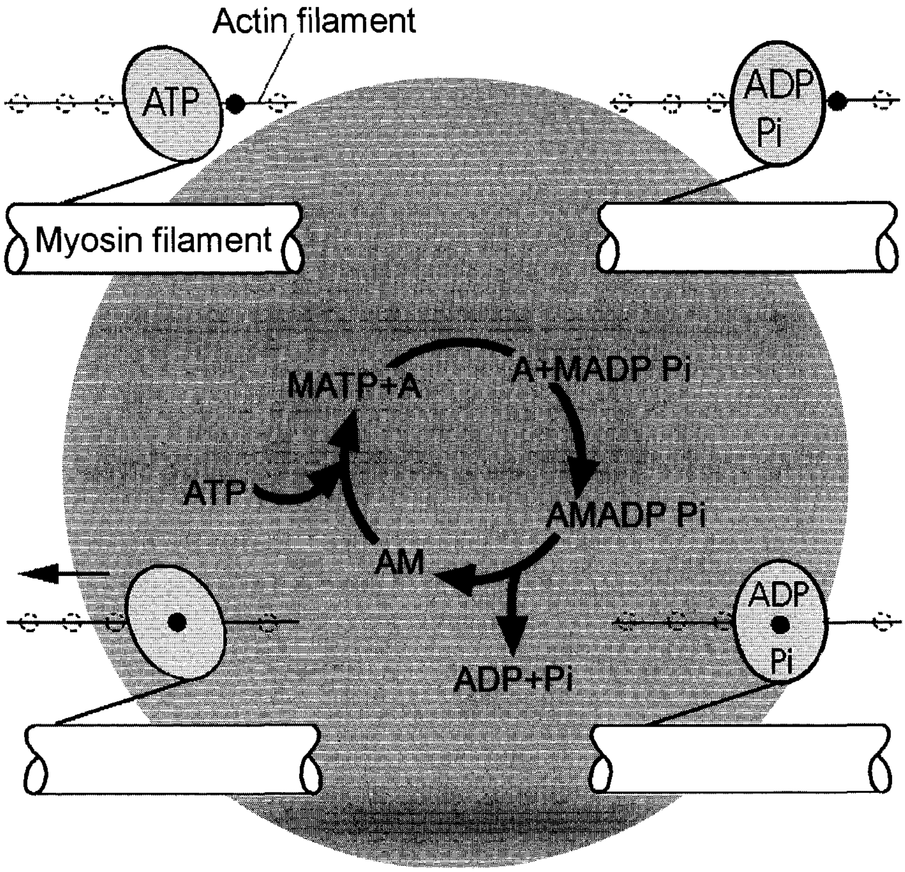


Figure 1.2.2 The cross-bridge cycle (starting with ATP, turning right): When ATP is available, the existing bond between myosin and actin filaments (AM) dissociates, then subsequent hydrolysis of ATP by the myosin ATPase (MATP+A) turns the cycle to the next stage (A+MADP Pi). At this stage in the cycle, initial attachment of the myosin head to one of the active sites of the actin filament is made (AMADP Pi). To make this attachment the presence of Ca^{2+} *ions is required. With the formation of a strong actin-myosin bond the myosin head turns 45 degrees. This causes the filaments to move across one another, while ADP and inorganic phosphate are lost from the myosin.*

In the cross-bridge cycle the chemical energy derived from the hydrolysis of ATP is transferred into mechanical energy. This transfer arises from the rotation of the myosin head (ATPase). This rotation causes an increased internal tension which in turn causes the myosin and actin filaments to slide across each other.

If the cross-bridge cycle did not exist, the actin and myosin filaments would slide across each another without making contact. The strength of the construction would then be minimal, because as soon as pulling force was placed upon the filaments the whole construction would be torn apart. Thus, the cross-bridges are vital for the generation of force, and because ATP plays a crucial role in the creation of these cross-bridges its presence is also vital. Without ATP the strong actin-myosin bond would remain intact, as in muscular rigor.

The cross-bridge cycle is anaerobic, but during contractions of longer than 15 seconds oxygen is needed for the burning of glycogen.

When the muscle is at rest, the thick (myosin) and thin (actin) filaments in a sarcomere have some overlap. This overlap is just large enough to allow cross-bridges to occur and force to be exerted. The shorter the muscle, the larger the overlap, the more attachment possibilities for cross-bridges.

However, this is limited. At some point the overlap will become larger than the length of the filaments and then the thin filaments will start to overlap as well. Then the available space for cross-bridges to occur will no longer increase, and neither will the force that can be exerted.

If shortened even more, the thick filaments will be squeezed and the available attaching positions will decrease. When there are no more cross-bridges possible the muscle cannot shorten any further. This process is presented in figure 1.2.3.

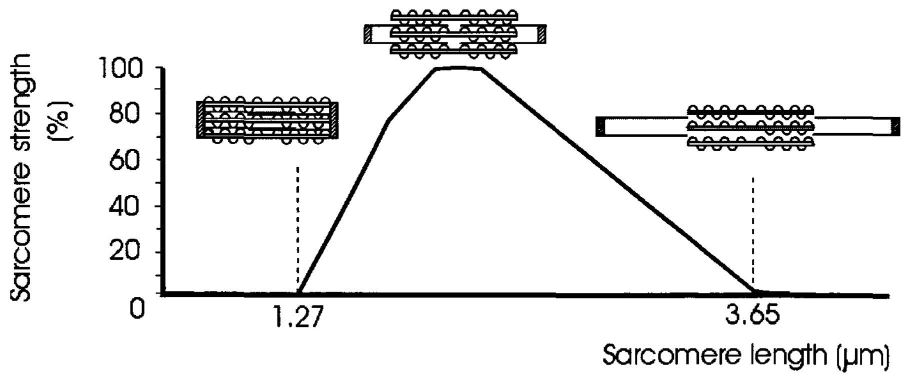


Figure 1.2.3 The degrees of overlap of the thick (myosin) and thin (actin) filaments within each sarcomere. The effect this has on the strength of the sarcomere is presented in the graph. Maximum strength is possible when the filaments fully overlap. Strength drops when the overlap becomes less, or when the thin filaments collide with each other. (After Gordon, Huxley and Julian, 1966)

The sliding of the filaments is also limited in the other direction. If the filaments are so far from each other that no overlap remains, no cross-bridges can be made and the sarcomere can be torn (figure 1.2.3).

The connection between two sarcomeres is called the Z-line (figure 1.2.4). The degree of overlap is established by the size of the H-zone (space between two rows of thin filaments, figure 1.2.4), the size of the I-band (space between two rows of thin filaments at the Z-line) and the size in the A-band (the length of the thick filaments).

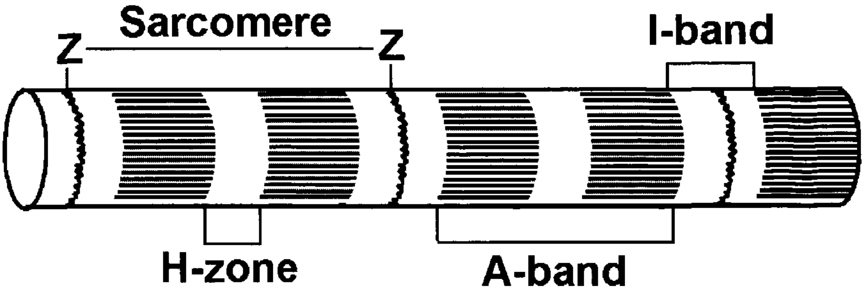


Figure 1.2.4 The characteristic sections of a sarcomere. The connection between two sarcomeres is called the Z-line. The space around a Z-line between two thin filaments is called the I-band. The section between two rows of thin filaments within a sarcomere is called the H-zone. The size of the A-band equals the length of the thick filaments. When fully contracted the length of the sarcomere will approach the length of the A-band.

The strength of a muscle depends largely on the number of parallel fibres, while the strength of the fibres is predetermined by the number of sarcomeres in series. To generate force by contraction the contracting element must somehow be connected to a rigid framework. Therefore, muscles are attached to ligaments and bone via tendons, or in some cases directly to bone. Tendons consist of slightly elastic fibres which dampen shock before it reaches the ligaments and bone.

In most parts of the body the belly of the muscle is located at or near the narrowest part of the bone. At a joint the muscle is slender and is attached via a tendon that is often connected to the ligaments of the joint. Because of their location near or around joints, muscles often create a moment around a joint. Therefore, joints usually have a very low friction; the moment will cause the joint to move in free space.

1.3 Force types

Force is a form of energy and can be described in terms such as 'work' and 'effort'. Force has different appearances and can be a load placed on something or can be an impulse to provoke movement. It can be mechanically described in formulas. Examples of standard formulas are F= m.a and i= mv, which are used in different situations.

In the case of human force exertion, energy is derived from the contraction or higher internal tension of one or more muscles. The muscle actions are the result of a chemical process.

The force generated can be measured in various ways. To come to a better understanding of the mechanisms, it is necessary to distinguish four muscle conditions under force measurement. In all these conditions there has to be a constant factor, otherwise the formula can not be solved. In table 1.3.1 the four different mechanisms and their distinctions are presented.

Table 1.3.1 *Four different types of force measurement conditions. All are characterised by their constant factor and a key formula**.

name	constant factor	key formula
Isometric	constant joint positions	$\Sigma F=0$
Isokinetic	constant velocity in movement	$P=v.F$
Isotonic	constant muscle tension	$I.\dot{\omega}=\Sigma M$
Isoinertial	constant body loading	$F=m.a$

Although the formulas might suggest that calculation of a conversion from one force type into another is possible, this is not correct. As mentioned earlier, muscles generate force through a chemical process. This process is influenced by various body conditions. The type of mechanism activated is highly influential and can be expected to significantly change the output of force (see also section 1.5.5).

In section 1.3.1 to 1.3.4, the four types of force measurement and muscle conditions will be explained.

1.3.1 Isometric force exertion

During isometric force measurements, the length of the muscles involved is kept more or less constant. In such a situation the joints do not move under force exertion. However, this constant muscle length does allow the internal muscle tension to vary. Thus the force is generated by changes in muscle tension. If a free body diagram is made of such conditions, the sum of all forces will be zero.

There are several types of isometric force exertion. For our purpose the distinction between build-up force exertion and peak force exertion is the most relevant.

The build-up type of force is gradually (i.e. in a few seconds) increased to the desired level and after a specific period of 'hold-on' is lowered back to neutral. The peak type of force is increased as quickly as possible to maximal and then abruptly released. For the first type the average force during the 'hold-on' phase is the main subject of measurement, and in the second it is the peak of the force reached during force exertion.

* i=impulse[N/s], m=mass[kg], v=velocity[m/s],F=force[N], P=power[W], I=mass inertia[kgm2], $\dot{\omega}$=angular acceleration[rad/s^2], M=momentum[Nm], a=acceleration[m/s^2]

In most isometric force measurements it is the maximal voluntary force which can be exerted during a few seconds which is researched. This force is often referred to as MVC (Maximal Voluntary Contraction). Only in studies on force endurance are submaximal or 'comfortable' force levels of interest. The reproducibility of maximal isometric force is thought to be better than that of submaximal force (Kroemer, 1970). Isometric peak force is always based on maximal force exertion. Build-up maximal isometric force exertion is more common in force measurements. The reproducibility of build-up force is thought to be better than that of peak force. (Daams, 1994; Kroemer, 1970)

Isometric force exertion is often referred to as static force (Kroemer, 1970; Caldwell et al., 1974). What this term refers to is the state of balance between all acting forces, when the length of the muscle is constant. However, on a more detailed level, for example in the changes in muscle tension mentioned previously, this term is not correct as the human body is never completely static.

The human body is not capable of generating a constant muscle strain and is therefore not capable of keeping the muscle length and thickness entirely constant. This can be easily verified by plotting graphs of force exertion over time. The 'hold-on' phase in the build-up type is characterised by a force fluctuating around a certain level (see figure 1.3.1). Therefore, on micro-level, the term 'isometric' is incorrect. On the other hand, when considering the ability of humans to exert force without motion when they are linked to equipment that moves only imperceptibly under force exertion, the terms 'isometric' and 'static' are acceptable.

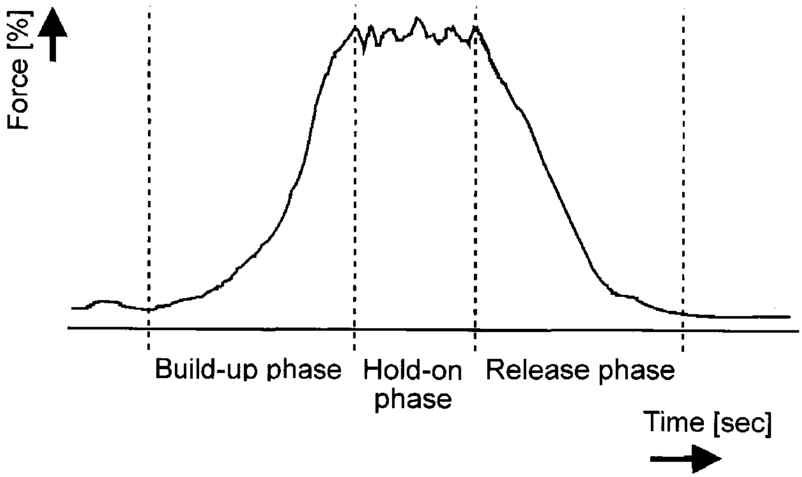


Figure 1.3.1 The flow of force in a build-up force exertion is characterized by a gradual increase in the build-up phase. This phase is followed by a 'hold-on' phase in which the force fluctuates slightly. After the 'hold-on' phase, the force is lowered back down. (After Kroemer, 1970)

1.3.2 *Isokinetic force exertion*

During an isokinetic force measurement, the velocity of the movement of a body segment is kept constant. This does not necessarily mean that the velocity at which the muscle length changes is constant. The reason for this is that, in most situations, the movement of a body segment involves the activities of more than one muscle, i.e. adjacent muscles which lie in a specific geometric configuration. Also, because muscles and tendons stretch across at least one joint and interact in sequence, it is clear that the movement of a limb is only indirectly related to changes in the length and tension of one specific muscle.

In most situations where isokinetic force exertion is being measured, the equipment provides a movement of constant velocity, while the subject is asked to follow the movement and exert continuous maximal force.

Studies on dynamic force exertion commonly concern isokinetic force exertion. It is based on the idea that muscles have a strength capacity. This capacity can be used to generate force or to generate movement, or a combination of both. The relation between maximal force at a certain velocity is mostly described in terms of amount of power. Power is formulated as $P=v.F$. By offering several velocities to the subjects, while recording their maximal force in the movement, a graph of the course of the power in the muscles involved can be made. Because acceleration in movement would alter the strength capacity necessary for movement, the power graph would be biased. For this reason the velocity is kept constant.

1.3.3 *Isotonic force exertion*

In isotonic force exertion, the tension in the muscle is kept constant. The sum of the moments then equals the product of mass inertia and angular acceleration. In theory a constant muscle tension during motion should be possible, but in practise it is not because in human motion it is not possible to control the muscle tension voluntarily. In the past researchers tried to realise constant muscle tension by having the subjects move a constant mass but this is not isotonic, as was clearly pointed out by Kroemer in 1970. He claimed that in motion the muscles do not strain isotonically when moving a mass or moving against a constant resistance, because during motion the tension of the muscles involved varies due to changes in length, position etc. The only condition in which tension is constant against a constant load is when the contraction becomes isometric.

Studies have been done under isotonic conditions, but these were all on muscles taken from cadavers, and in specific settings.

1.3.4 *Isoinertial force exertion*

In an isoinertial condition the muscles are loaded with a constant mass which has to be moved. Because of this movement, influences such as mass inertia and gravitational force apply. With the right equipment all these effects can be measured and identified. Then it is possible to reconstruct the force the subject has generated.

The measurements are based on the formula F=m.a (force is mass times acceleration). In the past equipment was used that had some friction which needed correction, but nowadays equipment exists that can register acceleration in free motion.

1.4 Force type and product design

1.4.1 *Product use and force exertion*

Almost every time that someone uses a product, force exertion and motion play a role. Apart from rare applications such as speech control, it is not possible for a human being to use something without moving and exerting force with the limbs. There are, however, great differences in types and courses of use. On some occasions, the force exertion is hardly noticed by the user. Nevertheless, even the slightest contact involves force. In the case of low level force exertion, the response of the product to the action is much more important to the user than the exertion. When the use of a product requires force that approximates to the maximal force of the user, the subject will be very aware of the action of force exertion.

The same goes for movements during product use. Some will be performed without the user being aware of them, while others will require serious effort. Moving towards or away from a product is necessary in almost all product use. Moreover, in most product use motion is combined with the force exertion, for instance in all handling of products.

Apart from the product and its user, the environment in which the product is being used also influences the course of the interaction. Human perception is especially influenced by the environmental input. Due to the large amount of variables in an interaction, the course of the use of a product differs intra- and inter-individually. Dirken (1997) developed a basic scheme of a human-product interaction. Daams (1994) presented a scheme that concentrated on the role of force and posture in such an interaction. Figure 1.4.1 gives a rough presentation of variables involved in force and motion during product use.

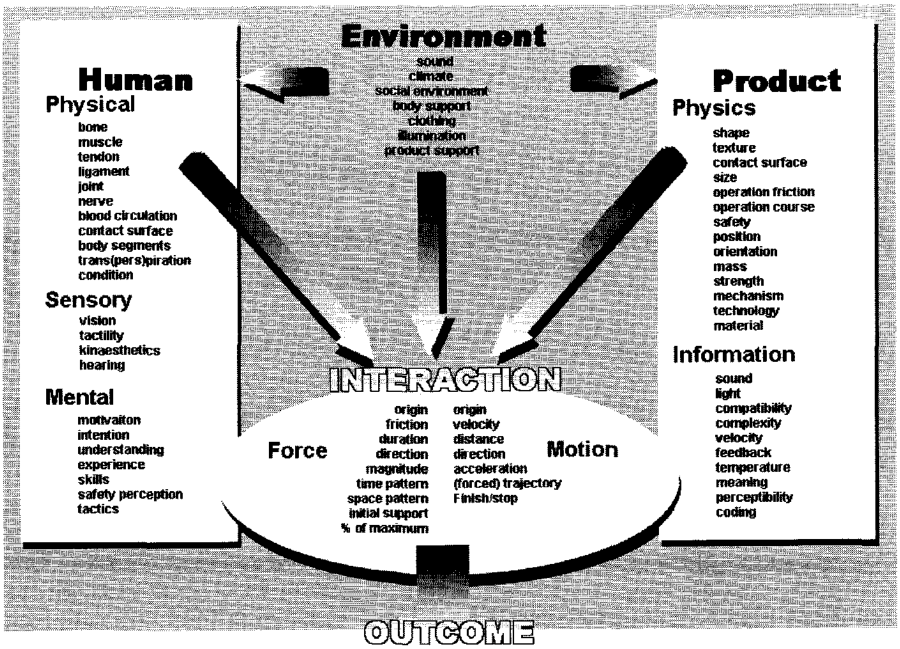


Figure 1.4.1 Important variables involved in force and motion during product use. The activities of the human are characterised by his physical, sensory and mental condition. These conditions are influenced by the product, the environment and by the interaction.

Many different aspects of the two participators directly involved in the use of a product will influence the outcome. The aspects of the product component are defined by its design. The human component of the interaction is more complex, and has physical as well as sensory and mental bases. Because of the complexity of the human, research is often required in order to predict to some degree the output of the person and the course of use.

1.4.2 Product design and force prediction

There are several methodologies involved in product design. In user-centred design the design engineer incorporates knowledge about all possible and intended users, through all stages of the design process. This concerns ergonomics, and includes what is known and theorised about human behavioural and biological characteristics, which can then be applied in the design process to enhance safe, effective and satisfying use. As mentioned in section 1.4.1, human force and motion are involved in almost all product use. This means that design engineers have to deal with expectations on forces exerted during the use of their design.

In most cases the design engineer will be able to make some prediction of the movements and types of force that are involved in the use of the product. When testing the concept of a product for its usability, and to determine the correct target group of users, the designer should be asking two question. First, can the weakest subjects in the group exert enough force, and are they able to make the movements required for product operation? Second, can the product withstand the force of the strongest user?

Unfortunately, information is not available on all types of force. Even when it is available, most articles are not suitable for use in the design process. Studies often only report on a small sample from a specific social group, which is usually much smaller than the target groups of the designer. Furthermore, almost all studies concentrate on isometric force exertion, which lacks the motion that the use of a product generally involves.

In ergonomics information on motion is rare (only a few movements are described), and although the information that does exist is focussed on designers, it seldom fits the design purpose. As a result, designers often have to improvise.

Because of the frequent need to improvise design engineers have developed a methodology. The designer will look for information which comes close to the type of force and motion that are needed for use of the product. When the information available is inadequate, the designer will try to establish how the required information differs from the available information. Graphs such as Hettinger's (1968) and those described in section 2.5, which show the relation between different age groups, are frequently used by designers. Graphs for motion are seldom found.

Information on the combination of force and motion that can be used is scarce, and is usually irrelevant to common product use. Adjusting and predicting graphs are therefore not available either. Designers are forced to ignore the fact that force and motion are combined, and to base themselves only on the isometric force information, when it is available.

Because of these improvisations and estimations, the designer will include one or more safety margins in the product. It is therefore not surprising that these actions and speculations in the concept phase of product design lead to uncertainty about the user-friendliness of the product.

1.4.3 Ergonomic research

Ergonomic research aims to provide design engineers with the relevant data on knowledge, methods and theories on human behavioural and biological characteristics that they need.

Because ergonomic research is intended to be relevant to daily life situations (work and home), it is mostly very practical. In some studies results are based on observations, and are presented qualitatively instead of quantitatively.

Ergonomic research on human force exertion focuses on force output in certain body postures. Ideally, these postures are related to situations in daily life, and therefore these studies tend to let the subject choose his own posture. The results gained from such ergonomic research are most valuable when they can be applied in the design and use of various products. In view of the large inter-individual variance in force exertion, subjects in these studies should be representative of all intended users.

1.5 Physiological comparison of isometric and isoinertial muscle action

As our understanding of muscle physiology continues to grow, so our insights into the different mechanisms that play a role in muscle actions are constantly changing.

1.5.1 Cross-bridge formation

As mentioned in section 1.2, cross-bridges are vital for force exertion. During isometric force exertion, the cross-bridges are stationary: the muscle shortens to a certain length and remains at that length. In dynamic conditions muscles can contract either concentric or eccentic. In the first and most general type of contraction the muscles shorten during contraction. In the second type of contraction the muscles are due to an external force lengthened in contraction. In the latter condition the external force is larger than the force generated by the muscle.

During dynamic contraction, that are concentric, the cross-bridges have to disconnect and reconnect at another location, otherwise the length of the muscle would not be variable. This makes it constructively impossible to have more than one cross-bridge connecting the filament couple in a concentric contraction. In an isometric force exertion, however, it is possible to have several cross-bridges. Because the number of cross-bridges is the primary factor which determines the strength of a muscle, the maximal muscle force is higher in isometric than in dynamic muscle contractions that are concentric.

Eccentric contractions occur when muscles operate against other muscle forces or against forces from deceleration limb inertia and these muscles are lengthened in this action. It is known that in eccentric contractions more force can be generated than in concentric or isometric contractions (Rozendal et al., 1994). Although in dynamic concentric contractions it is only possible to have one cross-bridge at the time connecting a filament couple, this seems not to be the case in an eccentric contraction. It is also assumed that the cross-bridges that occur are stronger in eccentric than in concentric contractions (Rozendal et al., 1994). Krylow and Sandercock (1997) found that there are also a number of differences in the force-velocity curces during concentric and eccentric contractions.

The rate at which the cross-bridges are formed depends on the type of myosin ATPase that hydrolyses ATP. There are two types of myosin ATPase, which hydrolyse either slowly or rapidly. The rate of hydrolysis determines the speed of contraction of the sarcomere i.e. the twitch.

1.5.2 Muscle control

Skeletal muscles do not contract spontaneously but are stimulated by signals from the central nervous system (CNS). The muscles are connected to the CNS by a nerve supply which transmits signals from the CNS to the muscle fibres. The axon of one motor nerve can innervate from 3 to 2000 fibres. The muscle fibres which are innervated by the axon of a single motor nerve are called a 'motor unit'.

The activation of a muscle can be controlled by the frequency of the commands sent by the CNS to a specific motor unit, or by the number of motor units recruited. By recruiting additional motor units muscle strength increases but the control of muscle tension is cruder than when compared to modification of force by changing the frequency.

A schematic model of muscle control is shown in figure 1.5.1 (after Kroemer et al., 1990). In this model there are feedforward and feedbackward loops. The feedforward loop starts with control initiatives. These are generated via an engram (executive program) for routine muscle activities, such as applying force to an object. The engram is modified by subroutines to adapt to specific conditions (such as the amount of force required), and by motivation to perform.

The outcomes of the complex interactions within the CNS are excitation signals which trigger the muscle actions. The frequency of commands and the recruitment of motor units are embedded in these signals.

Although the excitation signals contain information that is suitable for control of the muscle output, the actual output depends on the physical condition of the body, which is affected by such things as fatigue, muscle length, cross-sectional area and signal frequency. The actual output also depends on the mechanical configuration of muscles and skeleton.

The feedback loops resemble the internal control of the muscle action. First there are reflex-like signals that originate at proprioceptors; these cannot be controlled voluntarily. The other two originate at the exteroceptors and are routed through a comparator. These are, on the one hand, the kinaesthetic signals such as pressure, touch and body position and, on the other hand, sound and light.

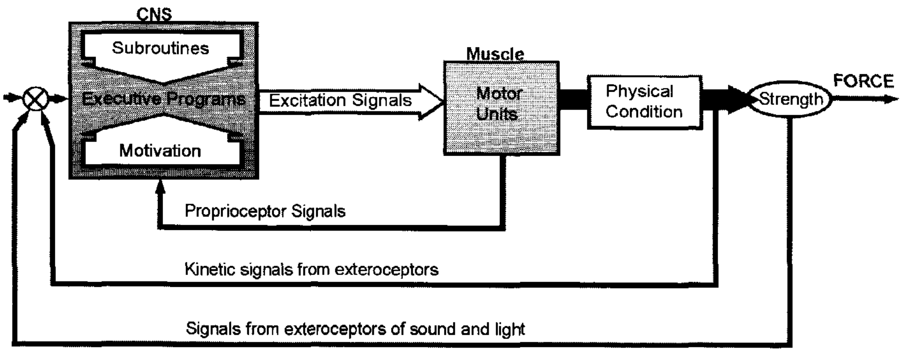


Figure 1.5.1 Schematic model of muscle control. In the Central Nervous System, executive programs are modified by subroutines and motivation. This results in excitation signals for the motor units in the muscle. The actual reaction of the muscle depends on this signal, in combination with the physical condition of the body. The feedback information is proprioceptive and exteroceptive. (After Kroemer et al., 1990)

The maximal velocity at which a joint can move depends not so much on the capabilities of the muscles and the muscle fibres, but on the motor nerves and the parts of the brain involved. The maximal velocity that nerves and brain can handle in order to control the complex pattern of the movement, heavily influences the maximal velocity that can be reached in the movement (Beelen, 1993).

Lagassé (1979) came to the conclusion that there seemed to be separate neuromotor systems for the control of strength and speed. In addition to this, he concluded that the interaction between agonist and antagonist is important for maximum speed.

Muscle fatigue, however, is probably not a result of lower activity in the central nervous system, but of biochemical changes in the muscles involved.

1.5.3 *Interaction with skeleton elements.*

As mentioned in section 1.2, muscles are generally attached to ligaments around the joints via tendons. It is theorised that there is some contraction of the muscles prior to a movement, to prevent the ligaments from being torn. This pre-tension is relevant, especially in the case of peak force.

Concerning this movement in the joints, it should be noted that a movement over a curved surface can usually be translated into a component of rotation and a component of translation. While the head of the bone is kept in place by ligaments and muscles, it will follow a trajectory that depends on the following elements (Rozendal et al. 1994):

1 The shape of the socket

2 The shape of the head

3 The alignment of the tensed ligaments (i.e. their length and location)

4 The direction of muscle force and the direction of other forces

If we look, for instance, at the elbow in flexion then the collateral ligaments will hold the joint together, while the articulating surfaces of the humerus will move in the sockets of the radius and ulna due to contraction of, among others, the m. biceps brachii.

In the case of isometric force exertion no movement will be generated. Consequently, the shape of the head and socket is less relevant.

In isoinertial force exertion, force is exerted in motion so that all four of the above elements play a role.

1.5.4 *Fibre distribution*

A muscle is built from fibres (see figure 1.4.1). Information on the different divisions of fibre types can be found in the literature (Close, 1972; Snyder-Mackler and Robinson, 1995; McArdle and Katch, 1994).

One classification is already mentioned in section 1.5.1, and is based on the rate of ATP hydrolysis by the myosin ATPase. A muscle fibre consists either of the slow type (type I) myosin ATPase or the fast type (type II). This classification of slow and fast corresponds with the division of slow twitch and fast twitch fibres, which is a classification also used in literature.

Muscle fibres can also be classified by their need for oxygen during performance. This classification is based on the colour of the fibres. Red fibres contain large quantities of myoglobin, are very vascular and require oxygen and glucose in order to perform. White fibres are glycolic, have very few mitochondria and require low oxygen and low myoglobine levels. There are also fibres that use both metabolic pathways. Red fibres are referred to in the literature as type I and are slow to contract compared to white fibres, which are referred to as type II. Fibres that use both metabolic pathways are referred to as IIa, IIb or IIc. These fibres are pink.

Type II fibres are fast and strong and provide quick limb movements. Type I are slow and weak; they generate little power and slow movements. The characteristics of types IIa, IIb and IIc lie between the characteristics of type II and I.

Slow muscle fibres have a lower tension cost (ATP-use/force) than fast fibres (6.5 times lower). This lower energy use in slow fibres is consistent with the higher resistance to fatigue found in slow muscles (Potma, 1995).

For isoinertial force it is important to know how fast a muscle can contract to its optimal length. Maximal isometric force can be exerted in a peak, or can be built up (see section 1.3.1). With the build-up type of force the maximal speed of muscle contraction is irrelevant, as the force will be built up gradually i.e. always at submaximal speed. In contrast, for peak force the maximal speed of contraction is very relevant because the muscle has to contract very fast to generate such force.

1.5.5 Physical condition

The condition of each individual body comes partly from nature and partly from its development throughout life. Some aspects of this body condition are the following parameters of muscle capacity: metabolism, mitochondria, myoglobin, vascularity, cross-sectional area, number of myofilaments, endurance and force. To improve the condition of the body at least one of these parameters must be improved. This can be done through training. With training the muscles change. Strength depends largely on the diameter of the muscle fibres, and on the number of cross-bridges that can be made. Velocity depends on the twitch contraction time. The number of muscle fibres usually remains constant.

The effect of training on a muscle depends on the type of training (Young and Bilby, 1993; Duchateau and Hainaut, 1984). Training can be characterized by its intensity and its duration. When intensity is high, duration will be low and vice versa. High intensity training will increase muscle strength, while long duration training will increase muscle endurance.

In theory, during high intensity training with fast muscle contractions and gaining as much acceleration as possible, the biochemistry of the slow muscle fibres will change. This will alter the muscle characteristics. In practise, however, it is not possible to train one type of fibre to convert to another type. In general, the fibres of a muscle convert from slow to fast when force is increased.

Conversion of slow fibres into fast fibres is a type of muscle change which is possible, but it is rather an uncommon reaction to training. Isoinertial force performance is influenced by this kind of speed training.

In training that concentrates on the highest possible force output, the primary reaction is that the type I muscle fibres will thicken. Maximal isometric force exertion increases after training at low speed and with much force.

Endurance training will also change the appearance of the muscle by combining the two previously mentioned effects.

Although fibre composition is individual, the fibre composition supplied by nature does not have much inter-individual variability. Although genetic selection plays an important role, the compostition gets more individualised through development. The more extreme the development the more exceptional the fibre composition. Subjects who train intensively have different muscle characteristics from untrained subjects. Sprinters can have around 60% of type II fibres, whereas marathon runners can have up to 90% of type I. People who have never done specific training tend to have rather similar muscle fibre composition. This information is of importance when deciding on the sample for research.

1.5.6 *Sex and age effects*

Males are generally stronger than females. This is demonstrated in isometric measurements, but is also proven in dynamic conditions such as sports. Because most of the muscle performance is decided by muscle fibre configuration and training, and as the training is often similar, it is reasonable to assume that females have a different muscle configuration from males. According to Schantz et al. (1983), the number of muscle fibres in the triceps brachii is equal in men and women, but there are large differences in muscle cross-sectional areas. There are, however, indications in literature that female muscles contain more type I fibres than male muscles, while the latter contain more of the fast type II fibres. As mentioned in section 1.5.5, how active a person is will have a great influence on muscle configuration. Because the functions and activities of men and women in society are increasingly similar it seems likely that, should the trend persist, muscle configuration in males and females will also become more and more similar in the future.

Lennmarken et al. (1985) found that the muscles of the female need more time to reach full contraction than those of the male. This corresponds with the difference in fibre type configuration, as the type I fibres are weaker and slower than the type II fibres. This would also imply that females have greater endurance than males, because type I fibres have a higher resistance to fatigue.

At birth children have a predominance of type I fibres. As they grow their increased mass makes conversions to type II necessary. After a certain age it is alleged that people revert to a predominance of type I. This may be the result of a decreased demand for power.

Grimby et al. (1984) found no differences in the functioning of the slow and fast twitch fibres in elderly subjects compared to younger subjects. McDonagh et al. (1984) found that in subjects over 70 the maximal voluntary contraction declines with age, especially in the legs. They also concluded that the number of fast twitch fibres decreases, while the time taken to peak twitch lengthens.

According to Lennmarken et al. (1985), the old have less endurance than the young. This is surprising because of the alleged reversion to a predominance of type I fibres, which are more resistant to fatigue. Endurance should therefore be much less affected than force.

Larsson et al. (1979) found that the elderly have a serious risk of developing selective atrophy (thinning of the muscle fibres). This accords with the earlier mentioned reversion to type II fibres, because type I fibres are thinner than type II fibres. The risk of selective atrophy can be decreased by frequent, intensive training. It should be noted, however, that the effect of training decreases with age.

1.6 Approach

1.6.1 State of the art in isometric and isoinertial force measurements

Isometric force exertion has been studied and described by a great many researchers. However, not all of this research is suitable for application in product design. Daams did a literature survey in 1994, to establish which force research was most useful and relevant for designers. Most research concentrates on isometric force. At the start of the present study some new results of isometric force exertion were published, but these did not substantially add to the information and insights already available for product design.

As far as we know, isoinertial force measurements have rarely been performed outside the field of sports. The methods and materials used by the different researchers vary a great deal (Rasch, 1957; Murphy et al. 1994; Jacobs et al. 1988; Stothart, 1973; Snijders and van Egeraat, 1986), and so do their findings. The results of the studies we found are not really suitable for use by product designers, as they do not relate sufficiently to every day life.

However, the field of study on the force-velocity relationship does have some relevance for isoinertial force exertion. The general conclusion, drawn from the studies of this relation in elbow flexion, is that speed and maximal force are strongly related. At high speed the ability to exert force is diminished. Maximal force is exerted isometrically (De Koning, 1984; Lagassé, 1979; Stothart, 1973; Slote and Stone, 1963; Young and Bilby, 1993; Sherwood et al., 1988; Krylow and Sandercock, 1997). However, in isoinertial force the muscles must also gain acceleration, and because this requires extra force the outcomes may be different.

1.6.2 Aim of the study

Several studies reveal that isometric force is often related to other body characteristics, such as body weight and stature. In addition, the isometric forces of different body segments or muscle groups are found to be related.

Very little is known about isoinertial forces, and even less about the relation between this force and other body characteristics.

As both isoinertial force and isometric force are a result of the contraction of muscles, it seems likely that these forces are somehow related, but as far as we know very little study has been done as yet.

The aim of this project was to study and describe the relationship between isometric and isoinertial force exertion, taking into account age, sex and some other physical and psychomotor variables.

The choice of the group of variables considered was based on two factors:

1. Suitability for use in the product design process
2. A possible relationship with isometric or isoinertial force

Force is involved in every user-product interaction and information on human force is therefore indispensable to a product designer. In a good product design the operating forces, as well as the handling and accidental forces, of all possible users are accounted for. Although safety and comfort do not depend solely on the force aspect of user-product interaction, adequate information on all human forces would be a step towards better products.

In daily product use isoinertial force exertion occurs more often than isometric force exertion, which makes it necessary to acquire information on this type of force.

Because isometric and isoinertial force are the result of muscle contractions, the condition of these muscles can be expected to influence the force that can be exerted. In addition, the condition of the nerves stimulating the muscle may affect the action of the muscle. It can be presumed that information on physical and psychomotor variables will lead to information on the ability to exert force.

Some anthropometric dimensions may give an indication of the condition of the muscles. When the condition of muscles is improved they can be contracted further and become thicker. The appearance of these muscles will then become more pronounced. For example, if the muscles of the upper extremities undergo training, the upper arm circumference will increase.

In healthy subjects training one group of muscles will increase the muscle power of that specific group, and will also improve the condition of the rest of the muscles. The overall condition of muscles is related to numerous variables, such as variability in oxygen and protein level. Information on the muscle group studied can probably be found in variables that indicate the condition of other muscle groups.

The questions in the current study were:

- Do the results of isometric and isoinertial force exertion differ?

- Is there an interindividual relation between isometric and isoinertial force in elbow flexion?
- How can the relation between isometric and isoinertial force be described?
- What relationships exist between the different groups of variables and isoinertial force?
- How can the results of isoinertial force exertion be presented adequately to product designers?

The aims of the current study were:

- To generate normative data on isometric and isoinertial force in flexion of the elbow.
- To describe (and test) hypotheses on relationships between isometric and isoinertial force, as well as their mutual relationships with the other variables studied.
- To provide guidelines for product designers on the use of isometric force information in situations where such information is needed.

1.6.3 *Contents of this study*

This study is based on two projects. The first project is the so-called Gerontechnology project, which concentrated on the measurement of the design relevant capacities of different age groups. This project was carried out by a team of researchers. The members of this team were individually responsible for a set of variables. In this study the results of the force measurements in this project are discussed. A general analysis of the forces is already presented in section 3.2 'Force exertion' in 'Design relevant characteristics of ageing users' (Voorbij and Steenbekkers in Steenbekkers and Van Beijsterveldt, 1998). The present work adds to this several, more detailed analyses of those forces. These are presented in the form of articles, that have been sent to the journals mentioned in the titles. They appear together in Chapter 2.

The second project, called the Stadyn project, concentrated on research into the relationship between isometric and isoinertial force exertion. This project is described in Chapter 3. Because this project covers an almost unexplored field of research, it was necessary to present in detail all the backgrounds and theories that were the basis for the method and materials. This kind of coverage is less suitable for publication through articles and is therefore written differently. There are three articles which cover some details of the results of this project. These are presented in Chapter 4.

Although both projects can be presented individually, the overall project also included integration of certain results and objectives. Chapter 5 contains hypotheses pertaining to some of the relations between the results of the two projects.

2 The Gerontechnology project

2.1 Introduction

The main subjects of this chapter are the forces measured in the Gerontechnology project. From 1993 to 1999, a project on the characteristics of ageing users in relation to design was carried out by a team of researchers from the Delft University of Technology. The project was divided into two studies: the collection of ergonomic data from 750 subjects (Steenbekkers and Van Beijsterveldt, 1998) and research into the use of home appliances (Freudenthal, 1999). Both studies generated guidelines. These guidelines were tested in practise by future industrial design engineers for their graduation projects.

Only the first study contained force tests. This study was done in two stages. In the first stage, the effects of region and urbanisation on various human capacities were studied, in different areas of The Netherlands. In this project the gripping force of both the left and right hand was studied.

In the second stage, 79 variables were measured in a laboratory at the Delft University. Among the ergonomic data collected were several force measurements: gripping force for left and right hand, pulling force with one hand, pushing force with both hands and twisting force. All forces in the Gerontechnology project were measured isometrically.

The information that was gathered on the various forces is presented in the form of articles

Gripping force is described in 'Differences in grip strength caused by various subject characteristics'. Twisting force is described in 'The twisting force of elderly consumers when opening a jar'. Pushing and pulling forces are described in 'Clearance of emergency exits for use by the elderly; a proposal for an addition to a Dutch standard'. The relationship between the different forces is described in 'Single and composite relations between modes of isometric force exertion in young and elderly adults'.

2.2 Differences in grip strength related to various subject characteristics.

A.I.M. Voorbij and L.P.A. Steenbekkers
(Submitted to Ergonomics, December 1999)

summary

This study concerns the design-relevant characteristics of ageing users. 79 variables were measured. The study included a test of maximum grip strength measured on a large sample of subjects, which enabled us to add to the state of the art information on grip force. Amongst other things we studied its relation to other variables.

We modified the standard method of measurement for grip strength in three projects. We introduced arm support and verbal encouragement in a first study which revealed that only two repeated measurements are required to obtain sufficient information on maximum grip force. This finding was implemented in a study of 750 young and old subjects, which showed high reproducibility and mean values of maximum grip strength that are, apart from some small differences, comparable with those found in the literature. We found a gradual decrease in grip strength with age, and higher means in men than in women for all age groups. The correlation coefficients varied considerably. Stature, pushing force and torque were best correlated with grip force. A follow-up study after two-and-a-half years demonstrated a small increase in grip strength that was unexpected, given the results of the earlier transversal study.

The results of this study can, for instance, be used by product designers to adequately gear their product specifications, and the grip strength of their users, to one another. Furthermore, the study enhances the existing information on grip strength.

Introduction

Grip force is the most often studied type of force exertion. In the present study we define grip as maximum voluntary force exertion squeezing a meter while the hand spans the meter. Although much of the handling of products requires dynamic actions, grip strength is most commonly measured isometrically. The measurement of grip force is wide-spread over a variety of studies, because it is a simple and objective test to do and because grip strength is often referred to as representative of whole body strength (Richards and Palmiter-Thomas, 1996). On the basis of this representativeness it is interesting to be able to compare grip strength with other physical and mental, psychomotor or sensory variables and see how they are related.

Only a few studies concentrate on the effect of ageing on grip force (Richards and Palmiter-Thomas, 1996; Mathiowetz et al., 1985). In adults strength decreases with age (Hettinger, 1968), which makes this a factor of great significance. The assumption that grip is an indicator for whole body strength makes it appealing to perform the simple grip test on elderly subjects.

Longitudinal studies seem to be essential in order to achieve a reliable presentation of the intra-individual decrease in strength. We are aware of only one ongoing study (The Baltimore Longitudinal Study on Aging since 1958).

To obtain an accurate, overall picture of the decline of force performance with age, it is necessary to also measure young people. However, studies on large groups that include old as well as young subjects are still limited.

We therefore decided to conduct a study on a large number of young and elderly subjects, and to do a follow-up study on a sample of them.

Method and materials

This study was divided into three projects. In the first project (henceforth known as study 1) 118 subjects, aged between 70 and 75 years, were measured on 22 variables. This project aimed at establishing the influence of the region and the urbanisation of one's place of residence on subject characteristics. The 22 tests were selected on three criteria: representativeness of the total group of variables in the main project (study 2), transportable equipment, expectation of reasonably well reproducible results. The project (no. 1) consisted of field measurements in six different locations, in three regions, spread over the Netherlands. These measurements were done in a public building, e.g.a hall or school, in the home town or village of the subjects. All subjects had lived all their lives in these locations.

All variables were measured in one session, lasting about one and a half hours. The grip test was performed three times with each hand, with two minutes resting time between each set of force exertions. The body mass and stature of the subjects are presented in table 2.1.

In the main project (study 2) 750 subjects were tested on 79 variables. Included in this number were the 22 variables of study 1. The tests were of a physical, cognitive, psychomotor or sensory nature. The measurement of the variables was split into two sessions lasting about one and a half hours each. One session concerned the cognitive, psychomotor and sensory tests. For details of these tests we refer to Steenbekkers and van Beijsterveldt (1998). Grip force was measured in the session with physical variables such as step height, walking velocity, anthropometry and reach envelopes. All tests were done in a laboratory in Delft. The age of the subjects in this project (no. 2) varied from 20 to 30 and from 50 to 94 years. For statistical purposes the subjects were divided into eight age groups (see table 2.2.1). For comparison with other studies the body mass and stature of the subjects are presented in table 2.1.

The order of the tests in the two sessions was kept constant throughout the project (no. 2). The scheme was designed to spread the mental and physical loading of subjects and increase the efficiency of both subjects and experimenters.

After the first measurement of the grip force of each hand, the step length test was performed. After the step test, and at least two minutes after the first grip test, the second grip test was done.

In study 2, 46 individuals were retested for the session with mostly physical variables, including the grip test. The time between test and retest varied from a few days to a couple of weeks.

A follow-up project (study 3) was performed about two and a half years after study 2. This project (no. 3) concentrated on isometric and isoinertial force exertion in flexion of the elbow, and its relation to age and sex. Forty subjects had earlier joined study 2. Grip was measured to establish any change in force over the ensuing period. It should be noted that this project was not meant to test reproducibility. Ten subjects were aged between 23 and 35 years and thirty-two were between 60 and 65 years. The mean stature and body mass of the subjects are presented in table 2.2.1.

Apart from the order and number of tests in a session, the measuring conditions were kept the same as in study 2. Therefore, grip force was measured twice for the left and twice for the right hand.

Table 2.2.1 Subject information. Number of subjects and the mean and standard deviation of stature and body mass are presented.

	number		stature [cm]		body mass [kg]	
age group	men n	women n	men $\bar{x}$ (s)	women $\bar{x}$ (s)	men $\bar{x}$ (s)	women $\bar{x}$ (s)
project 1						
70-75	58	60	173.4 (6.6)	161.0 (5.3)	82.0 (11.4)	73.9 (11.1)
project 2						
20-30	55	68	184.8 (8.0)	168.6 (6.6)	80.8 (14.3)	66.7 (9.6)
50-54	35	35	177.8 (8.1)	165.4 (5.5)	82.5 (11.7)	70.4 (12.4)
55-59	46	50	176.7 (7.5)	165.3 (6.3)	82.1 (12.8)	70.7 (11.2)
60-64	44	53	176.1 (5.7)	163.9 (5.9)	80.2 (8.9)	71.4 (11.6)
65-69	50	51	173.7 (6.9)	161.1 (4.9)	77.6 (9.0)	68.9 (8.6)
70-74	59	62	172.5 (7.0)	161.9 (5.7)	78.3 (10.1)	71.4 (12.0)
75-79	36	38	170.8 (6.0)	158.6 (7.0)	79.3 (9.5)	70.5 (9.7)
80+	33	35	170.7 (6.4)	155.3 (5.9)	76.8 (10.2)	63.9 (10.2)
project 3						
23-35	5	5	177.4 (6.8)	168.5 (6.4)	68.5 (10.9)	70.0 (11.0)
60-65	15	17	176.5 (6.2)	165.1 (6.5)	82.4 (7.0)	69.8 (9.7)

In all projects the grip force was measured with a Jamar Hand Dynamometer Model 1 (Asimov Engineering Company, California, USA) see figure 2.2.1. This type of meter is the one most commonly used in grip measurements (Richards and Palmiter-Thomas, 1996). The meter is made of aluminium and works on a hydraulic system. It weighs 0.4 kg. It has two handles, one of them curved to fit the hand. The distance between the two handles can be adjusted to the hand of each successive subject. There are five positions possible, varying the distance between the handles to 3.43, 4.70, 5.97, 7.24 or 8.50 cm. On the basis of the relative hand size, each subject was offered at least two settings of the meter. The subject indicated the preferred setting. After the subject had chosen a setting, this setting was constant in all measurements.

All statistical analyses were performed with SPSS for Windows (SPSS Inc.).

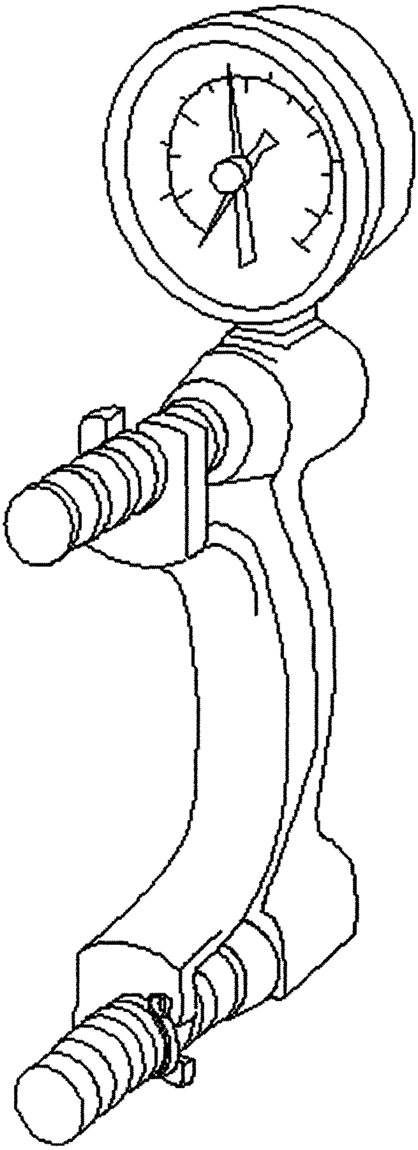


Figure 2.2.1 Jamar Hand Dynamometer (Asimov Engineering Company, California, USA).

In all projects the grip force tested was the maximum isometric force that was gradually build-up from nil to maximumin in about two seconds. It was therefore a transient measurement of grip strength. The meter had an analogue read-out dial. The maximum value reached was displayed by a memory pointer. When this pointer no longer progressed in the force exertion the measurement was stopped. During force exertion the subjects were verbally encouraged by the experimenter to exert maximum force.

In all projects the subjects were seated on a chair with armrests. The arm that held the meter was laid on the armrest, with the hand unsupported (see figure 2.2.2).

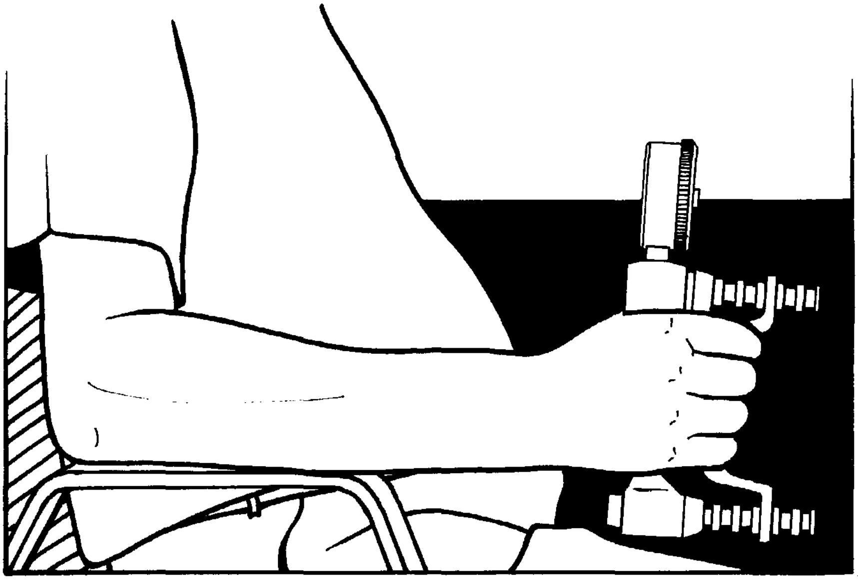


Figure 2.2.2 Subject position: the hand that held the meter was laid on the armrest with the hand unsupported. (Figure by J. Trappenburg)

Results

For all statistic results the significance level that was used depended on the number of subjects. For subject groups smaller than 100 a level of 0.05 was used, and for subject groups over 100 individuals 0.01.

The results from study 1 show that there are no regional or urbanisation effects on grip force. This effect was tested with a one way Anova and a t-test respectively.

In study 1 grip force was measured three times. For the right hand there was no significant difference between the means of the first and third measurement, and for the left hand the mean of the third was not significantly different from the means of the first or the second attempt ($p>0.01$) . The results (presented in table 2.2.2) show that for the right hand the mean of the third measurement was only significantly different from the second measurement ($t=-4.01$, $p=0.000$). The mean of the second measurement is higher.

Table 2.2.2 t-tests three measurements; study 1.

	t-value (two sided) left hand			t-value (two sided) right hand		
test no.	$\bar{x}$ [N]	test no. 1	test no. 2	$\bar{x}$ [N]	test no. 1	test no. 2
1	30.8	.	.	32.9	.	.
2	31.8	2.5 (ns)	.	33.5	2.4 (ns)	.
3	31.3	1.4 (ns)	-1.6 (ns)	32.8	-0.9 (ns)	-4.0 (p=0.000)

ns = not significant

In table 2.2.3 the mean grip force in study 1 is presented, per sex , for the left and right hand. The standard deviation is placed between brackets.

Table 2.2.3 Mean and standard deviation of the left and right grip force as measured in study 1.

left hand [N]		right hand [N]	
men $\bar{x}$(s)	women $\bar{x}$ (s)	men $\bar{x}$ (s)	women $\bar{x}$ (s)
399.8 (81.0)	243.6 (50.7)	419.3 (75.6)	261.8 (57.5)

In study 2 we used the higher of the two measurements to establish the mean maximum grip force per age group. The results per age group, per sex, are placed in table 2.2.4.

Table 2.2.4 Mean grip forces of left and right hand and standard deviations as measured in study 2.

	number		grip force left hand[N]		grip force right hand[N]	
age group	men n	women n	men $\bar{x}$ (s)	women $\bar{x}$ (s)	men $\bar{x}$ (s)	women $\bar{x}$ (s)
20-30	55	68	503.4 (90.4)	311.5 (53.8)	536.2 (84.2)	339.3 (58.9)
50-54	35	35	459.9 (73.0)	262.6 (67.5)	495.1 (82.9)	295.4 (60.7)
55-59	46	50	456.3 (87.5)	257.6 (62.5)	469.4 (78.7)	276.7 (65.1)
60-64	44	53	405.6 (80.5)	251.9 (64.2)	439.7 (74.0)	269.5 (64.0)
65-69	50	51	389.1 (73.9)	229.3 (52.1)	413.6 (67.5)	252.9 (53.6)
70-74	59	62	359.4 (76.6)	223.6 (54.2)	381.4 (83.0)	236.1 (58.1)
75-79	36	38	343.6 (78.5)	209.4 (64.0)	363.0 (84.9)	225.4 (61.5)
80+	33	35	304.4 (57.4)	173.7 (56.0)	319.9 (62.1)	184.4 (57.7)

In figure $2.2.3^{A+B}$ the data on grip force from table 2.2.3 are presented graphically. Lines are fitted to these data with an asymmetric transition function, according to the procedure of Levenberg-Marquardt.

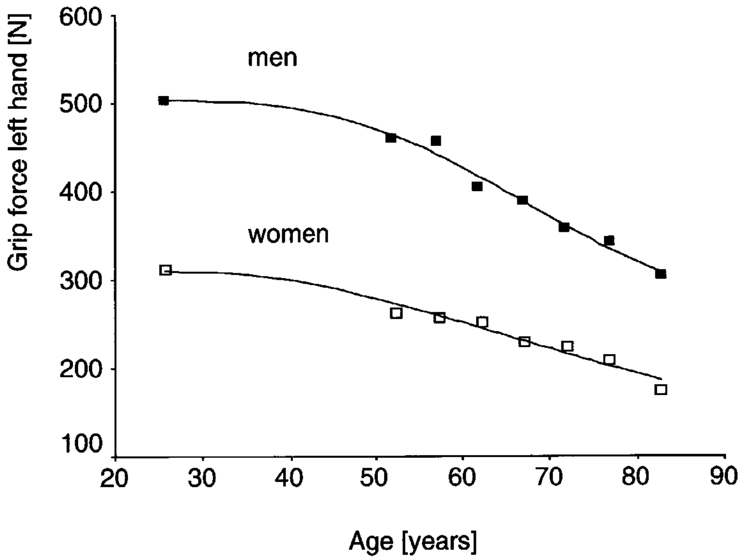


Figure 2.2.3[A] *Grip force curve for the left hand. The curve showes that men have generally a stronger grip in their left hand than women. Men over 80 have generally a somewhat lower grip in their left hand than women under 30.*

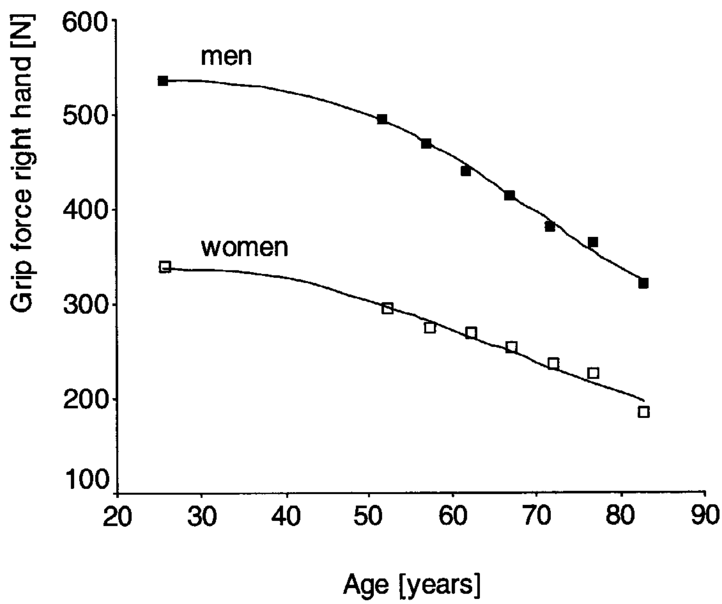


Figure 2.2.3[B] *Grip force of the right hand. The subjects were generally stronger in their right hand compared to their left. Men are generally stronger than much younger women; only the men over 80 are generally weaker than the women under 30.*

For both the left and the right hand we found significant differences in average grip between age groups. The differences in the mean values of the age groups were tested with a one-way ANOVA (Post Hoc Scheffé). The results are presented in a triangle (figure 2.2.4). In this triangle a large dot indicates that the mean of the vertically positioned age group is significantly higher than the horizontally positioned age group.

age group	20-30	50-54	55-59	60-64	65-69	70-74	75-79	80+
20-30	.	.	(•)	•	•	•	•	•
50-54	.	.	.	.	.	•	•	•
55-59	.	.	.	.	.	•	•	•
60-64	.	.	.	.	.	.	.	•
65-69	.	.	.	.	.	.	.	•
70-74	.	.	.	.	.	.	.	.
75-79	.	.	.	.	.	.	.	.
80+	.	.	.	.	.	.	.	.

Figure 2.2.4 Significance of differences between age groups; one-way Anova (Scheffé). The (•) does only apply for the right hand. Example: $\bar{x}$ age 55-59> $\bar{x}$ age 70-74.

The results of the 46 individuals from study 2 who joined a retest show that the reproducibility of the test is acceptable. No significant difference was found between the mean of test and retest (left: t=1.37, p=0.18; right: t=0.21, p=0.84). The correlation coefficients varied between 0.92 and 0.96 (p=0.000).

In table 2.2.5 the results from study 3 are presented, in combination with the results of the same subjects in study 2. The age mentioned is the age in study 3

Table 2.2.5 Results study 3 and results of the same subjects in study 2.

age group	number men n	number women n	std	grip force left hand [N] men $\bar{x}$ (s)	grip force left hand [N] women $\bar{x}$ (s)	grip force right hand [N] men $\bar{x}$ (s)	grip force right hand [N] women $\bar{x}$ (s)
23-35	5	5	2	415.9 (82.3)	317.8 (29.9)	443.4 (121.6)	347.3 (52.7)
			3	431.6 (66.9)	341.4 (32.1)	463.0 (83.1)	355.1 (35.0)
60-65	15	17	2	417.8 (101.1)	243.9 (65.5)	442.6 (62.3)	436.3 (73.0)
			3	427.6 (94.5)	276.6 (55.8)	436.3 (73.0)	298.9 (58.3)

T-tests indicate that there is no significant difference between the means of both age groups (left: t=0.81, p=0.42; right: t=1.11, p=0.28). In figure 2.2.5, for the subjects who joined both studies 2 and 3, their results in both projects are plotted out against each other. When a line is drawn that marks the positions of identical results, it can be seen that for the left hand the result of the last test was higher than that of the previous test in 64% of the cases, and for the right hand in 57% of the cases. The mean of the left hand was significantly higher in the third project (t=-2.8, p=0.008).

In all projects men had significantly higher results than women. In the results of all t-tests done to test the differences between the sexes, the t-value varied between 5.98 and 25.4 with p=0.000 in all cases.

We studied the differences between the mean values of left and right hand, and the preferred and the non-preferred hand. The preferred hand was defined as the hand that the subjects indicated was mostly used in forceful actions. In study 1 the mean of the preferred hand was significantly higher than the mean of the non-preferred hand (t=-4.20, p=0.000). The mean of the preferred hand in this project (no. 1) was also higher than that of the right hand, but this difference is not significant. For the left-handed subjects the difference between the average grip in left and right hand is not significant (t= 0.15, p= 0.889). In this project (no. 1) 109 subjects were right-handed, 9 left-handed.

Both lateral effects were also found in study 2. The mean value of the preferred hand was not significantly higher than the mean value of the right hand (t= 0.95, p= 0.342). The differences between left and right hand were not significant in the left-handed subjects (t=0.95, p=0.344). In this project (no. 2) 666 subjects were right-handed and 84 left-handed.

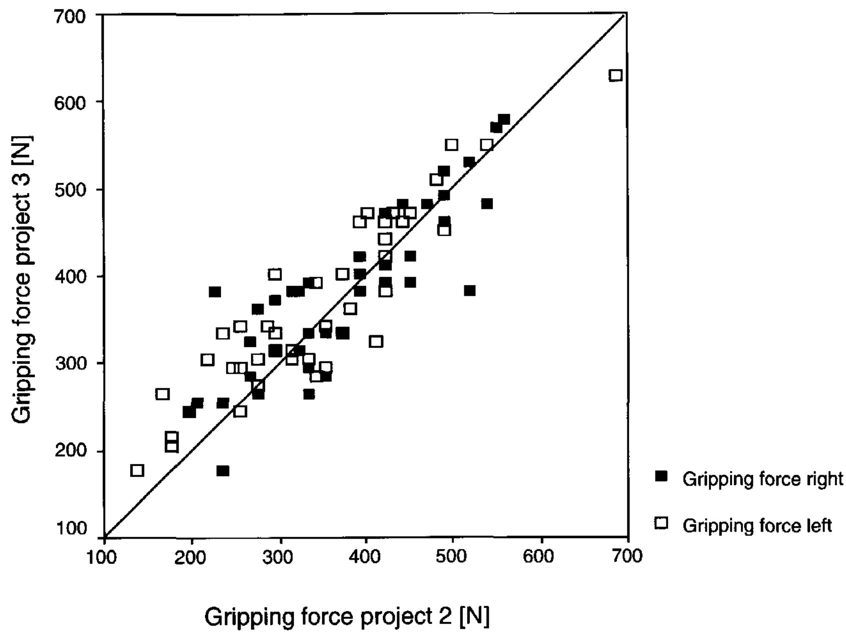


Figure 2.2.5 Differences in grip force in studies 2 and 3. The results in study 3 are generally higher than in study 2.

In study 3 the mean of the preferred hand was not significantly higher than the mean of the right hand. In this project (no. 3) 5 subjects were left-handed and 38 right-handed.

Thirty of the 79 variables available from study 2 were correlated with grip force. In table 2.2.6 the variables are presented on the basis of the correlation coefficient with grip force. All coefficients presented here are significant. On the basis of the correlation coefficient we divided the results into five categories: 0-0.1 (no relation), 0.1-0.33 (poor relation), 0.33-0.5 (some relation), 0.5-0.71 (relation), 0.71-1 (strong relation).

Table 2.2.6 Relation of grip force with other variables of study 2.

Variable name	Correlation coefficient				
	0-0.1	0.1-0.33	0.33-0.5	0.5-0.71	0.71-1
arm length				x	
balance			x		
body mass			x		
daily activity		x			
ear length	x				
education/profession		x			
foot breadth			x		
foot length				x	
grip circumference			x		
hand breadth				x	
hand length				x	
hand steadiness		x			
head bending		x			
head rotation			x		
health (perceived)		x			
hearing		x			
maximal step height				x	
memory		x			
peg board time		x			
pulling force				x	
pushing force					x
reaction time			x		
shoulder breadth				x	
stature					x
step length				x	
thumb breadth			x		
torque					x
walking (fast)				x	
walking (normal)			x		
wrist rotation		x			

Discussion and conclusions

In our study, grip was measured with the arm of the subject on an armrest. This deviates from the standard according to Richards and Palmiter-Thomas (1996). We chose to use an arm support because of the weight of the grip dynamometer in relation to the advanced age of a number of the subjects. In this way we hoped to avoid causing fatigue.

In a deviation from the standard we also verbally encouraged all subjects during force exertion. This was done because the cautiousness of subjects increases with age (Virokannas et al., 1997), and because laboratory surroundings are often perceived by them as uncomfortable.

Despite the arm support and the special subject approach, the decline of grip strength from 20-30 up to 80+ years of age was in agreement with the literature (Mathiowetz, 1990; Imrhan and Loo, 1989). While their results were based on measurements repeated three times, we decided to use only two repeated measurements after doing study 1. A third measurement proved not to add information to the first two, because in general it was on the same level as the first measurement and lower than the second. Even with the right hand the level of the third measurement was significantly lower than the second. This is in agreement with Verbrugge et al. (1998), although in that study no encouragement was given.

Study 1 also showed that for The Netherlands, urbanisation and region do not have a relation with force levels. Therefore, for study 2 we decided to measure in one location only. While in other studies individual results are based on the mean of all measurements, we aimed at information on maximum grip force, and only used the higher of the two measurements.

Because we changed some aspects of the measurement procedures as mentioned above, we checked reproducibility on 46 subjects. The reproducibility was shown to be good. This was, on the one hand, expected because of the simplicity of the test but was, on the other hand, somewhat surprising because in the opinion of Kroemer (1970) and Caldwell et al. (1974), encouragement influences the results in an uncontrollable way. They recommended that encouragement should not be given, because they found higher results with the use of encouragement.

We compared the results of study 2 with several other studies (Aniansson et al. 1978; Mathiowetz, 1985; Era et al., 1992; Woldstad et al., 1995; Ihmran and Loo, 1989). Our results are, in most cases, on a comparable level to the results of others, or higher (ranging from -14 to 25% of our means). Because we searched for maximum grip strength, higher results were acceptable.

Only Era et al. (1992) found higher results for men in the age groups 51-55 (572 N) and 71-75 (433 N). This Finnish study, however, was performed with both white collar workers and manual workers who were still working. This differs from the Dutch situation where almost everyone retires at 65 and often earlier. This makes comparison of the two groups difficult.

Our study confirmed the rule that at all ages grip force in men is higher than in women. We even found that the mean grip force in the men aged 75 to 80 was higher than the mean of the youngest women (i.e. aged 20-30 years).

Because we wanted more information on the decrease of grip force with age, we did a follow-up study (study 3) on a sample of the subjects from study 2. We restricted ourselves to the age groups 20-30 and 60-65. We found an increase in grip force in the majority of our sample, in spite of the time that had elapsed. This increase in the 20-30 year old subjects was not unexpected but the higher force in the older subjects was.

The graph in figure 2.2.3 is based on transversal research. From the literature (Shock et al., 1984) it was expected that the results of the longitudinal part would not precisely follow the lines indicated in that figure. However, an increase in force in the 60 to 65 year old subjects was not expected. This does not necessarily imply that there should also be a rise in the line in figure 2.2.3, because this represents grip strength differences between different age groups in a population. We speculate that this increase was caused by the fact that the subjects in study 3 were more familiar with the test situation and therefore felt more comfortable with the exertion of maximal force.

In order to study the possibility of grip force being a good predictor for all sorts of other human capacities, we selected 30 variables from study 2. Firstly, we selected them on the basis of scale similarity; comparing metrically scaled grip strength with, for example, the nominally scaled colour preference for bicycles would be far fetched. Secondly, we limited the number of body dimensions and selected ten out of the 26 variables available.

We found no indications that grip force is a particularly good predictor for most of the variables in study 2. For those presented in table 6 most correlations are under 0.5, which indicates that less than 25% of the variance is explained. Twelve correlation coefficients exceed 0.5 and only three are larger than 0.71. All twelve are physical variables. Using grip force to predict the three variables that are best correlated can be considered.

Although most of the grip force results we present here are not so different in magnitude from the results we found in the literature, the form of presentation is far more suitable for use by product designers. For instance, the graph in figure 2.2.3 gives, in addition to existing literature, detailed information about the relation between age and force. This information is valuable to a designer because most literature contains only information on a specific age group, or on one or other of the sexes.

When a designer needs information on a group and they find that the information is incomplete or that no previous study as been done, then they must calculate the necessary information themselves without the availability of the original data. With the graph in figure 2.2.3 this problem is solved for users of both sexes between 20 and 90 years of age.

Furthermore, with the means and standard deviation of the eight different age groups the designer will, in most cases, be able to determine the grip strength of both the weakest and the strongest possible user of the product he is designing. For instance, in the design of a tin-opener the grip required to make the opener cut through the tin should not exceed the maximal force of the weakest possible user, while the tin-opener should not collapse under the maximal grip force of the strongest possible user.

The information on the difference between longitudinal and transversal studies is mainly of interest for designers of personal items that are used over a long period of time (such as prostheses).

When a variable is a good predictor for other, less easy to acquire or assess variables, this is good news for designers. Had grip force been found to be a good predictor for sensory, psychomotor or cognitive variables it would have been sensational news, because information on grip force is more readily available and measurements are simpler. Unfortunately, we can't bring such news.

This study leads to the following conclusions:

- Arm support and verbal encouragement do seem to alter the level of grip strength in relation to other studies, and do not result in an unacceptable reproducibility.
- Two repeated measurements are sufficient to determine maximum voluntary grip strength.
- Mean Dutch grip strength for both hands in the age group 20-30 is significantly higher than the means of all age groups above 60 years ($P<0.01$).
- Grip strength in men is higher than in women in all age groups.
- The results of transversal measurement of grip (in consecutive age groups) differs from longitudinal measurements of grip after two-and-a-half years (in the same age group).
- Grip strength is significantly correlated to most variables, but is not an especially good predictor for psychomotor, sensory and cognitive subject characteristics.

2.3 The twisting force of aged consumers when opening a jar

A.I.M. Voorbij and L.P.A. Steenbekkers

(Submitted to Applied Ergonomics, November 1999)

Summary

Many people experience difficulty when opening a vacuum-sealed jar. This is common knowledge. Yet solutions to the problem continue to be tool-based rather than exploring the possibility of innovative changes in product packaging.

Improvement depends on gaining knowledge of the capabilities of users, and of using that knowledge as a base for product innovation. To establish such a base we took a sample of 750 subjects and asked them two questions about how they opened jars at home. We then carried out torque measurements using a force transducer shaped like a jam jar. We reached the conclusion that if opening torque was reduced to 2 Nm then 97.6 per cent of users between 50 and 94 years of age and 100 per cent of 20 to 30 year old users would have no difficulty opening a jar.

Introduction

Opening vacuum-sealed jars can pose a problem for a large percentage of the elderly population (Berns et al., 1981; Steenbekkers and Logman, 1987) because they are unable to exert sufficient twisting force. Yet many consumer goods are packed in such jars. This points to a design problem, caused by the need for glass packaging that can be re-closed, can withstand vacuum and is suitable for preserving perishable foodstuffs. With such packaging a minimum torque is required to retain the vacuum. There are no regulations that prescribe the torque required to open a jar. The degree of torque applied in the manufacturing process is often large, because other factors are involved such as preventing people from opening jars accidently or stopping consumers from tasting before buying.

At present no general solution for the easy opening of jars exists. Tools such as clamps, vacuum releasing levers or antiskid pads could be used, but these tools all have drawbacks in their design and are not always available. At present, the optimal solution is to design packaging that can be opened manually by the majority of the population. This should include all independently living adults. The starting point for this study is not to design an alternative-opening device, but to present information to manufacturers which will promote the use of the capacities of users as a basis for their packaging.

We decided to restrict ourselves to the circular turning lid, which is the one most commonly used in glass packaging. Imrhan (1993) found that for lid diameters under 74 mm, ridges and other patterns for increased grip do not result in an increased torque. Data are available on maximum twisting force as well as on opening jars (Ivergard et al., 1978; Berns et al., 1981; Rohles et al., 1983; Imrhan and Loo, 1988; Daams, 1994). However, information on the capacities of the elderly is scarce. Because the number of elderly people who live independently is increasing rapidly, the capacity of these consumers is now very relevant for package design and must be taken into account. Therefore, the aim of this study is to determine the maximum twisting force the elderly can apply when opening a jar.

Method and Materials

This study is part of a larger study on the design-relevant capacities of ageing users (Steenbekkers and Van Beijsterveldt, 1998). In this study 79 variables were measured on 750 subjects. 123 of them were aged between 20-30 years and 627 were over 50 years of age. In table 2.3.1 information on number, sex, body mass and stature is presented for comparison with other studies.

Table 2.3.1 Subject information

	Number		Stature [cm]		Body mass [kg]	
Age	men	women	men	women	men	women
group	n	n	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
20-30	55	68	184.8 (8.0)	168.6 (6.6)	80.8 (14.3)	66.7 (9.6)
50-54	35	35	177.8 (8.1)	165.4 (5.5)	82.5 (11.7)	70.4 (12.4)
55-59	46	50	176.7 (7.5)	165.3 (6.3)	82.1 (12.8)	70.7 (11.2)
60-64	44	53	176.1 (5.7)	163.9 (5.9)	80.2 (8.9)	71.4 (11.6)
65-69	50	51	173.7 (6.9)	161.1 (4.9)	77.6 (9.0)	68.9 (8.6)
70-74	59	62	172.5 (7.0)	161.9 (5.7)	78.3 (10.1)	71.4 (12.0)
75-79	36	38	170.8 (6.0)	158.6 (7.0)	79.3 (9.5)	70.5 (9.7)
80^{+}	33	35	170.7 (6.4)	155.3 (5.9)	76.8 (10.2)	63.9 (10.2)

All subjects were selected for their ability to live independently, and none of them had needed to consult a medical specialist in the three months preceding the experiments. The variables were tested in two sessions on two separate days, each lasting about two hours. Twisting force was measured in a session along with other physical variables such as gripping force, walking velocity and reach envelopes.

A written ADL (Activities of Daily Living) questionnaire was sent to each subject before they attended the measurement sessions. The questionnaire contained 44 questions. Questions 17a and b referred to the opening of jars. Subjects were asked to classify the problems they experienced when opening jars:

17 a Can you twist off the lid of a new jar?

- ❑ *Yes, I can without any difficulty*
- ❑ *Yes, I can with some difficulty*
- ❑ *Yes, I can with great difficulty*
- ❑ *No, I cannot*

17b If you are able to open a jar, do you use an aid, such as a multi-opener?
- ❑ *Yes*
- ❑ *No*
- ❑ *Sometimes*

Twisting force was measured while the subject was standing. The subject was asked to adopt the posture normally used for opening jars. It was therefore possible to place the jar on a table or on a surface at worktop height, or to handle the jar without the use of any support. All possibilities were mentioned to the subject. The only limitation the subject had to cope with was a thin wire leading from the jar to an amplifier. An arrow on the lid indicated the twisting direction corresponding with opening.

The jar, which was made of aluminium, weighed 650 grams and contained a torque transducer (Engineering Dept., Cambridge University). The jar-shaped unit was linked to a strain indicator (Peekel instruments, CA690). The lid had a diameter of 66 mm, while at its widest point the jar was 75 mm in diameter. The total height was 113.5 mm (see figure 2.3.1). The dimensions of the jar were copied from a jam jar available in Dutch supermarkets.

Figure 2.3.1 The handling of the jam-jar-shaped force meter, the subject was to choose how to hold the handle in his hands. (Figure by J. Trappenburg)

Before the subjects exerted maximum twisting force, they were instructed to wipe their hands thoroughly to prevent the possibility of sweaty hands affecting their grip on the lid. During the actual maximum force exertion, one attendant verbally encouraged the subject. Subjects were not able to see the results, which were recorded on paper by an XT-writer. The subject was instructed to build up force to maximum and to hold this maximum force until the second attendant called a stop. This attendant checked for an acceptable length of the constant phase in the force graph (i.e. one-second).

The force exertion was repeated once after a two minutes period of rest.

The attendants noted the maximum force exerted in combination with the position and laterality of the hands for force exertion. The force graphs were analysed visually and the maximum force assessed was entered into the computer. All statistical analyses were performed with SPSS for Windows (SPSS Inc.).

Results

There was no significant difference between the results of the first and second measurements of twisting force. It was decided to have the mean of both measurements representing twisting force. Figure 2.3.2 is a scatterplot of twisting force in relation to the age of the subjects.

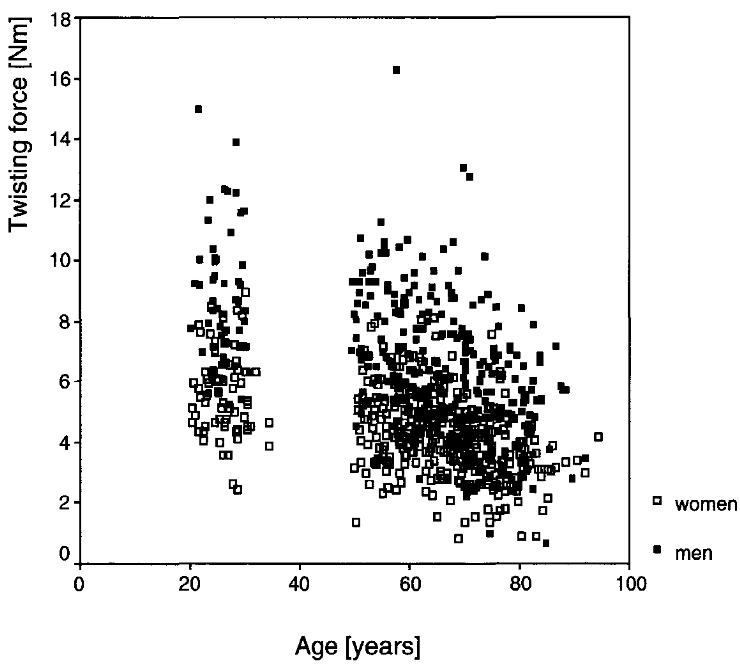


Figure 2.3.2 Scatterplot of twisting force versus age. The black dots represent the men while the white ones represent the women. Men are generally stronger than women.

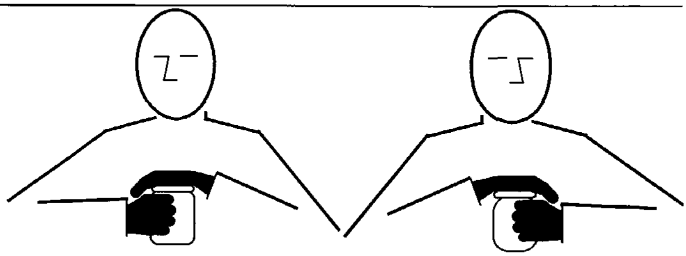
The highest twisting force found was 16.3 Nm and the lowest was 0.7 Nm. Table 2.3.2 contains information on the average twisting force and the standard deviation. The results are presented per age group.

Table 2.3.2 Mean and standard deviation of twisting force.

	Twisting force [Nm]	
Age group	Men $\bar{x}$ (s)	Women $\bar{x}$ (s)
20-30	8.7 (2.2)	5.6 (1.4)
50-54	7.6 (1.8)	4.8 (1.5)
55-59	7.6 (2.3)	4.7 (1.4)
60-64	6.4 (1.8)	4.8 (1.4)
65-69	6.5 (2.1)	4.0 (1.2)
70-74	5.4 (2.1)	3.7 (1.1)
75-79	5.0 (1.7)	3.5 (1.3)
80+	4.9 (1.7)	3.4 (0.9)

All subjects used both hands in the force exertion. One hand was on the lid while the other grasped the jar. An effect of laterality was found in the use of the hands. Most right-handed people preferred to have their left hand on the lid while the other hand grasped the jar (see table 2.3.3 figure 3A), most left-handed persons used the other hand combination (see table 2.3.3 figure 3B). This difference in handling was significant according to the frequency distribution $X^2_{(1)}=93.3$ (p=0.000).

Table 2.3.3 Numbers on hand configuration and laterality. Left handed subjects tend to open the jars differently from right handed subjects.

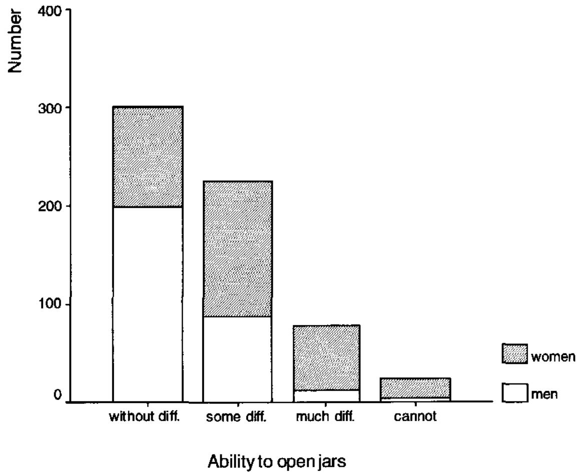


Subject laterality	Figure 3A Right hand grasping the jar Number	Figure 3B Left hand grasping the jar Number
Right-handed	511	147
Left-handed	23	62

In table 2.3.4, the answers to the questions in the ADL-questionnaire are presented per answer for the subjects over 50.

Table 2.3.4 Answers to ADL-questionnaire for subjects over 50.

Ability to open a jar per sex



Ability to open a jar with or without tools

	no diff. (47.2%)	some diff. (35.9%)	much diff. (12.4%)	can not (3.8%)
use of tools [%]				
no	35.7	20.0	16.7	16.7
yes	25.3	40.4	55.1	70.8
sometimes	39.0	39.6	28.2	12.5

The subjects from 20 to 30 years of age had considerably fewer problems. None was unable to open a jar and only 1.6 % had much difficulty in opening a jar. The use of tools was less common in this age group as 60.7 % never use one.

Discussion

Opening a jar often involves a great deal of effort. In a group of elderly persons we found that 16.2 % had great difficulty, while 3.8 % were unable to open a jar without help. Only 47.8% had no problems. Although the figures mentioned here might not be general knowledge, it is generally recognised that opening jars can be difficult. It is strange, therefore, that the packaging industry has not yet addressed the problem by changing this type of packaging.

In The Netherlands there are some regulations concerning food and packageing. With respect to the closing of lids, maximum opening force is not prescribed by law.

A Dutch producer of jam packed in jars measured the opening torque of those jars and found that, depending on the type of jar, the required opening torque was between 2.9 and 5.5 Nm.

The present study is an attempt to answer the question of what maximum torque is allowed for opening a jar. This information needs to be transformed into a design requirement for reclosable glass packages.

The elderly population is of increasing interest because, when living independently, they combine the lowest force levels with the consumption of jar-packed food. Therefore, the majority of the subjects we studied were over 50 years of age. We also studied subjects between 20 and 30 years of age as a reference group. Because we wanted to find out what happened in an everyday situation we allowed the subjects to adopt their own position during force exertion. We encouraged them during the actual force exertion, because in daily life they would be motivated by a wish to reach the contents of the jar.

We used a lid with a diameter of 66 mm, which represents the size of a common jam jar. This size also enables comparison with data on opening torque found by Rohles et al.(1983). Their subjects were aged between 62 and 91 years and for comparison we selected subjects in the same age category. The data of Rohles et al. (1983) and our data from this study were found to be comparable; for men 6.5 Nm and 5.7 Nm respectively and for women 3.6 Nm and 3.9 Nm respectively. Comparison with other studies, such as Ivergard et al. (1978), Berns et al. (1981) or Imrhan and Loo (1988), is difficult primarily because of different test situations. A different lid diameter, for example, can have an effect on force exertion (Imrhan, 1993).

With respect to the facilitation of easy opening by means of modifications made to the jar, it should be realised that all subjects used both hands, and that modifications should not hinder hand configuration as preferred by left and right-handed consumers.

Products will always be designed on the basis of compromise between conflicting optimal solutions for specific aspects but we feel that, as this concerns food, it is essential that the majority of consumers are able to open the product without help. Therefore, in our recommendations we accept that only 2 to 3% of our sample is in need of help.

Interpreting our data in order to provide a recommendation for manufacturers, results in a limitation of opening torque to 2 Nm. This implies that only 2.4% of people over 50 years of age would remain unable to open a jar without help. In view of the large number of elderly people who actually have problems with opening a jar (52.2%) we conclude that the present torque requirement is much higher than the recommended 2 Nm.

From this study we conclude the following:

- The preferred way of opening a jar is with both hands; one on the lid and one on the jar.
- Laterality is significant: the preferred hand grasps the jar
- The required torque for opening a jar should not exceed 2 Nm.

2.4 Clearance of emergency exits for use by the elderly, a proposal for an addition to a Dutch standard

A.I.M. Voorbij, L.P.A. Steenbekkers and C.J. Snijders

(Article in the International Journal for Consumer and Product Safety, vol.6, no.4, p171-182, December 1999)

Abstract

In this article the maximum pushing and pulling forces of 750 persons between 20 and 30 and over 50 years of age are presented. Measurements were done using a framed strain gauge transducer and recorder. Both forces were measured in a free standing position that was related to opening a heavy door. The latter makes it possible to use the information in a standard on emergency exits. Such a force standard is not available in The Netherlands. We propose an addition to NEN 6082:1997 concerning human capacities in opening unfastened, hinged doors that are on an escape route.

Introduction

The strength of adults decreases with age. This decrease in strength is documented in literature, for general strength (Asmussen and Heebøll-Nielsen, 1962; Åstrand, 1968; Hettinger,1968)as well as for some specific forces. It can be concluded that all researchers agree on a gradual decrease in strength, but agree less about the onset of this decrease or the magnitude of the forces.

However, specific information on values is not available for all forces except for the more wide-spread force measurements such as gripping force (Imrhan and Loo, 1989; Mathiowetz, 1990).

Information on forces is vital for the design and innovation of products and workplaces. Moreover, if this information includes information on the maximum performance of all possible adult users then it can be used as input for safety standards and product requirements.

In The Netherlands NEN 6082:1997 is the standard for fire safety regulations in different types of buildings. This standard contains information on time taken to reach an exit and distance to the nearest exit, but does not contain information on the force required for opening doors. Such information is vital for emergencies, where the safety of all users, including the weakest subjects, is of paramount importance.

Standards for force requirements on opening doors exist, such as the current paper of the British Building Research Establishment 1/82 (Covington, 1982), but are not especially relevant to the Dutch situation. The Dutch are known to be tall people, and their pushing and pulling force may also differ from other populations. Daams (1994) measured the pushing and pulling force of Dutch subjects but did not include the elderly.

Therefore, we decided to measure the maximum pushing and pulling force of elderly Dutch people. We chose a setting that allowed for the adoption of any posture in which a door is normally opened. The aim of this article is to conceptualize a standard for opening unfastened hinged doors in emergency situations.

Method and materials

This study was part of a larger study on design-relevant characteristics of ageing users (Steenbekkers and van Beijsterveldt, 1998). In this transversal research 79 variables were measured.

The measurements were divided over two sessions, lasting two hours each, which were held on two separate days. Pushing and pulling forces were measured in the same session, together with other physical variables such as gripping force, step length and walking velocity. Between two force measurements of the same hand there was a two minute rest period. All measurements were repeated once in the same session.

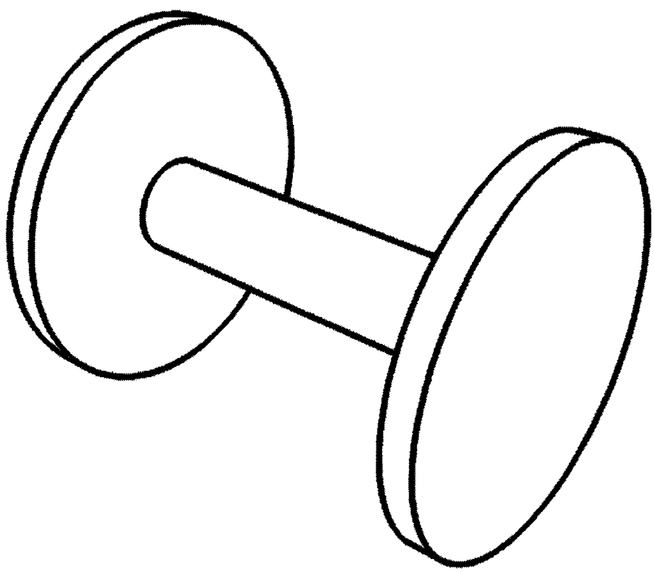


Figure 2.4.1 Handle for pulling force with one hand (cylinder: ø 3.2cm, length 13cm)

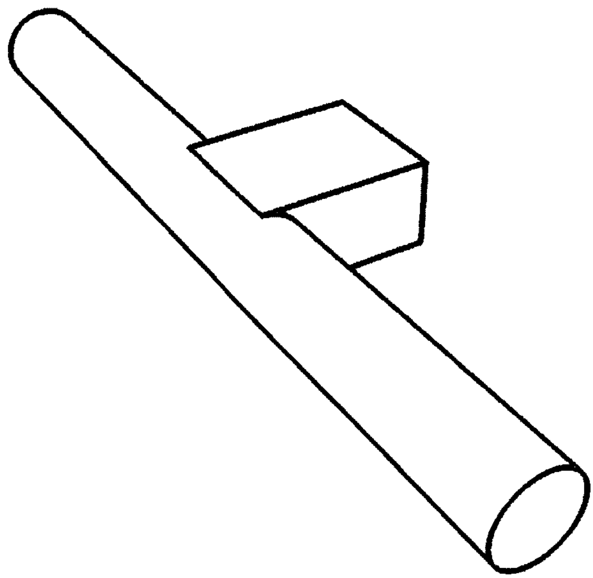


Figure 2.4.2 Handle for pushing force with two hands (cylinder: ø 3.0cm, length 22cm)

Both forces were measured using a special, very rigid construction. The subject stood on a platform that was wide enough to allow them to adopt any position desired. Pulling force was exerted with the left and right hand separately, while pushing force was exerted with two hands. We used different handles for each type of force (see figure 2.4.1 and 2.4.2). The height of the handle could be adjusted in steps of 5 cm (e.g. 91,96,101,106-cm etc.). Handle height was set at the height closest to the subject's elbow height (standing).

Before each measurement the respective handle was mounted on a strain gauge transducer that supplied information to an XT-writer. The force graphs thus made were analyzed visually and the maximum force assessed was entered into the computer. The raw data contained two results on maximum pushing force and four results on maximum pulling force for each subject.

While standing on the platform the attendant gave the subject an instruction and a demonstration. The subjects were instructed to build-up their force to maximum and to hold this force for a few seconds. Apart from which hand(s) needed to be on the handle no specific instruction was given on body position or on the length of the hold-on phase. In figures 2.4.3 and 2.4.4 the measuring equipment and an example of a subject in position are presented.

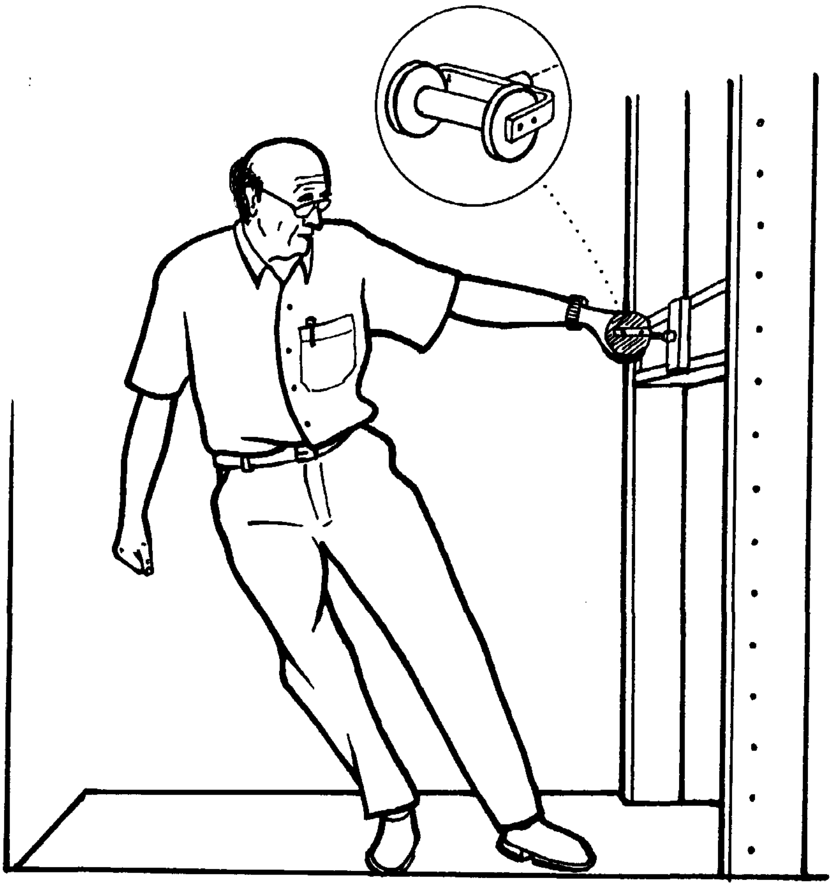


Figure 2.4.3 Position for pulling. (Figure by J. Trappenburg)

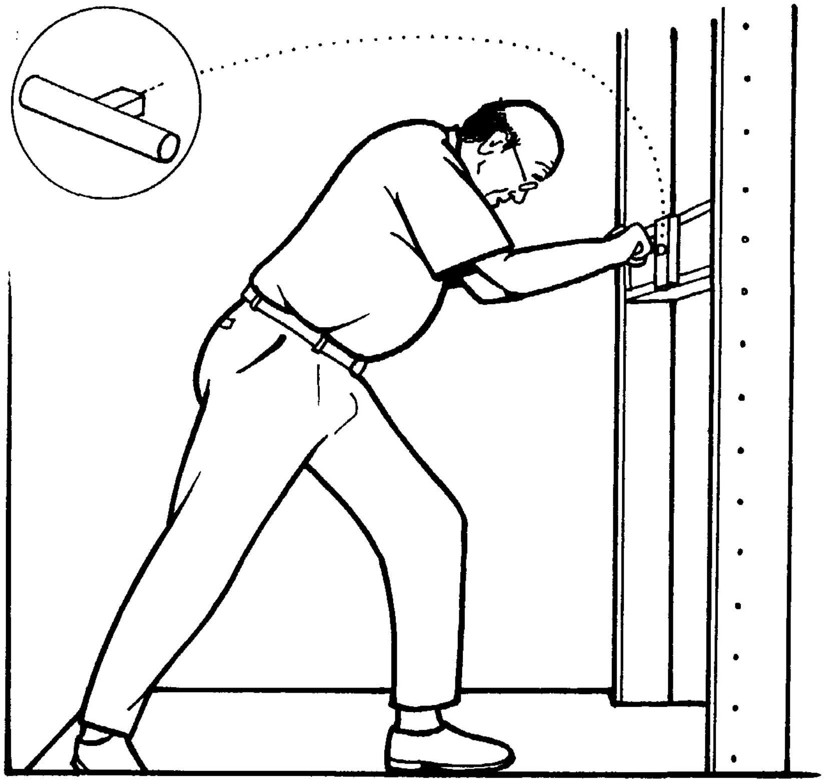


Figure 2.4.4 Position for pushing. (Figure by J. Trappenburg)

During the force exertion the attendant verbally encouraged the subject. The second attendant, who was monitoring the force graph, called a stop after the necessary information (i.e. one-second constant phase) was retrieved.

All analyses were performed with SPSS for Windows (SPSS Inc.).

Results

A total of 750 subjects took part in the measurements, 123 of them aged between 20 and 30 years and 627 who were 50 years of age or older. All subjects were selected for their ability to live independently. In addition to this they had not been treated for any illness by a medical specialist in the three months preceding the measurements.

For statistical purposes the subjects were divided into eight age groups. In table 2.4.1 the number of subjects per age group for men and women is presented, along with information on body mass and stature.

Table 2.4.1 Subject information

Age group	Number men n	Number women n	Stature [cm] men x̄ (s)	Stature [cm] women x̄ (s)	Body mass [kg] men x̄ (s)	Body mass [kg] women x̄ (s)
20-30	55	68	184.8 (8.0)	168.6 (6.6)	80.8 (14.3)	66.7 (9.6)
50-54	35	35	177.8 (8.1)	165.4 (5.5)	82.5 (11.7)	70.4 (12.4)
55-59	46	50	176.7 (7.5)	165.3 (6.3)	82.1 (12.8)	70.7 (11.2)
60-64	44	53	176.1 (5.7)	163.9 (5.9)	80.2 (8.9)	71.4 (11.6)
65-69	50	51	173.7 (6.9)	161.1 (4.9)	77.6 (9.0)	68.9 (8.6)
70-74	59	62	172.5 (7.0)	161.9 (5.7)	78.3 (10.1)	71.4 (12.0)
75-79	36	38	170.8 (6.0)	158.6 (7.0)	79.3 (9.5)	70.5 (9.7)
80+	33	35	170.7 (6.4)	155.3 (5.9)	76.8 (10.2)	63.9 (10.2)

The first and second measurements of pushing force were compared with each other via a t-test, and significant differences were found between the two mean values (r=0.943, t=-11.78 and p=0.00). The mean of the second measurement was in most cases higher than the first. On the basis of this result we have chosen to use the higher of the two results as the maximum pushing force.

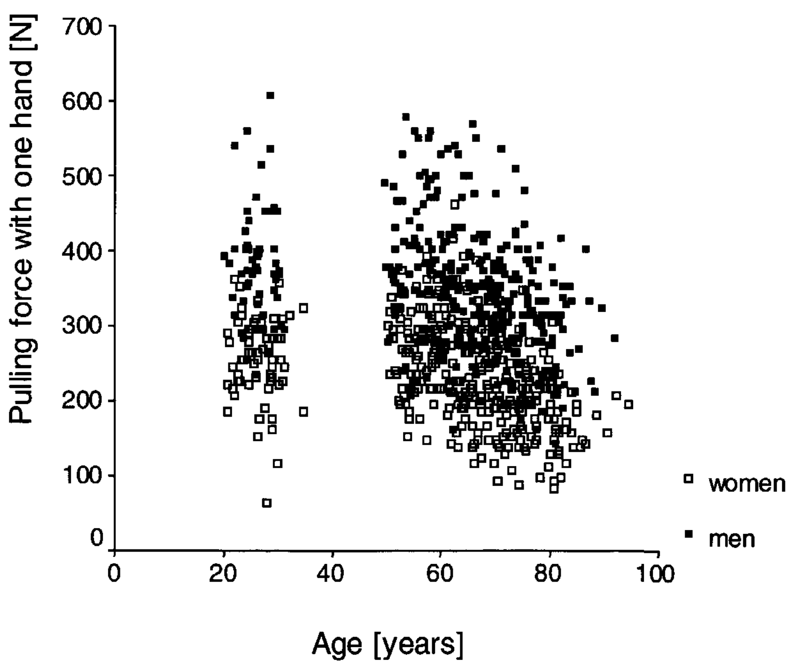


Figure 2.4.5 Scatterplot of pulling force in relation to age.

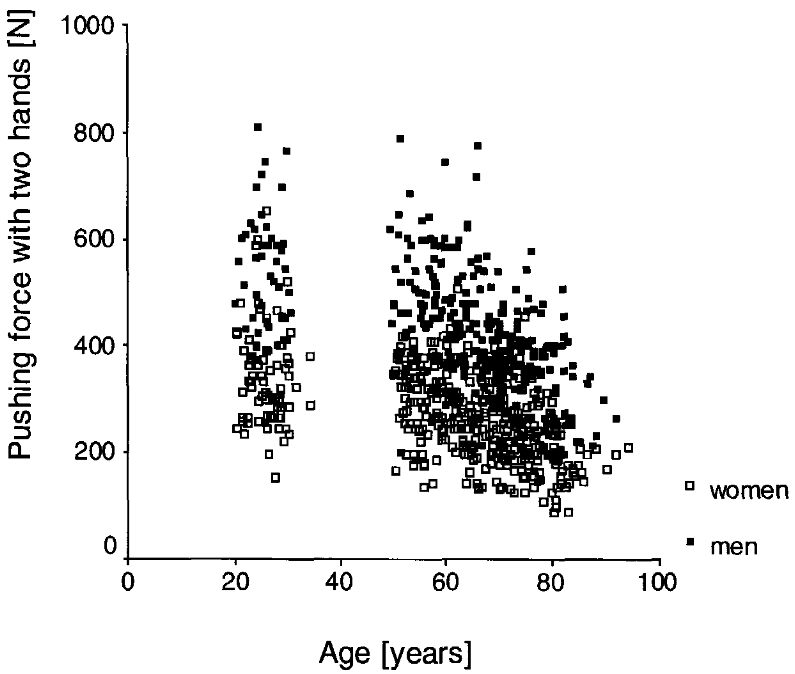


Figure 2.4.6 Scatterplot of pushing force in relation to age.

For the average results of the first and second measurement of pulling force with the left hand the difference was significant (r=0.899, t=-8.47 and p=0.000). There was also a significant difference found between the first and second result of the right hand (r= 0.904, t=-15.65 and p=0.000). However, the differences between the results of the right and left hand were small (means 261 and 272N) so we decided to combine the results into one value. When the data were analyzed by preferred versus non-preferred hand the outcome was the same. Therefore in this article the term 'pulling force' refers to the maximum of the results of all four measurements and has no laterality aspect.

Figures 2.4.5 and 2.4.6 show the results of pushing and pulling force plotted against age in a scatterplot.

The mean values per age group are presented in table 2.4.2. The minimum pushing force found was 88.3 N exerted by an 82-year-old woman, while the minimum pulling force was 63.7 N and was exerted by a 27-year-old woman. The highest pulling force was 578.8 N exerted by a man of 28 years. The highest pushing force was 809.3 N and was exerted by a man of 24 years.

Table 2.4.2 Mean and standard deviation per age group for pulling and pushing force.

Age group [years]	Pulling force with one hand [N] Men $\bar{x}$ (s)	Pulling force with one hand [N] Women $\bar{x}$ (s)	Pushing force with both hands [N] Men $\bar{x}$ (s)	Pushing force with both hands [N] Women $\bar{x}$ (s)
20-30	379.2 (77.8)	260.5 (59.9)	514.5 (122.2)	340.6 (95.1)
50-54	368.9 (88.0)	267.8 (54.7)	463.5 (130.1)	309.4 (68.5)
55-59	405.5 (90.6)	271.5 (57.8)	491.1 (102.7)	290.0 (69.7)
60-64	358.6 (83.6)	261.9 (70.9)	433.5 (87.7)	294.8 (75.8)
65-69	351.1 (76.4)	231.3 (63.6)	417.5 (109.0)	256.9 (66.3)
70-74	319.9 (71.8)	212.6 (61.6)	365.9 (74.2)	236.3 (68.6)
75-79	316.8 (69.8)	204.4 (51.8)	352.0 (102.7)	226.4 (54.5)
80^+	285.5 (67.2)	171.8 (45.4)	299.4 (83.06)	173.3 (42.4)

To study the significance of the differences in mean values for the different age groups two one-way ANOVAs (Post Hoc Scheffé) were performed. These ANOVAs have resulted in the triangles of dots presented in figures 2.4.7 and 2.4.8.

Age group	20-30	50-54	55-59	60-64	65-69	70-74	75-79	80^+
20-30		.	.	•	•	•	•	•
50-54			.	.	.	•	•	•
55-59				.	.	•	•	•
60-64					.	.	•	•
65-69						.	.	•
70-74							.	.
75-79								.
80^+								

• Marks a significantly higher mean for the vertically placed group compared with the mean for the horizontally placed group (e.g. $\bar{x}$ 20-30 > $\bar{x}$ 60-64).

Figure 2.4.7 One-way ANOVA for pushing force.

Age group	20-30	50-54	55-59	60-64	65-69	70-74	75-79	80^+
20-30		.	.	.	.	•	•	•
50-54			.	.	.	•	•	•
55-59				.	.	•	•	•
60-64					.	.	.	•
65-69						.	.	•
70-74							.	.
75-79								.
80^+								

• Marks a significantly higher mean for the vertically placed group compared with the mean for the horizontally placed group (e.g. $\bar{x}$ 20-30 > $\bar{x}$ 70-74).

Figure 2.4.8 One-way ANOVA pulling force.

In order to study the predictive value of both age and weight a linear regression analysis was performed, with pushing and pulling as dependent variables. This regression analysis (pulling $r^2 = 0.379$; pushing $r^2 = 0.379$) showed that the beta for body mass was, in both cases, higher than for age. The betas are presented in table 2.4.3.

Table 2.4.3 Linear regression for body mass and age.

	pulling with one hand		pushing force with two hands	
	Beta	p	Beta	p
body mass	0.577	0.000	0.475	0.000
age	-0.235	0.000	-0.387	0.000

In figure 2.4.9 the different heights at which the handles were placed for pushing and pulling are presented. This height was adjusted to elbow height with the subject standing. The maximum height found was 131 cm and the minimum 96 cm. Mean height for men was 112 cm (s=6) and 106 cm (s=5) for women.

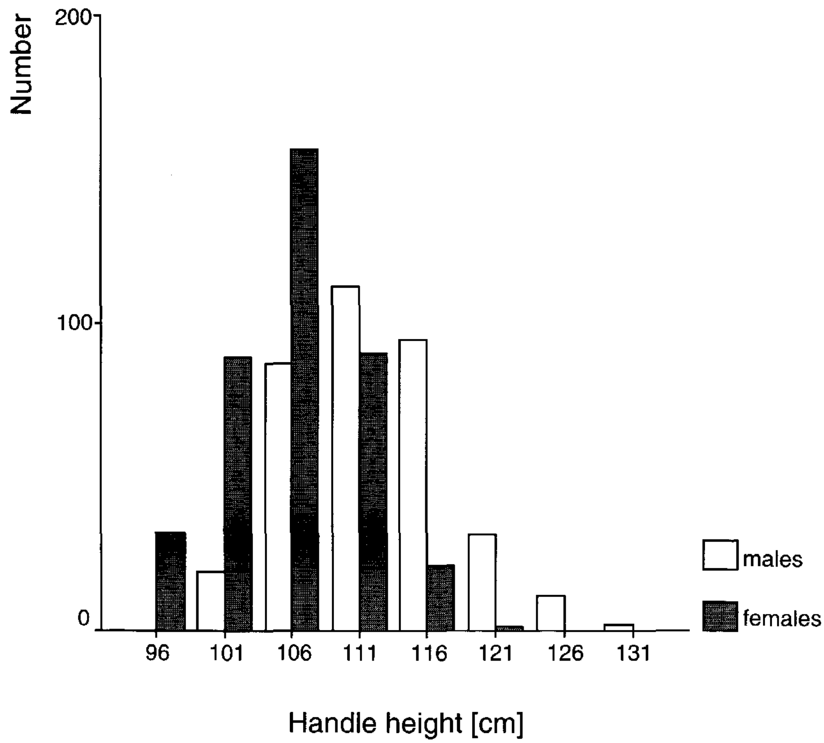


Figure 2.4.9 Different handle heights.

Discussion

The standard for emergency situations is usually set by the weakest of the possible users. It is a matter for discussion whether the subjects in our study can be categorized as the weakest. However, the women in the eldest age group of our sample are very relevant because women are weaker than men and the elderly are weaker than the young. Of course, there are weaker groups among, for example, hospital patients, the functionally handicapped and young children. Nevertheless, when considering people who are mostly unaccompanied in their day-to-day activities, the ambulant, independently living elderly are a rapidly growing group. This group no longer forms a minority, and their capacities should therefore be taken into account in the design of products and buildings.

Because we selected the subjects in our study on their ability to live independently, none of our subjects was severely handicapped. We excluded only those who had suffered from a recent illness and who had been treated for this illness by a medical specialist. Therefore, our subjects were 'normally healthy'. This means that some of the subjects suffered from a chronic disease or were temporarily impaired. It should also be noted that most of the subjects in the eldest age group had one or more 'old person's complaints'. We feel that as long as people are capable of living independently they should be regarded as ordinary consumers, despite their age and infirmities.

However, our methods and materials were slightly adjusted to the aged subjects in our sample. We decided to make these adjustments based on the expectation that the elderly are more cautious in unfamiliar situations (Virokannas et al., 1997). We feared that this would significantly lower the results of maximum force exertion.

For this reason, we verbally encouraged our subjects during force exertion, while during the actual measurement the attendant stood at the side of the platform in close range to the subject. Although both Kroemer (1970) and Caldwell et al. (1974) argue in their article that encouragement might lead to higher but more diverse results, we accepted the possibility of such an effect. Knowing that people are highly motivated in an emergency supported this decision.

In addition to the decision on encouragement, we adjusted our way of instructing the subjects. To increase their motivation the attendant demonstrated the force exertion in the presence of the subject. In this demonstration, it was drawn to the attention of the subject that the handle would not move under force exertion.

We instructed the subject to adopt a position suitable for pushing or pulling, this posture was not prescribed. In literature, such a position is referred to as a 'free position'. Daams (1994) claims that force exertion in a free position leads to higher results for both pushing and pulling than in a standard position. Again, we did not object to this effect.

Caldwell et al. (1974) state that a proper isometric force measurement has a constant phase of one second in which the fluctuations from the mean level do not exceed 10% of this mean. Recordings with too much fluctuation should not be used for further analysis and an extra measurement needs to be done. There was a high risk of this in our study with subjects who were unfamiliar with force measurements.

We tried to avoid extra measurements, because there were a lot of variables to be measured on a tight schedule. Therefore, we did not instruct the subject on the length of the hold-on phase, but had a second attendant monitoring the force curve on-line. This attendant told the subject to stop force exertion when sufficient information was obtained. This method was efficient because no extra measurements were necessary.

Although the younger subjects in our study may not have needed all the adjustments made to the method, the procedure was kept the same for all participants.

In this study we tried to simulate the postures most often adopted when opening a heavy door. Therefore, the subjects were asked to pull with one hand and push with two hands. Most studies on pulling described in literature concern pulling with one hand, mostly with the preferred hand (Daams, 1994; Thompson, 1975). We measured pulling with both hands seperately, but the difference between left hand and right hand was small. This may be explained by the fact that legs and trunk are involved in pulling, and the hand and arm are merely coupling units. We decided to combine the results for the left and right hand, because the difference was small and there was some uncertainty about the nature of the difference found.

Literature (Kroemer, 1970; Caldwell et al., 1974) advises that force should be measured three times or more. However, we measured only twice because we found in a pilot study (Steenbekkers and van Beijsterveldt, 1998) that for gripping forces the third measurement did not add information. Verbrugge et al. (1998) agree on this and came to the same conclusion for several types of forces.

In agreement with the literature (Daams, 1994) most subjects had a higher second force exertion in pushing than in the first. We were interested in the maximum force exertion and therefore selected the higher of the two.

The same approach was used for pulling force, and because we combined left and right we present the highest of all four recordings as pulling force.

The use of submaximal force information in the standard might be considered, to ensure ease of use for the whole range of users. However, our force information is based on a laboratory situation, without the effect of an emergency. People are known to be able to exert immense forces in an emergency. We therefore expect that the actual forces that are exerted in an emergency are higher than the forces we measured. This expectation is shared with other researchers (Daams, 1994; Virokannas et al., 1997; Woodson, 1981) although there are no values available because such a situation can not be studied in practise. The maximum values in the standard are therefore based on maximal forces as measured in the study.

Figures 2.4.7 and 2.4.8 show that the mean values of the older age groups are significantly lower than the mean values of the younger age groups. However, considered on an individual level the young are not always the stronger. For instance, the lowest result in pushing force was achieved by a 27-year-old female.

The whole body is used in the exertion of pushing and pulling force, therefore many other physical aspects can influence the outcome of a force exertion. Some of the results of the regression analysis (table 2.4.3) show that, for instance, body mass has a higher predictive value for pushing and pulling force than age. However, weight is not used as input information for the standard because, in establishing the possible users, weight is never used as a criterion and age often is.

Although we searched sources of European and American standards, apart from the British BRE CP1/81 we did not find other standards on force requirements for emergency exits.

The regulations in the Dutch NEN 6082 state that all doors on an escape route must open in the escape direction. This means that all emergency exits are opened from the inside by pushing. However, people who come to the rescue need to open these doors by pulling. Doors outside a registered escape route are not subject to this regulation and can open in either direction.

In the British BRE CP1/82 (Covington, 1982) data on maximum pushing and pulling force are given for unfastened doors with handles (65 N for pulling and 95 N for pushing). These data are based on the P5-results of 60-75 year old females subjects (n=62). In our study the P5-results of this age group (n=166) show considerably larger maximum force (137 N for pulling and 139 N for pushing). However, if we compare the British results with the P5-results of our eldest age group (n=35), i.e. 80-94 years of age, the results are much closer (91 N for pulling and 88 N for pushing).

This remarkable difference may be partly due to a difference in national characteristics, but can also be ascribed to our selection criterion for independently living, elderly people. Of course, differences in the methods applied might also have an influence. Working on the principle that the oldest and weakest but still ambulant and independently living person must be able to open an emergency exit, we advise the following addition to the Dutch standard NEN 6082:

On an escape route, all unfastened hinged doors with handles must open with a pushing force lower than 88 N or a pulling force lower than 91 N.

The mechanical laws prescribe that force equals mass times acceleration. This means that an unfastened door can be opened by any force, but the time taken to open it depends on the force applied. Although NEN 6082 prescribes the maximal distance from any point in the building to an exit and the maximal time necessary to reach this exit, this is not specific enough to arrive at an adequate door-opening time allowance. People tend to panic when opening takes too much time. Noticeable motion is essential in the opening of an exit. We therefore advise that emergency exits should be able to be fully opened within a few seconds, when the forces mentioned above are applied. Although such information is not mentioned in the British standard, we recommend extending the standard to include information on the length of time that should be allowed for opening. This will require further study.

The British standard states that 450 N can be regarded as abusive force (Convington, 1982). The direction of the force is not specified. In our study, the mean maximum pushing force in 20-30 year old males was 514.5 N and the highest force we found was 809.3N. Because a broken door might hinder people when leaving a building, we recommend that all doors on an escape route should be able to withstand 1000 N pushing force (the mean of the 20-30 year old plus four times the standard deviation). In addition to this requirement, the handles on these doors should not break under 770 N pulling force (the mean of the 55-59 year old plus four times the standard deviation).

We also recommend adding information on the height of the handle to the information on the opening force. Pushing and pulling force is highest at elbow height when standing (Daams, 1994). In the British standard, handle height is said to be optimal at 1000 mm (Covington, 1982). Although our equipment only allowed for adjustments in steps of 5 cm, the information gained was sufficient to generate a recommendation for a suitable handle height. Because pushing and pulling slightly above elbow height is biomechanically more difficult than pushing or pulling lower than the elbow, we advise having a lower handle on emergency exits and placing it at 96 cm to ensure that all possible users can exert maximum force. For other doors the handle height should be between 96 and 116 cm (P5 and P95 of all females). It should, however, be noted that these heights apply for pushing and pulling only. For the additional forces used to unfasten doors other heights may be better.

Conclusions

The following requirements should be added to NEN 6082:

- On an escape route, all unfastened hinged doors with a handle must open with a pushing force lower than 88 N or a pulling force lower than 91 N.
- On an escape route, all doors must be able to withstand 1000 N pushing force, while the handle on these doors should not break under 770 N pulling force.
- The handles on emergency exits should be placed at a height of 96 cm above floor level.
- For inner doors (not on an escape route) the handle height should be between 96 and 116 mm.

2.5 Single and composite relationships between modes of isometric force exertion in young and elderly adults

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(Submitted to Applied Ergonomics December 1999)

Summary

This study is part of a large project on design-relevant characteristics of ageing users. A total of 750 young and elderly, male and female subjects were tested. Differences between the sexes were mapped as well as changes in force with age. The relationships between five different isometric forces (left and right gripping, twisting, pushing and pulling) were investigated. The possibilities of extending information on these forces to other forces and other subject groups were also studied. The results indicate that the different types of force are closely related. A strength score was devised. We conclude that calculation of unmeasured forces by means of a general strength score could be possible. Furthermore, we found that the percentage decrease in strength with age is similar for men and women.

Introduction

In general it is assumed that people can be separated into distinct levels of performance on the basis of whole body strength. This implies an equal level of strength throughout the body, regardless of the type of force. However, research on relationships between different types of isometric force exertion has yielded highly divergent results. Åstrand (1968) as well as Hettinger (1968) presented a graph that shows the percentage decrease in total body strength. However, neither of them specified either the original forces or the composition of the results. Asmussen and Heebøll-Nielsen (1962) derived a strength score from the strength of 25 different muscle groups. Era et al. (1992) defined a strength score, representing total body strength based on elbow flexion, trunk flexion and knee flexion, but other studies reported less pronounced or even contradictory results concerning uniformity in strength. Daams (1994) concluded on the basis of her literature survey that "Correlations between different maximal forces vary enormously." (page 44), while Laubach (1978) goes even further in his conclusion "... that there is no single quantitative function that can be called general static strength." (page VII-2).

Knowledge about the relationships between modes of force could be used to define a reliable strength score that stands for total body force. With the help of such a score it would become possible to derive new information on types of forces which are difficult to measure. The results of the measurement of such a force in a statistically insufficient number of subjects can be enhanced with the help of a strength score.

When a designer of products designs for a specific age group, information about that group is required. There are graphs and tables available that show the decline of strength with increasing age (Asmussen and Heebøll-Nielsen

1962, Rohmert and Hettinger 1963, Hettinger 1968, Åstrand 1968, Metter et al. 1997). With the information from these graphs and tables, it is theoretically possible to calculate the force in a certain age group using force information on another age group. This method of approach is often applied by product designers to obtain values for forces of certain age groups that cannot be found in literature. Since it is mainly information on forces exerted by the elderly that is lacking, these values are often calculated for this age group instead of measured. However, because the designers in question do not perform research, justification of the extrapolation procedures thus applied, both with respect to modes of force as well as transgenerational differences, is poor.

This study aims to provide more insight into the possibilities and limitations of the procedure of extrapolation and calculation of human strength for transgenerational design.

Method and materials

This study was part of an extensive project which aimed at establishing several design-relevant characteristics of ageing users. A total of 79 variables was measured in this transversal research project. The measurement of these variables was performed in two sessions lasting about two hours each. All forces were measured in one session, together with the other physical variables, such as reaching envelopes, step length and walking velocity (Steenbekkers and Van Beijsterveldt, 1998). Because of statistical considerations, the subjects in that study were divided into eight age groups. In the current study the same division into age groups is used (see table 2.5.1).

Subjects

A total of 750 subjects took part in the experiments. All lived independently and none suffered at that moment from serious diseases. Table 2.5.1 shows the number of subjects, mean stature and mean body mass for each age group according to sex.

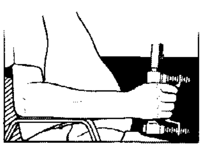
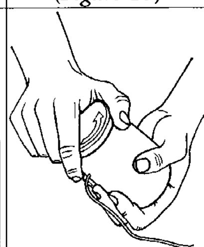
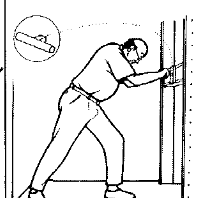
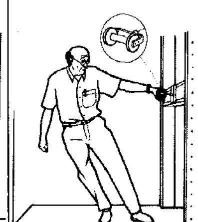
Table 2.5.1 Subject information.

	number		stature [cm]		body mass [kg]	
Age group	men n	women n	men $\bar{x}$ (s)	women $\bar{x}$ (s)	men $\bar{x}$ (s)	women $\bar{x}$ (s)
20-30	55	68	184.8 (8.0)	168.6 (6.6)	80.8 (14.3)	66.7 (9.6)
50-54	35	35	177.8 (8.1)	165.4 (5.5)	82.5 (11.7)	70.4 (12.4)
55-59	46	50	176.7 (7.5)	165.3 (6.3)	82.1 (12.8)	70.7 (11.2)
60-64	44	53	176.1 (5.7)	163.9 (5.9)	80.2 (8.9)	71.4 (11.6)
65-69	50	51	173.7 (6.9)	161.1 (4.9)	77.6 (9.0)	68.9 (8.6)
70-74	59	62	172.5 (7.0)	161.9 (5.7)	78.3 (10.1)	71.4 (12.0)
75-79	36	38	170.8 (6.0)	158.6 (7.0)	79.3 (9.5)	70.5 (9.7)
80+	33	35	170.7 (6.4)	155.3 (5.9)	76.8 (10.2)	63.9 (10.2)

Modes of force

All forces were built up to maximum gradually and then maintained for three seconds. The subjects were encouraged during measurement. The forces measured and information on the measuring conditions can be found in table 2.5.2.

Table 2.5.2 Method and materials.

Force mode	Gripping	Twisting	Pushing	Pulling
Specification	left and right hand	two hands	two hands	one hand
Position	Sitting, arm on arm rest (*Figure 1a*)	Standing, free position (*Figure 1b*)	Standing, free position (*Figure 1c*)	Standing, free position (*Figure 1d*)
	 figure 1 a	 figure 1 b	 figure 1 c	 figure 1 d
Equipment	Jamar Hand Dynamometer Model 1 (Asimov Engineering Comp., USA)	Jam jar shaped strain gauge transducer	T-shaped handle connected to a strain gauge transducer	H-shaped handle connected to a strain gauge transducer

Results

Results of all forces for males and females are presented in figure 2.5.2a-e. The mean forces are shown per age group and are marked with a dot. The lines shown were fitted to the mean results for the different age groups (Levenberg-Marquardt, asymmetric transition function).

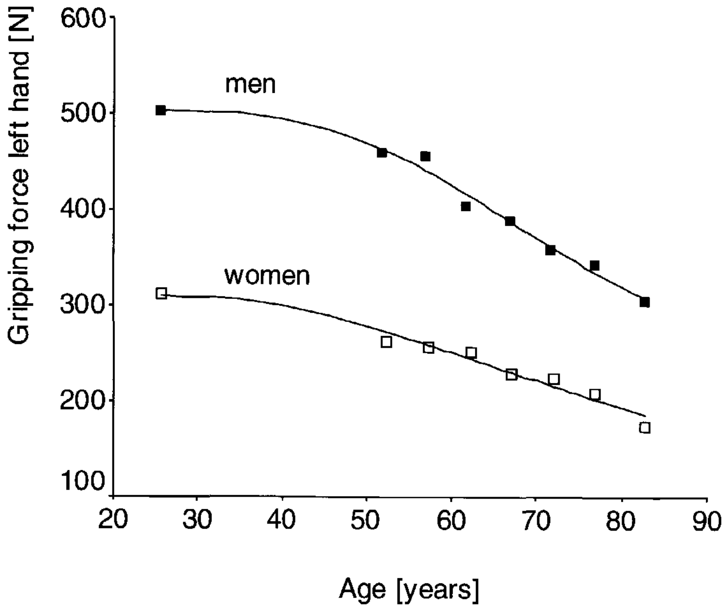


Figure 2.5.2a Gripping force left hand.

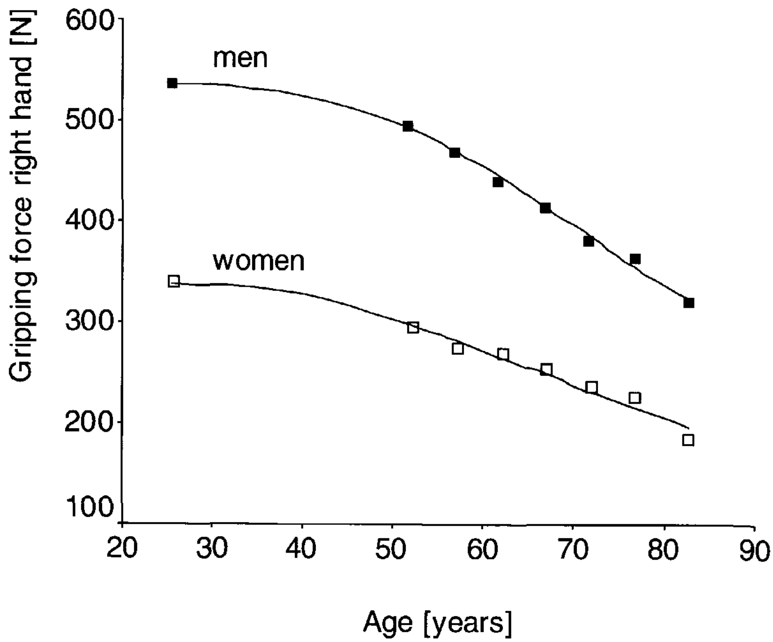


Figure 2.5.2b Gripping force right hand.

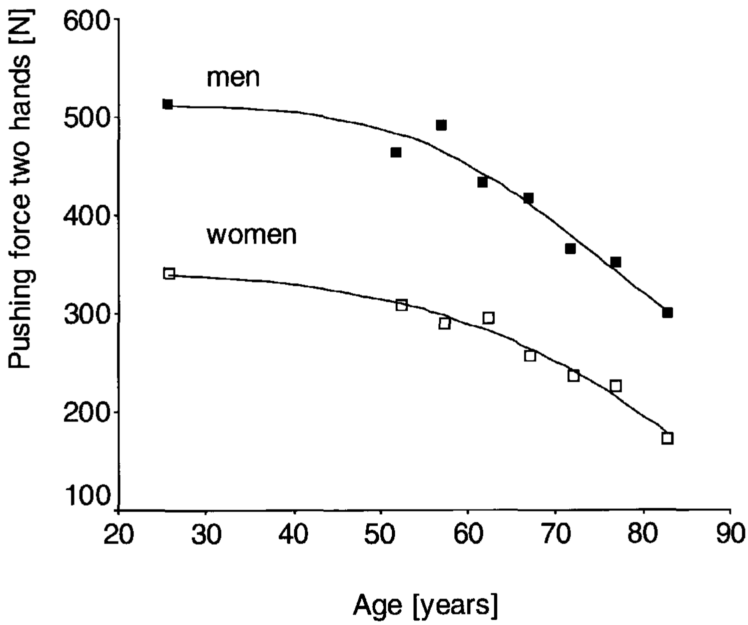


Figure 2.5.2c Pushing force with two hands.

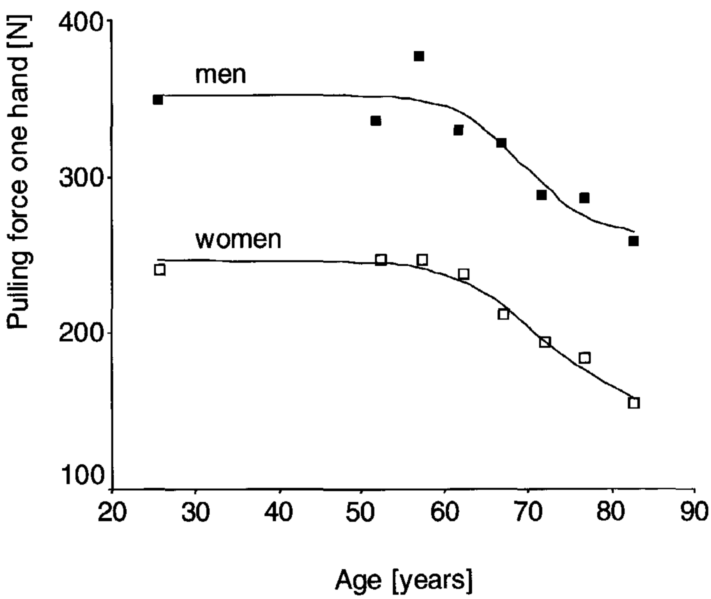


Figure 2.5.2d Pulling force with one hand.

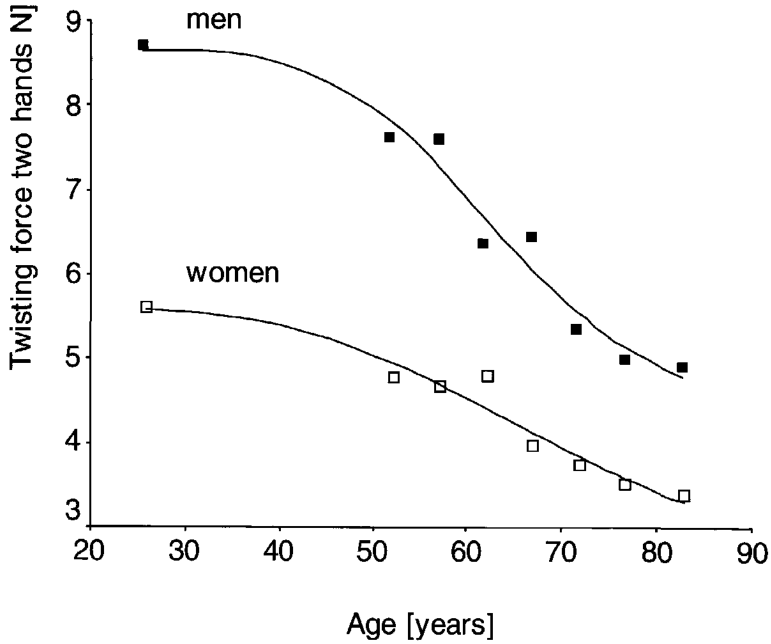


Figure 2.5.2e Twisting force with two hands.

Figure 2.5.2a-e Mean force for men and women per age group.

The partial correlation coefficients for all forces measured are presented in table 2.5.3. The coefficients were corrected for age. The lowest correlation coefficient was 0.60 and the highest 0.90. All correlation coefficients are significant (P=0.000).

Table 2.5.3 Partial correlation coefficients, correcting for age.

	gripping left	gripping right	twisting	pushing	pulling
gripping left	1.00	o	o	o	o
gripping right	0.90	1.00	o	o	o
twisting	0.68	0.68	1.00	o	o
pushing	0.70	0.72	0.63	1.00	o
pulling	0.67	0.68	0.60	0.82	1.00

The bivariate correlation coefficients for all ages are presented in table 2.5.4. These correlation coefficients were not corrected for age. The correlation coefficient ranged from 0.64 to 0.92. All correlation coefficients are significant (P=0.000).

The values from the bivariate correlation matrix are only slightly higher than the partial correlation coefficients, the maximum difference is 0.06.

Table 2.5.4 Bivariate correlation coefficients.

	gripping left	gripping right	twisting	pushing	pulling
gripping left	1.00	o	o	o	o
gripping right	0.92	1.00	o	o	o
twisting	0.73	0.74	1.00	o	o
pushing	0.75	0.76	0.69	1.00	o
pulling	0.70	0.70	0.64	0.83	1.00

Factor analysis (Principal Components) was performed on the basis of the bivariate correlation coefficient-matrix. This resulted in one factor that explained 79.7 percent of the total variance. Factor loadings ranged from 0.85 to 0.93, so they were rather similar.

Because of the similarity in factor loadings we decided to work with z-scores which do not include loadings. Standardized z-scores are dimensionless variables which are independent of the scale.

Z-scores were calculated for all ages together on the basis of the median for each force. Per subject the sum of the z-scores per force was used as the z-score for strength.

Because a factor thus computed will always have a mean of 0 and a standard deviation of 1, the means per age group can be negative. In order to avoid a negative score, the quotient of the mean and the standard deviation of each force was added to the sum of the z-scores.

The means and standard deviation of the total scores per age group per sex are presented in table 2.5.5.

Table 2.5.5 Standardized strength scores based on 5 modes of force.

	Men			Women		
Age	n	$\bar{x}$	s	n	$\bar{x}$	s
20-30	55	20.50	3.10	68	13.31	2.32
50-54	34	18.79	3.18	35	12.11	2.11
55-59	47	19.23	3.25	50	11.60	2.08
60-64	44	17.01	2.65	53	11.49	2.52
65-69	50	16.47	2.78	51	10.27	1.84
70-74	58	14.69	2.72	62	9.54	2.08
75-79	37	14.23	2.95	38	9.04	1.86
80+	33	12.67	2.42	35	7.62	1.52

If the mean strength score for 20-30 year-old male subjects is considered to be 100% and the strength scores for the other age groups and for women are expressed as a percentage of this strength, a graph similar to that presented by, for instance, Hettinger (1968) and Åstrand (1968) can be drawn. In figure 2.5.3 a line is fitted to the mean values per age group expressed as a percentage of the mean for the 20-30 year-old males.

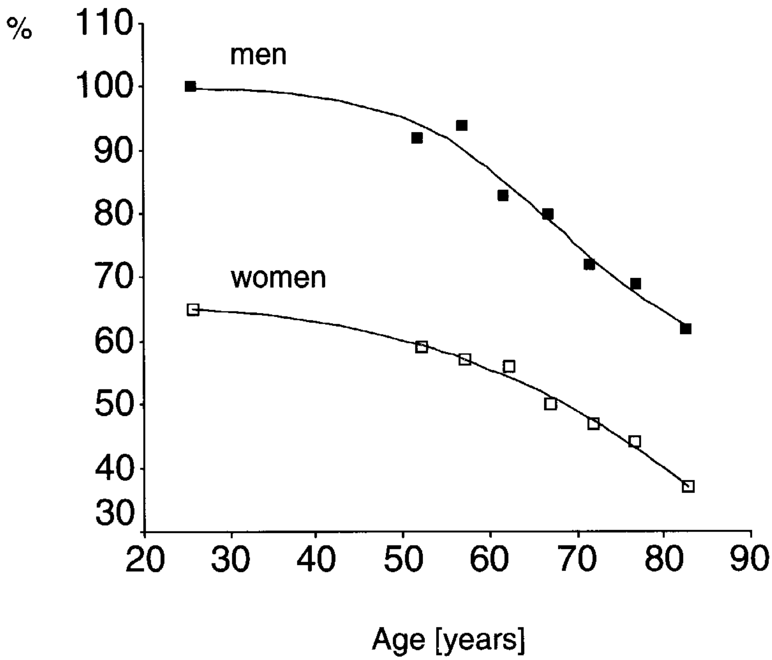


Figure 2.5.3 Percentage decrease of strength compared to the 20-30-year-old males.

In table 2.5.6 the percentage decrease in force with age is presented for men and women separately. Again the results for the youngest age groups were considered to be 100%.

Table 2.5.6 Percentage decrease in strength.

age group	men	women
20-30	100%	100%
50-54	92%	91%
55-59	94%	87%
60-64	83%	86%
65-69	80%	77%
70-74	72%	72%
75-79	69%	68%
80+	62%	57%

Discussion

On the basis of a literature study (Daams, 1994) it was assumed that the optimum physique is reached between the ages of 20 and 30 years. Asmussen et al. (1962) found that the optimum value for hand and arm force occurred at about 22 years of age, the optimum trunk and leg forces near 30 years of age. We used the youngest subjects as a reference group in order to establish the total decrease in strength among the elderly. A significant decrease in human capacities was not expected to occur before 50 years of age. Therefore the age group of 30-50 years was not included in the sample.

Of course, this might affect some of the results. However, because the differences between the bivariate and the partial correlation coefficients were smaller than 0.06, it was concluded that the factor analysis could be based on the bivariate correlation matrix. The effect of the age gap on the standardized z-scores cannot be determined precisely, but it is not expected to be substantial.

The curves in figures 2.5.2 and 2.5.3 were fitted to the results by assuming a gradual decrease in strength, stabilization at an imaginary high age and optimum forces between 20 and 30 years of age. The curve is obtained by means of an asymmetric transition function. In the current study we used a non-linear equation and the procedure of Levenberg-Marquardt for logistic-dose-response curves with the equation $y=a+b/(1+(x/c)^d)$. In this equation 'a' is the transition height, 'b' is the transition centre, and 'c' and 'd' are shape controllers.

Because this equation contains four parameters while there are only eight points per graph, just four degrees of freedom remain. This means that the shape of the graphs is highly dependent on the eight means. Points which more or less diverge from the pattern of the other points alter the curvature of the graph markedly. This explains why the curves for male pulling force and twisting force level out at 83 years. Because the number of subjects in the male age groups only varies from 33 to 59 (for females from 35 to 68), adding weight factors such as '$\sqrt{n}$' would not provide a solution. Although we assume that the curves should not level out at 83 years we do not have instruments to change them correctly.

Since information on the age group between 30 and 50 years is absent, the course of the curve could not be checked for a satisfactory explanation of the variance in this section.

If we compare the results shown in figure 2.5.3 with those of Metter et al. (1997) the similarity between the results for the same age groups is remarkable. However, for males aged 30-50 years our simulated curvature differs from their measured curvature since they found maximum strength at 35 years of age. For all other age groups the results seem to be equal. Moreover, this was the only study we could find that included age groups above 60 years. The fact that the study of Metter et al. (1997) is a longitudinal study apparently does not lead to different results.

Compared to Åstrand (1968) the course and height of the graphs (figure 2.5.3) are fairly similar for subjects from 20 to 60 years. There is only a small difference in the percentage at 60 years, since Åstrand places the percentage near 83%, while we found 88% for that age. The graphs of Asmussen and Heebøll-Nielsen (1962) and Hettinger (1968) both show a gradual decrease in strength, but the course in Asmussen and Heebøll-Nielsen and the height in Hettinger at different ages are not comparable with our findings. It is difficult to explain the differences, since we do not have enough information on the nature of the forces they used for their graphs. The answer may even be the fact that there is a considerable time span of 30 to 35 years between our study and their three studies.

In our study we found high correlation coefficients for the different types of force (see table 2.5.3 and 2.5.4). Moreover, we found a strength score that represents the different forces and explains 79.7% of the total variance (see table 2.5.5). This percentage is in accordance with the results of Era et al. (1992) and Daams (1994). The latter found that 99% of the correlations between the 29 different maximal forces she studied were significant, while 60% outreached 0.71. Among the forces she measured were pushing, pulling, twisting and gripping force. Mital (1986), however, found very low correlations coefficients between twisting and arm strength.

We focussed on forces relevant to the interface between hand and product. Therefore, the forces measured were all dependent on the hand as force contact area. The relationships found in this study may have been influenced by this, since in all cases the muscles of the hand and arm were involved in the force. However, pushing and pulling requires effort of the whole body, not only the upper extremities. Therefore, we expect that the strength score will also be predictive for the strength of the lower extremities and the trunk. Studies in this field are rare. In their study Metter et al. (1997) assume that the combination of eight forces exerted by the arm and two gripping forces will be representative of total body strength. In their study, Verbrugge et al. (1998) conclude that for the elderly it is not necessary to separate the forces of the upper and lower body, because there is no significant difference between the characteristics of the forces of these body segments.

According to Daams' (1994) literature review, the fact that the mean forces found for men were all higher than the mean forces found for women is in agreement with other studies. The similarity in the percentage decrease in strength between the ages of 50 and 90 years in men and women is in agreement with the results presented by Rohmert and Hettinger (1963), but not with those of either Asmussen and Heebøll-Nielsen (1962) or VanCott and Kinkade (1972). They contend that the strength of women declines more rapidly with age than that of males. We found no explanation for these different findings.

As far as the handling of products is concerned, the strength score in this study has, in our opinion, two applications. Firstly, it can be used to extrapolate data about the elderly from data on the maximal strength of young age groups.

Secondly, on the basis of the results of factor analysis and the uni-dimensional force profile, this strength score might possibly be used to obtain information on other types of maximum force by means of calculation.

Conclusions

The conclusiuons of the present study are the following:

- Men are stronger than women
- Between 50 and 90 years of age, the percentage decrease in strength is about the same for men and women
- Extrapolation of strength for age is possible
- Extrapolation of strength for modes of force seems to be possible

3 The Stadyn project

3.1 Introduction

This chapter contains information on the second project in this study. It is called the *Stadyn project* (referring to the comparison of static and dynamic force). The main goal of this project was to establish the existence of any relationship between the results of isometric and isoinertial force exertion.

The fact that the same muscles are somehow involved in both types of force exertion indicates that a relationship should exist, but the complexity of the physiology of muscles has so far excluded a precise description.

There are all kinds of chemical, biomechanical and sensory influences, which permanently and simultaneously exist. As well as these direct processes, indirect processes such as mental and cognitive status also influence the rest, action and capacity of muscles (confer with sections 1.2 and 1.5).

Because these effects are cumulative, although in a complex interaction, we decided to study the gross effects of isometric and isoinertial force exertion empirically.

Because of the lack of literature on this subject, we were not able to make adequate specific hypotheses. Therefore this study was mainly explorative. Apart from three general hypotheses (see below), we did not know what to expect.

With the expectation of general tendencies the hypotheses are:

1. There is a positive relation between isometric force and isoinertial force.
   Background: Isometrically strong persons are expected to be also dynamically strong.

2. Men are stronger than women.
   Background: Males are, if only because of muscle mass, isometrically stronger than females in almost all force exertions; it is therefore expected that they are also isoinertially stronger.

3. The young are stronger than the old.
   Background: After the time of optimal physique (between 20 and 30 years of age), the ability to exert force decreases with increasing age.

The main reason for conducting this study lies with its relevance for the design of products for daily use. As isoinertial force exertion occurs more often in daily activities than isometric force exertion, research into the former has the potential to provide significant information for product designers. However, because the value of isometric force information for this field has been established, we concentrated our research on a study of the relationship between the two force types.

3.2 Selection of the movement

3.2.1 Introduction

In the aim of the study (section 1.6.2) two restrictions for the selection of variables were laid down. These were that all variables must be relevant to product design and related to isometric or isoinertial force. The variables generated in the Stadyn project had to meet these restrictions. This was done by selecting a movement that concurred with the two restrictions. Consequently, the variables describing this movement meet with the restrictions

To meet the first restriction the movement had to be relevant to product design. The use of products often involves action from the hand and arm. The term 'handling products' refers to this. Thus, the movement had preferably to involve the hand and/or the arm. In section 1.6.2 the choice of elbow flexion was already mentioned. This choice was made for several reasons, which were also mentioned by Wilkie (1950). The fact that this movement is approximately uni-axial is one of the reasons.

To meet the second restriction a sample of subjects would have to exert force, both isometrically and isoinertially, and a way of measuring and analysing has to be designed accordingly.

3.2.2 Skeleton movements

Anatomically the elbow joint (articulatio cubiti) is one single joint, which is an attachment of the humerus, ulna and radius. The joint is surrounded by the capsular ligament, which is laterally and medially strengthened by the radial and ulnar collateral ligaments (see figure 3.2.1). However, from a functional perspective it is considered as two separate units. These units are, respectively, the joint which provides the pronation-supination movement (rotating the forearm) and that which provides the flexion-extension movement. This thesis conentrates on the flexion-extension movement.

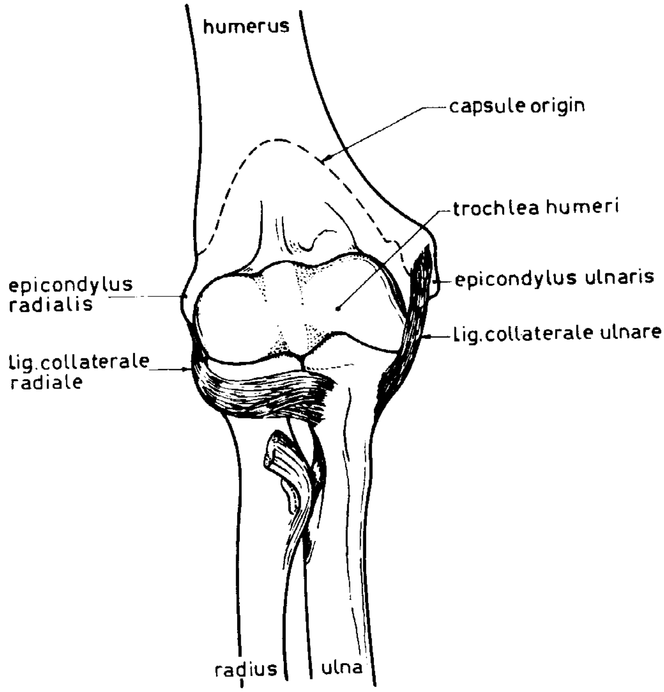


Figure 3.2.1 Anterior view of the elbow joint. The ligaments keep the joint together when it is moved in flexion-extension or pronation-supination. The axis of the flexion-extension movement runs through the epicondyli. (Adapted from Rozendal et al. 1994).

The flexion-extension movement occurs in two joints simultaneously; the joint between the humerus and the radius (a spherical joint) and the joint between the humerus and the ulna (a hinged joint).

The axis of the movement of the elbow in flexion and extension runs through the epicondyli (see figures 3.2.1 and 3.2.2). There are several studies on the movement of this axis during rotation (Youm et al., 1979; London, 1981; Slote and Stone, 1963; An et al., 1983; Chao and Morrey, 1978; Morrey et al., 1976). There are some discrepancies between the conclusions that can be drawn from these articles, but it is possible to come to an overall conclusion. Apart from the extreme angles of flexion and extension (the outer 10° in both directions), flexion and extension of the elbow occur about a single axis and are of a sliding type. This means that the heads of the ulna and radius, which are concave, slide along the head of the humerus, which is convex.

In flexion the movement of the elbow is limited mostly by the apposition of the soft parts. In active flexion the angle between upper and forearm can be reduced to 35°. When forced into flexion this angle can be decreased further to 20°. In this situation the rim of the radial head and the tip of the ulnar coronoid process enter the radial and coronoid humeral fossae respectively (figure 3.2.2).

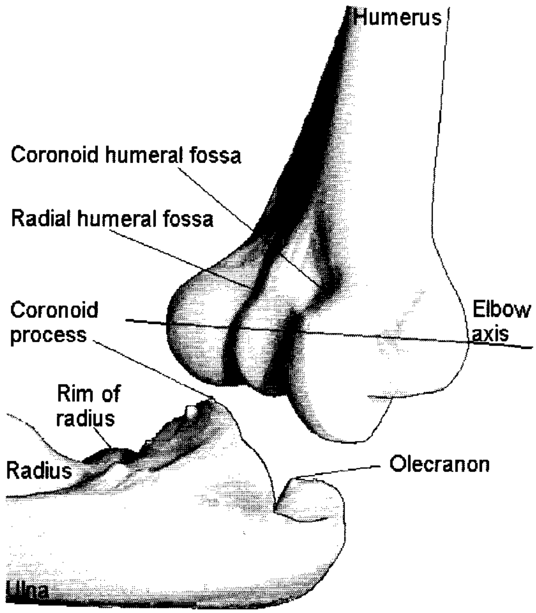


Figure 3.2.2 The shape of the contact surfaces of humerus and radius. The flexion movement of the forearm is limited because the coronoid process of the ulna and the rim of the radius will slide in, respectively, the coronoid and the radial humeral fossa. The extension movement is limited by the collision of the olecranon with the olecranon fossa at the back of the humerus.

The degree of extension is limited to 180° between upper arm and forearm due to the entrance of the tip of the olecranon into the olecran fossa, the resistance in the flexing muscles and the tension in the capsule and muscles anterior to the joint. In full extension the olecranon is not in contact with the trochlea, and neither is the corresponding lateral strip in full flexion.

It should be noted that the anatomy and anthropometry of the individual influences the angles that can be reached in both directions. According to the American Academy of Orthopaedic Surgeons (Greene and Heckman, 1994), the activities of daily living are accomplished in an arc of elbow flexion from 50° between upper and forearm to 150°.

3.2.3 *Muscles involved in elbow flexion and extension*

Flexion and extension of the elbow joint are made possible by the action of certain muscles. All the muscles in front of the elbow axis (see figure 3.2.3) are needed for flexion and those behind the axis for extension. Some of the muscles are active in the movement of other joints as well. They are pluri-articular, and their name is not suited to their function in the movement of the elbow. However, this is not as important as the fact that their pluri-articularity causes them to be influenced in their action by the position of the other joints (Platzer, 1986; Rozendal et al., 1994; Kapandji, 1999; Williams et al., 1989).

The activity and effectiveness of the muscles involved in flexion and extension differ per muscle. It is easy to look up these muscles in the literature; some sources even mention an order of importance in muscles that are active in a movement. However, other literature sources have reservations about such a simple classification and add nuances. In 'Gray's Anatomy' (Williams et al., 1989) it mentions increased activity of the m. brachio radialis with increasing speed. The same source also mentions that the m. pronator teres and the m. flexor carpi radialis may act in the case of resistance.

Nakazawa et al. (1993) studied the activity of two muscles (the m. biceps brachii and the m. brachio radialis) during isometric contractions at different elbow angles. They concluded that the mean power frequency (MPF) that represents the activity of these muscles depends on the angle of flexion. In full extension, for instance, the MPF of the m. biceps brachii (b.b.) is higher than the MPF of the m. brachio radialis (b.r.) as MPF b.r./ MPF b.b. =0.40, but in a 90 degree angle the intensity of activity is turned to MPF b.r./ MPF b.b. = 1.2. The latter is biomechanically explicable, as the moment arm in the brachio radialis increases with the decrease of the angle between upper and forearm. On the basis of their findings, listing the muscles involved in elbow flexion and, mutatis mutandis, in extension should be done with reference to the elbow angle.

However, there are more muscles involved in elbow flexion and according to Platzer (1986) neither of the muscles studied by Nakazawa et al. (1993) are involved in elbow extension. Therefore, in figure 3.2.3 and 3.2.4 the muscles involved in elbow flexion and extension respectively are presented as indicated by Platzer.

Listed below, in order of importance according to Platzer (1986), are the muscles that take part in flexion of the elbow (figure 3.2.3). The m. flexor carpi radialis, m. extensor carpi radialis and m. palmaris longus play a minor role in flexion of the elbow.

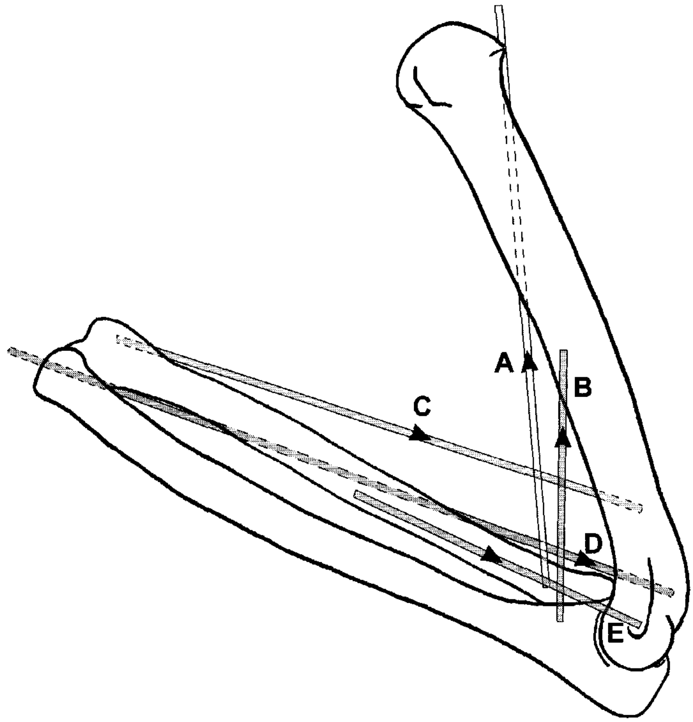


Figure 3.2.3 The muscles that are active in elbow flexion, in medial view of the elbow (adapted from Platzer, 1986)

A m. biceps brachii
B m. brachialis
C m. brachio radialis
D m. extensor carpi radialis longus
E m. pronator teres

In extension of the elbow only the m. triceps brachii (mostly carput laterale and mediale) plays a significant role (see figure 3.2.4). The influence of the m. anconeus is minimal. In rapid extension m. brachio radialis acts as a shunt muscle (Williams et al., 1989).

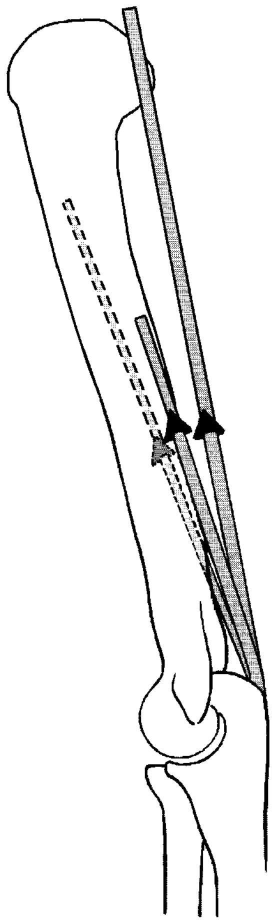


Figure 3.2.4 Position of m. triceps brachii in medial view of the elbow joint. (adapted from Platzer 1986)

There are several muscles that cross the elbow but not all of them are involved in moving it. An et al. (1981) studied 24 muscles that cross the elbow joint. For each of these muscles the flexion-extension moment arm and their volume, fibre length and physiological cross-sectional area were described. Their conclusion on the muscles that have the largest moment arm in elbow flexion confers with the findings of Platzer (1986). In elbow extension, however, they also mention the influence of m. flexor carpi ulnaris and anconeus, which Platzer indicates to be of insignificant influence.

3.2.4 Repetitive movements

In repetitive movements there are two main factors which influence force exertion. The first is training of the muscles involved and the second is an increase in suppleness of the joints and tendons.

Regarding the training of the muscles, it should be noted that this is mostly based on repetitive movements. When muscles are used repeatedly under the same conditions and using the same movements, the capability of the muscles to perform improves in different ways. The effect of training has an upper limit and the effort to gain an effect from training has a threshold, e.g. in frequency and loading. Both the upper limit and the threshold are specific characteristics of a muscle.

However, opposing this effect is the fact that extreme acidification of the muscle counteracts the improvement gained in muscle function. Training of muscles needs to be in balance with the condition of the muscles.

Increased suppleness of joints is also a result of training. The threshold for the occurance of this specific effect is lower than for the increase of muscle force, but the threshold to make the effect persistent is higher. Suppleness can be improved through repetitive stretching but only to a certain extent.

Because of the complexity of the relationship between the different muscle characteristics, we cannot predict whether a flexion movement that is followed by an extension movement differs from a movement that is only flexion. We therefore decided to measure flexion, both in a series of movements that were only flexion and in a series of movements of flexion followed by extension.

In isometric force studies it is recognised that, in most cases, the first attempt produces a lower result than subsequent attempts. No information is available on repetitive movements and isoinertial force. It seems likely that the force curves change with the increase of repetitions.

In the Gerontechnology project we found that in isometric measurements it was most often the second measurement which gave the highest result. The third measurement did not add information (confer with 2.2). These were separate measurements with a pause in between.

We therefore decided to study the effect of repetitive isoinertial force exertion in one series of measurement. We were interested in whether some sort of pattern would occur in the force exertion during repetitions. We chose to have the subject flex and extend the elbow five times in a row. We wanted to study the effect of repetition, but with a minimal risk of training.

3.2.5 Angles of study

De Koning (1984) found that during elbow flexion maximal power was generated when the elbow was at an angle of 70 degrees between upper and forearm, with the upper arm held vertically. The movement was started at an elbow angle of 120 degrees. No extra weight was applied.

Although power is a different quantity from isoinertial force exertion, both have an intrinsic relation with force and movement. In order to have the opportunity to compare the results on power generation from De Koning (1984) with both the isometric and isoinertial results, we specifically studied the

70 degree angle and whether the optimum for both force types is also at or near 70 degrees.

For the isometric measurements this means that maximal force exertion will be measured at the 70 degree elbow angle, and also at some other angles for purposes of comparison. For the isoinertial measurements the angle needs to be passed in full motion. This means on the one hand that the distance between the starting angle and the 70 degree angle has to be wide enough to reach maximal speed, but on the other hand that the starting angle must not be at the border of the motion range of the elbow joint, which is 180 degrees. The latter would be biomechanically adverse because there is lack of moment arm. In this extreme position, when an extra load is applied, the tension in the muscle is very great and there is a risk of arm injuries.

The starting angle for the movement, therefore, has to be smaller than 180 degrees and large enough to pass the 70 degree angle in full motion. A starting angle of 140 degrees was chosen. In isometric force exertion speed and acceleration are left out, but in isoinertial force exertion acceleration and speed are the main components. Because at the start of a movement speed is zero, it can be expected that at that point isoinertial force is most similar to isometric force. This is not yet confirmed. Therefore, this point is of special interest for the comparison of the two force types. Hence, the isometric build-up will be determined at an elbow angle of 140 degrees.

The smallest angle that can be reached in a fully flexed position does not depend on the suppleness of the joint and its ligaments, but on the thickness of the upper and forearm. Because of variation in the shape of human arms, the smallest angle varies individually and depends on the force used in the collision of the two parts of the arm against each other. This means that it is more complicated to compare the results of different subjects at this point in the movement. However, breaking off the movement at a wider angle will make the movement less natural. Also, any difficulties with the inter-individual differences in the angle of return in the analysis of these isoinertial results are judged to be minor. Although, in the repeated as well as in the single upward movement, the fully flexed position is characteristic, for the isometric measurement the smallest angle studied is a 35 degree position. For most people this angle approaches maximal flexion (Greene and Heckman, 1994). Force exertion in actual maximal flexion is too difficult for the subjects.

Therefore, in the isoinertial measurements the movement was started at an angle of 140 degrees between upper and forearm and, depending on the test performed, returned or stopped at the smallest possible angle between upper and forearm (designated zero). Figure 3.2.5. shows these angles.

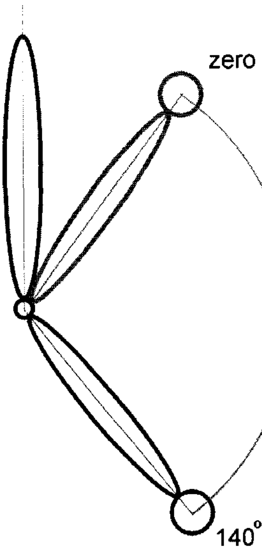


Figure 3.2.5 Trajectory of the movement in the isoinertial measurements. The elbow will be flexed between 140° and zero (i.e. the smallest possible angle), while the upper arm is kept vertical.

For the isometric measurements the remaining point chosen to fill in the gap between 140, 70 and 35 degrees was 105 degrees. In these positions isometric force in flexion and the flexion-extension movement was studied. The angles studied are shown in figure 3.2.6.

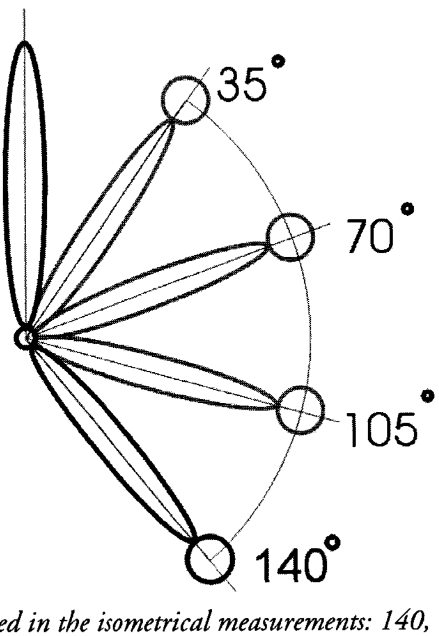


Figure 3.2.6 The four angles studied in the isometrical measurements: 140, 105, 70 and 35°.

3.2.6 *Backgrounds for the selection of the applied weight*

As mentioned in section 1.5 and 3.2.5, measuring maximal isoinertial force is difficult because a satisfactory balance between, on the one hand, the imposed trajectory and the extra weight and, on the other hand, the condition and fibre distribution of the muscles is essential. The condition of the muscles and their fibre distribution can not be determined in this study as this requires invasive methods. To arrive at an optimal isoinertial condition, the weight and trajectory must be optimal. In section 3.2.5 the trajectory was set at a rotation between zero and 140 degrees (see figure 3.2.5). In this section the selection of the applied weight and the background for this selection are described.

In isoinertial force measurements the extra, hand-held weight load must correspond with the strength of the subject. In dynamic force investigations 1RM is often used as an indication of the maximal force that can be exerted (Murphy et al., 1994, Weir et al., 1994). 1RM stands for one-repetition maximum: the mass that can be moved only once. In these investigations the applied load is described as a percentage of 1RM. Using such an index makes the degree of loading similar. This index for force capacity works well for isokinetic measuring, and for predetermined path movements. Under these conditions the subject can stop at every point on the path. In our isoinertial force measuring the extra weight was not routed, and stopping at any point would mean that the subject exerted braking force. When the weight is too great it can cause serious damage to tendons or muscle tissue. Not stopping but letting go of the weight is also very dangerous. In the setting chosen, establishing 1RM would have put the subject at risk and was therefore unacceptable. Although it seems ideal to set a standard on the weight to be used in isoinertial measurements, for safety reasons the decision on the weight applied was based on a different principle.

It was considered best to set an index based on results from measurements other than isoinertial. Isokinetic or isometric measurements were both possibilities. Because of the intrinsic variability, isotonic measurements do not produce reliable results when measured on live human beings, as was explained in section 1.3.3.

Translating isokinetic measurements into isoinertial measurements is difficult, as the results differ in the relation between force and speed. The acceleration phase in a movement is disregarded in isokinetic measurements as the speed must be steady, while the isoinertial measurements are based on processes in this phase.

Although the results of isometric measurements are more easily translated into isoinertial data, there was an objection to doing this. As the aim of the Stadyn project was to investigate the relation between isometric and isoinertial force exertion, it was considered incorrect to use isometric measurements to determine a suitable extra weight for the isoinertial measurements, as it would risk creating an artificial relationship. We found an answer to this objection as follows.

There are two ways of measuring isometric forces (refer to section 1.3.1). Most isometric force measurements are based on 'build-up' force exertions, where the subject holds maximal force for a few seconds. The time during which the force needs to be exerted varies among researchers. This measuring method is fairly reproducible. Because of its commonality and its known reproducibility this method was used in the Stadyn project, to establish isometric force in different angles.

The second, and much less common, possibility is to measure isometric force exerted in a peak. Measuring force in a peak concurs better with isoinertial force measuring than the build-up method. The force capacity needed to get the load moving is a critical aspect of isoinertial force exertion. In a split second all force has to be focussed and collected to accelerate the load. In the same posture this starting power is comparable to the maximal isometric peak force. In the exertion of isometric peak force the muscles show a high contraction speed, which is absent in build-up force exertion. The fact that this dynamic contraction force is instantaneous agrees also with isoinertial force exertion, where the initial force decreases rapidly when the mass has started to move.

How 1RM isoinertial force and maximal isometric peak force are related is not known. Berg et al. (1988) found maximal isometric peak force to be higher than maximal build-up force (hold for 5.5 sec.). Nevertheless, we decided to use the maximal isometric peak force to create a scale for the selection of the extra weight used in isoinertial force measuring. It provided us with an opportunity to compare people on an equal base, comparable to the use of 1RM as basic index.

The result of these considerations was that, for the selection of the extra weight, the isometric peak force in an elbow angle of 140 degrees was used. For the actual comparison of static and dynamic force the build-up isometric force was used.

Hill (1938) did research on the force-velocity curve of isolated muscles. He found that maximal power (force x velocity) is attained when velocity is about one-third of its maximum. Binkhorst et al. (1977) researched the same matter and concluded that at this point force is also one-third of its maximum. This is shown in figure 3.2.7.

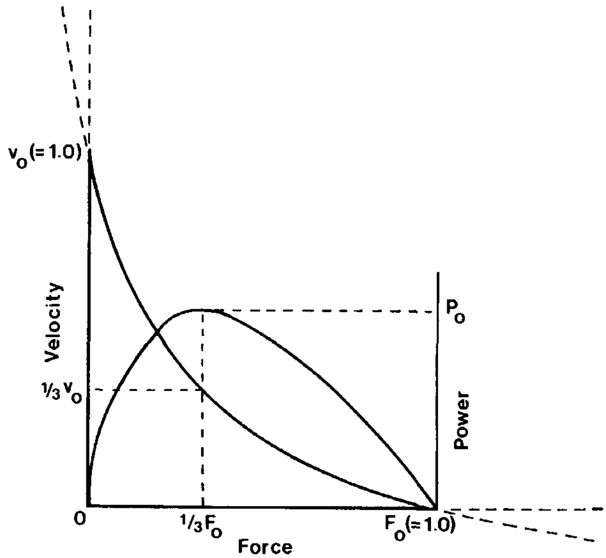


Figure 3.2.7 The force-velocity curve represented as part of a rectangular hyperbola, where maximal power is attained when force and velocity reach about 1/3 of their maximum. (After Binkhorst et al. 1977)

This relationship was also only established for isolated muscles. However, research on maximal power (force x velocity) in flexion of the elbow joint has revealed that in this movement the same relationship exists (De Koning, 1984). Hence, optimum power was found at one-third of the maximum force. Although isoinertial force is based on the acceleration gained and not on power, there is some relation between the two quantities. Because the trajectory chosen was rather short, maximal acceleration (i.e. maximal force) would be needed to arrive at maximal speed. It was therefore decided that subjects would be offered a weight that was about one-third of their maximal isometric peak force.

Using one-third of the maximal peak force as the weight in the isoinertial force measurements raises practical problems. Because maximal peak force will almost always vary per subject, making an individual weight per subject necessary, supplying such a large number of different weights would be impossible. It was therefore decided that the subjects should be divided into groups according to the required weight.

Placing the subjects in categories was not an ideal solution. Some subjects might have a peak force lower than three times the weight, while others might have a higher peak force. Apart from the fact that these subjects would have a small difference in relative loading, working with a suboptimal weight could endanger the generation of maximal isoinertial force. Subjects might be unable to apply all the acceleration they could generate and would not exert maximal isoinertial force exertion. This would depend not only on the accuracy of the amount of extra weight but also on trajectory, motivation etc. As one-third of the 1RM was the mean in the research of De Koning (1984),we used it only as a guideline in the decision on the weight.

Because the risk of unintentionally fragment the results by using categories of different weights was apparent, it was decided to also add a mass of 1kg to every subject. If necessary, we could use the results to compare the effects of a relative loading with an absolute loading.

From the current section the conclusion can be drawn that maximal isoinertial force exertion was established with two weights: one of one kilogram and one that represents one-third of the maximal isometric peak force.

3.2.7 Resting time

In the literature on isometric forces length of the interval between two tests varies. Caldwell et al (1974) and Kroemer (1970) both advise a three minute interval between two measurements. More recent literature on rest intervals between measurements shows different results when the time between measurements is cut back to a very short interval of ten or more seconds (Morrissey et al., 1995; Weir et al., 1994). The overall conclusion that we came to was that the resting time needed depends on the relative degree of loading of the subject. What remains to be discussed is the classification and estimation of the degree of loading.

In the Gerontechnology project we used a resting period of two minutes. This was an arbitrary choice based on rather old literature. The experiences of Morrissey et al. (1995) suggest a recouperation time of less than half a minute would be sufficient, but the knowledge that the muscles of the elderly need more time to recouver, made us decide on a resting time of one minute.

3.2.8 Subject selection

In order to compare the results of both projects it was logical to use the same subjects. Because the Gerontechnology project took place before the Stadyn project, subjects for the Stadyn project would have to be recruited from among the subjects in the Gerontechnology project. Because the Gerontechnology project focussed on the differences between different age groups, eight different age groups were studied. The Stadyn project was meant to include a study on the relation between age and force performance, but this was not its main object. Furthermore, because this was a new method of measuring isoinertial force and very little literature could be found, it was thought that measuring too many different age groups might result in an unbalanced analysis. We therefore decided to limit the range of ages we wanted to study to subjects between 20 and 30 years of age, and subjects between 60 and 65 years of age.

The Gerontechnology project studied 125 subjects aged between 20 and 30 years and 121 subjects aged between 60 and 65 years. For the Stadyn project we required 40 subjects, 20 young and 20 elderly, with men and women evenly divided in both age groups.

Because there was more than two years between the two projects it might not be possible to draw all the subjects from the Gerontechnology project but might be necessary to recruit new subjects.

3.3 Format isometric measurements

Because the information on peak force exertion was needed in the isoinertial measurements, the isometric measurements took place before the isoinertial measurements.

3.3.1 Apparatus

Handle

Because in the act of gripping the position of the fingers influences the effective length of the muscles in the forearm, the shape of the weight was expected to have some influence on the results. Therefore, we made the shape of the handle in the isometric measurements similar to the weights used in the isoinertial measurements.

In addition, the subjects were asked to grip the handle firmly in all the experiments.

The force exerted was recorded by a force transducer with strain gauges (Hottinger Baldwin Messtechnik, type U2A) which was attached to an adjustable handle. The handle was a cylinder with a diameter of 30 mm and a width of 130 mm. This is shown in figure 3.3.1. It could be adjusted in four directions: rotation around the hinge near the horizontal rail[A], sliding vertically along a rail[B], sliding horizontally along the side of the subject[C] and sliding in the direction of the handle[D].

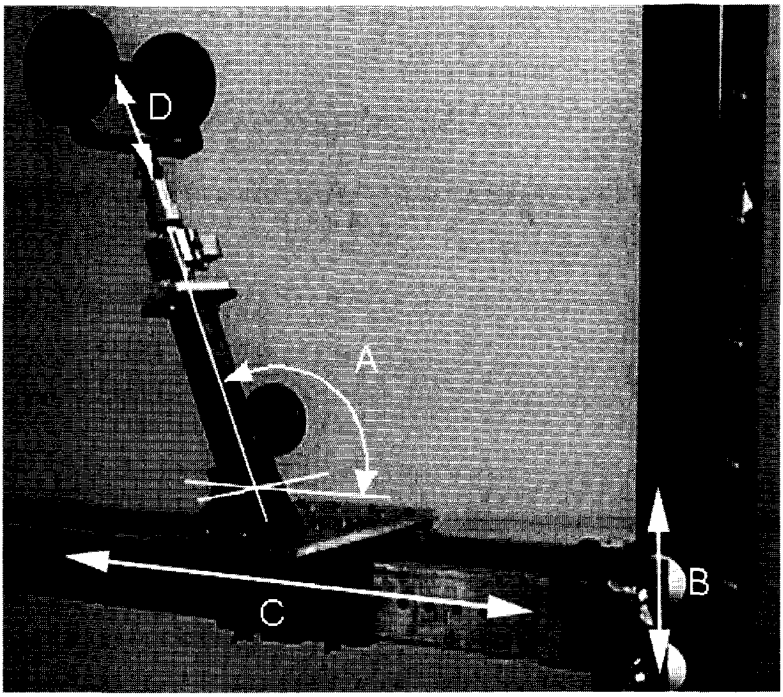


Figure 3.3.1 The moveability of the handle. The handle could be adjusted in four directions: rotation around the pivot at the base (A), vertical placement in steps of 5cm (B), horizontal displacement in steps of 2.5 cm (C) and extension of the handle shaft (D).

It should be noted that the vertical and horizontal adjustability of the handle is not continuous. The vertical adjustment has steps of 5 cms and the horizontal of 2.5 cms. Adjustment of the angle and the height is continuous. Because of the stepwise adjustability of the handle it was not possible to have the arm of each subject precisely positioned at the prescribed angle. However, this was not considered a serious problem because, as mentioned in section 1.2.1, isometric force exertion is never completely motionless. We anticipated that the subjects would move slightly during force exertion, and that the amount and direction of this motion would vary. In this respect no two subjects react in the same way.

Data collection

The force transducer was connected via an amplifier to an UV recorder and a data shuttle. A PC interpreted the data supplied by the data shuttle. With the aid of a computer programme (QuickLog PC, Strawberry Tree Inc.) the force exerted could be constantly monitored. Because we wanted to avoid errors in the linking of the results of the two force types, we chose to use software that was as aligned as possible. Using entirely the same computer programmes from the start was not possible, as the OPTPTRAK 2010-system (Northern Digital Inc.,Waterloo ON, Canada) requires the programmes submitted by the provider in order to function properly. These programmes are an unnecessarily complex and outdated way of making a proper recording from the isometric measuring apparatus.

Because it was impossible to use the same equipment and setting for measuring isometric and isoinertial force, the noise of the apparatus and method differed per force type. The isometric measurement had a degree of noise that was caused by the strain indicator (Peekel instruments, CA690). Before and after measurement the accuracy was tested with calibrated weights. When we found deviations in the values of the transducer, we corrected them on the outcomes.

Subject support

The chair in which the subjects were seated could be adjusted in several ways, making it possible to provide consistent support. During measurements the back, upper leg, right upper arm and left forearm of the subject had to be supported. The left arm support was adjustable in height. The back support could be adjusted in a horizontal direction.

To keep the right arm vertical a moveable board was placed at the side of the back support.

In figure 3.3.2, the chair and its adjustability are presented.

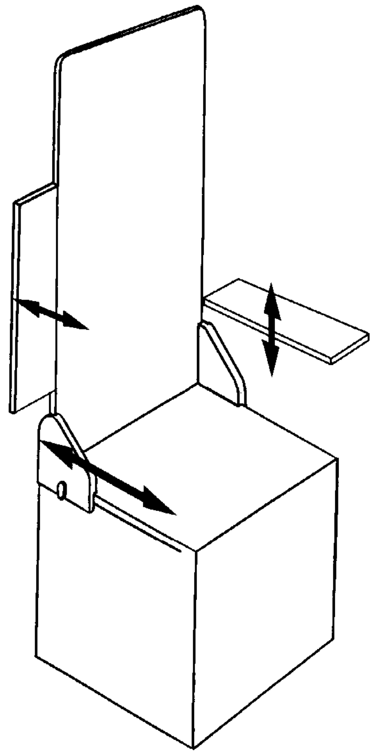


Figure 3.3.2 Adjustability of the chair. It was possible to adjust the back of the seat to the length of the upper leg of the subject. Furthermore, the rest for the left arm could be adjusted in height and the vertical support of the right upper arm could be adjusted by sliding horizontally against the upper arm.

The feet were left unsupported to prevent subjects from using their feet to increase force. Because the smooth surface of the chair might cause the subject to slide off the chair, an anti-skid mat was placed on the seat.

Additional measuring equipment

In order to establish the best position for the subjects several adjustments had to be made to the chair and the handle. To shorten the adjustment time, metal angle templates were used to establish position. To enable us to verify the elbow angle in later measurements, the elbow-grip length and upper arm length from the Gerontechnology project were used and measured on the new subjects. The body mass and stature of these new subjects were also established in the isometric session. This was done with a standard anthropometer.

3.3.2 Postures

Laterality is known to influence the results of force exertion. For instance, in the Gerontechnology project the preferred hand was stronger in gripping than the non-preferred hand (see section 2.2). Because, for the isoinertial measurements, changing the side measured is complicated due to the use of half-static cameras, only one side could be measured in one session. As for most people the preferred hand is the right, this is the side that was studied. It was also the only side studied in the isometric measurements.

In all the isometric measurements the subject sat on a chair. The knees were bent at an angle of 90 degrees, with the upper legs resting on the seat. The back and the right upper arm were held vertically against the support. The left arm was supported by an armrest, keeping the forearm horizontal (See figure 3.3.3).

The subject gripped the handle enclosing the bar in the right hand, with the palms up (see figure 3.3.3 and 3.3.4).

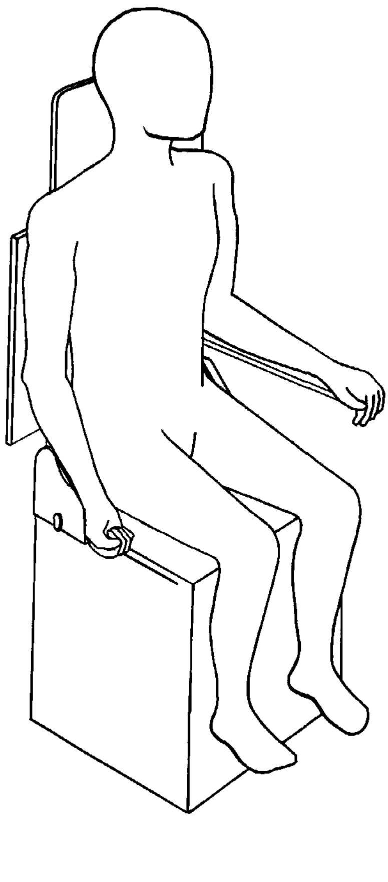


Figure 3.3.3 Position of the subject. The left arm was supported horizontally and the right arm as well as the back were supported vertically. The feet were left unsupported to prevent the subject from using them for additional force.

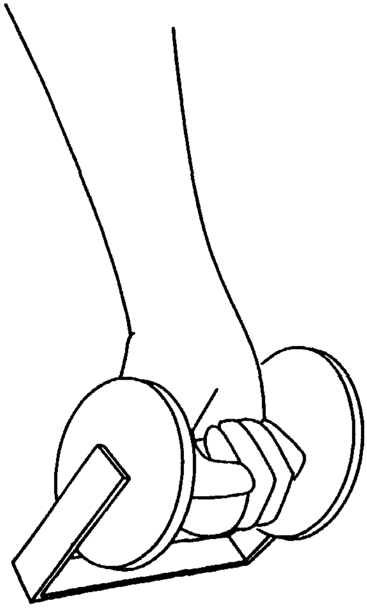


Figure 3.3.4 and holding the handle. The fingers and thumb enclosed the bar of the handle with the palm up.

All subjects were told to turn the wrist and exert force with the side of the hand, because at an angle of 35° some subjects needed to oversupinate their wrist and forearm, which might unintentionally lower the maximum force. (See figure 3.3.4).

Figure 3.3.4 Grip at the 35° angle. The fingers are no longer around the bar, instead the bar is hold between the thumb and the upper side of the fist.

During the measurements the subject was asked to look straight ahead.

It has already been mentioned in section 3.2.6 that the peak force would only be measured at an angle of 140 degrees between upper and forearm, and only for flexion.

The build-up flexion force was measured at four different angles: 140°, 105°, 70°, 35°.

3.3.3 Instructions

Two attendants were present during the sessions. Subjects did not necessarily have the same attendants at both of their measuring sessions. One attendant gave instructions to the subject, while the second attendant only gave short commands or additional information.

A substantial number of the subjects were selected from those who had earlier participated in the Gerontechnology measurements. These subjects were already familiar with measurements on build-up force. New subjects were given information on this type of force exertion during the session.

To obtain additional information on the force status in comparison with the Gerontechnology project, gripping force was measured again. The protocol for this measurement was the same as in the Gerontechnology project. This protocol and the results can be found in section 2.2. During the measuring of this force, the new subjects became familiar with build-up force.

The subjects were briefed on the main object of the study before they made the decision to participate. Subjects were given instructions shortly before measurements began. At the same time the task of the experimenter was to urge subjects to exert maximal force, but not to encourage them during the actual force exertion.

In the Gerontechnology project, as measurements were taking place, subjects were verbally encouraged to exert maximal force (see section 2.2.2). Kroemer et al. (1970) and Caldwell et al. (1974) found that with encouragement human force increased. Although the aim of this study was to compare maximal isometric force exertion with maximal isoinertial force exertion, it was decided that after prior motivation the subjects in the Stadyn project would not be encouraged during the actual measurements. Encouragement in the isoinertial measurements was difficult, as the actual flexion movement only lasted a second, making proper audible support impossible. Encouragement given in the isometric measurements was similar to that in the isoinertial measurements.

The subjects were asked to build up their force to maximum and to hold on until the second attendant called a halt. The same attendant was able to monitor the time during which the maximal force was held.

3.4 Format of the isoinertial measurements

3.4.1 Apparatus

The infrared-emitting diodes (IREDs) were placed on the right arm of the subject. A computer controlled a strober that activated the IREDs, one by one, at a prescribed frequency. The IREDs were connected to the strober via thin wires. The wires were bundled together and attached to the arm of the subject in a way that did not hinder the movement. The strober was mounted on the back of the chair.

The infrared light emitted by the diodes was received by two camera units with two infrared cameras each. The cameras were linked to a data acquisition system unit that combined the information of the two cameras, providing raw data sets. A computer attached to the data acquisition system translated the raw data sets into the co-ordinates of all the IREDs.

The whole system was an OPTOTRAK 2010 (Northern Digital Inc., Waterloo, ON, Canada) 3-D opto-electric motion registration system.

The data acquisition system can process a sampling frequency of 1250 Hz with one IRED. Because the IREDs are activated in serial order, enlarging the number of IREDs means proportionally lowering the maximal possible sampling rates. With five IREDs the maximal sampling frequency would be 417 Hz (2500/(1+5)). Because data files easily become extremely large, the sampling frequency has to be as low as possible. In these measurements the choice of sampling frequency depended on two factors.

The first was the frequency of the movement generated by the subject. The frequency of the system should always be higher than the acceleration frequency in the movement that has to be measured. Otherwise, if a significant peak occurs in the time between two samples, the peak will remain totally unnoticed. To assess the minimal frequency necessary, a small pilot study was done. None of the subjects in the pilot study exceeded 40 Hz in their movement. To be on the safe side 50 Hz was used.

The second factor was a sampling rate that was high enough to allow reconstruction of all maxima with acceptable accuracy. Most biological signals can be accurately expressed in sinusoid shapes. With such a shape a minimum of four points per peak is needed to get an accurate impression of the original signal (three for shape and one for vertical displacement). Therefore the sample frequency had to be (4 x 50 =) 200 Hz.

Because an overlong measurement time enlarges the data file unnecessarily, the measurement times were carefully selected. For the single flexion movement it was limited to two seconds, for the single flexion-extension movement to four seconds and for the five times repeated movement to seven seconds. The measuring time was started by the push of a button.

Subjects sat on the same adjustable chair that was used in the isometric session (See section 3.3.1). The chair had to support the back, right upper arm, left forearm and upper legs. Figure 3.3.2 shows the chair and the possible adjustments.

The chair was positioned at a distance of approximately two-and-a-half metres from the cameras, in accordance with the coordinate-axes of the cameras. These axes were set and calibrated to gain optimal accessibility to the infrared emitters placed on the right arm of the subject. In practise, this means that the right side of the chair is aligned with the x-axis while the back of the base of the chair is lined up with the z-axis. Figure 3.4.1 shows the position of the chair in relation to the co-ordinate system.

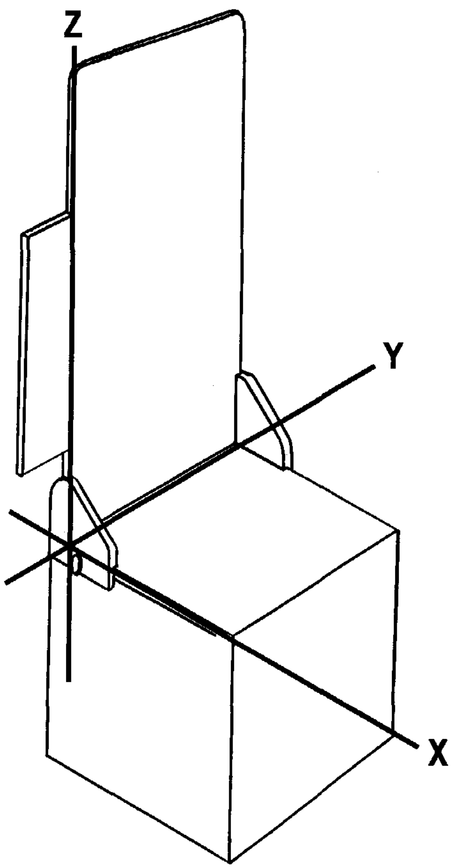


Figure 3.4.1 The position of the chair in relation to the co-ordinate system of the cameras. The origin of the co-ordinate system is aligned with the right side of the chair, the backrest and the surface of the seat.

The angle between the two infrared cameras was set at 60 degrees. According to the specifications of Nothern Digital Inc. the reading of the emitter positions is optimal at this angle. The inaccuracy in this setting is 0.15mm for the y-axis and only 0.1mm for the x- and z-axis. This is sufficiently precise, because the movements made in the measurement are of an order that is at least a 100 times higher. The fact that the chair was placed at a distance of two-and-a-half metres contributed to the accuracy as this is given as the best distance for this system (Northern Digital Inc.).

In order to obtain the best possible results from the cameras, all lights in the room needed to be extinguished and all windows blacked out. However, because it was necessary to monitor the movements with a video camera, and because the subjects needed to see what was happening, it was not possible to do this. It was also found to be not essential, as the accuracy was already within the parameters required for the measurements.

The video camera was an S-VHS type (Panasonic, NV-MS1). It was placed on a stand and operated by the experimenter. The recordings were started just before the start command was given to the subject. These recordings are meant to provide a visual back up in case irregularities or extremes are found in the OPTOTRAK data.

Two people were with the subject – an experimenter and an attendant. The experimenter sat behind the computer and operated the OPTOTRAK system and the video camera. He also monitored the data of the OPTOTRAK, which was presented on the screen in real time. When the visibility of the markers was seriously obscured, the experimenter could order a repeat of the measurement. The attendant sat next to the subject and gave instructions on the required movements. This attendant also watched the subject closely during each movement. If the movement was not correct the attendant gave additional instructions or ordered a repeat if necessary. During the measurements the attendant was seated behind the subject, out of the range of the cameras. During the instructions the attendant sat beside the subject and took over the weight during the resting time. Figure 3.4.2 shows the top view of the experimental setting (the instruction position is represented in dotted lines).

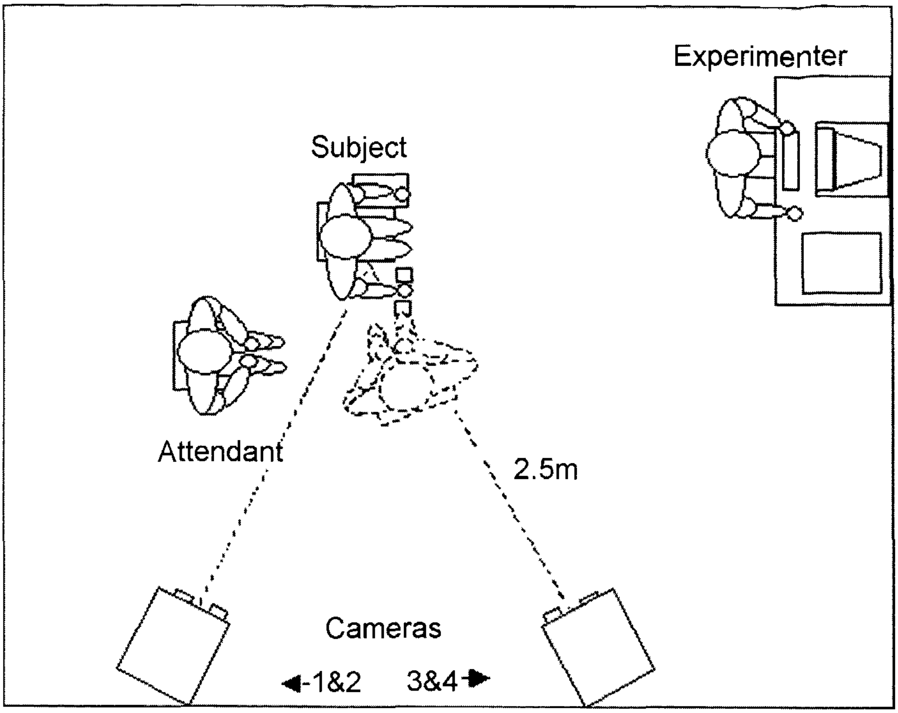


Figure 3.4.2 Top view of the experimental setting. The subject is positioned on a special chair that is positioned at 2.5 m from two camera units, with each two cameras, that are under an angle of 60° with each other. An attendant instructs the subject before each movement (dotted lines) and sits behind the subject during the movements. The experimenter sits behind a computer to collect data.

3.4.2 Posture and movements

The subject was instructed to sit on the chair and look straight ahead during the measurements. As mentioned in paragraph 3.4.2, all measurements were performed on the right arm.

The starting position was the same for all the measurements. For this position the angle between upper and forearm had to be 140 degrees. Marking this position with some sort of forearm rest was considered. Because it was thought that this would influence the movement too much the idea was rejected. Instead, the subject was instructed to keep the weight at the starting angle of 140°. The accuracy of the angle would therefore depend on the muscle control of the subject. The reasonable assumption was that should deviations occur these would be small and would not significantly change the outcomes.

The angle at which the arm was stopped or returned was also not marked. The subjects were instructed to return or stop at the smallest possible angle (designated zero).

The starting position is presented in figure 3.4.3.

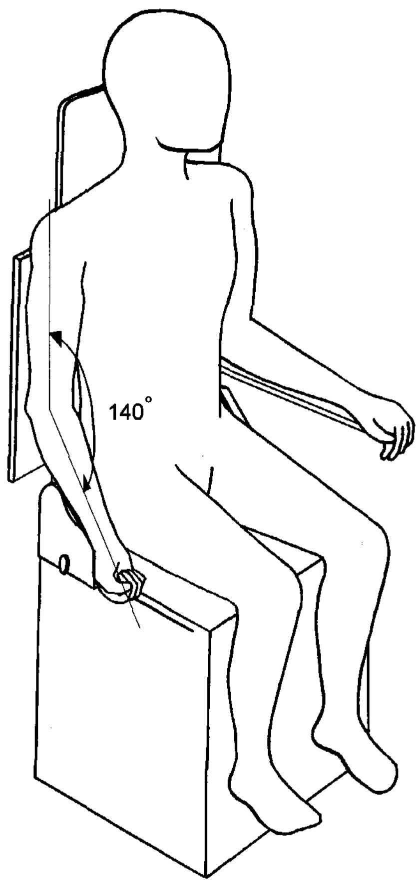


Figure 3.4.3 Starting position of the subject: seated on a chair with the upper arm and back against vertical supports and an angle of 140° between upper and forearm.

The subjects were instructed to grip the weight firmly during the movements to prevent the wrist from bending. To study the eventual effect of a small degree of wrist flexure on the elbow flexion strength, we performed a sub-study on a sample of 15 subjects. The results of this sub-study are presented in section 4.1.

We decided to measure flexion force in three different movements (see section 3.2 and figure 3.2.5):

- Flexing the elbow from 140 degrees to zero and stopping at zero

- Flexing the elbow from 140 degrees to zero and immediately extending back to 140 degrees
- Flexing the elbow from 140 degrees to zero and immediately extending back to 140 degrees repeated five times in a row

We wanted to study the effect of the extension movement and the repetition of movements on the flexion force and force patterns of the elbow. We did not study force exertion in the extension movement.

3.4.3 Position of the IREDs

The results of the isoinertial measurements consist of information on the acceleration of the extra weight over time. This information was gained from the movement of the weight. To compare the results of the isoinertial measurements with the results of the isometric measurements, the results had to be related to the angle of the elbow. To compute the angle between upper and forearm it was necessary to create two vectors, one representing the position of the upper arm and one representing the position of the forearm. Because we also needed information on the acceleration of the weight, it was necessary to collect data on five points: two on the lateral side of the forearm, two on the lateral side of the upper arm and one on the lateral side of the weight moved. If the upper arm is properly held against the vertical rest, the two on the upper arm are not needed. We investigated whether the deviations from the vertical were too large to ignore.

The information on the marker positions on the arm is slightly biased because the markers are placed on the skin and not rigidly connected to the bone. Therefore, the position of the markers is not a hundred percent accurate, as the skin under the markers on the fore- and upper arm sometimes shifts a few millimetres when the muscles thicken in contraction and lengthen in relaxation. This shift was not measured.

Five IREDs were attached to the right arm of the subject after the subject was positioned in the chair. One IRED was placed on the weight that the subject was instructed to move[1], one on the wrist near the processus styloideus[2], one at 12 cm from the epicondylus ulnaris on the forearm[3], one at the same distance on the upper arm[4] and the fifth one on the most proximal point of the caput humeri[5]. The position of the IREDs is presented in figure 3.4.4.

As the IREDs are small, light-weight devices, they can be attached to the skin of the subject with sticking tape.

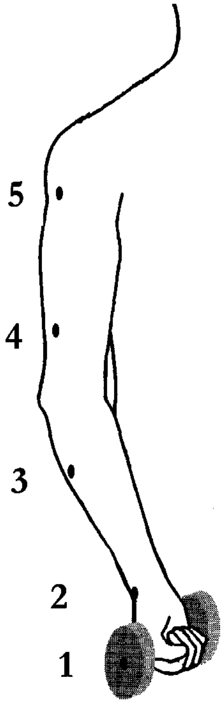


Figure 3.4.4 *Position of the markers: no.1 is placed upon the weight that is to be moved by the subject; no.2 is on the wrist near the processus styloideus; no.3 at 12 cm from the epicondylus ulnaris on the forearm; no.4 at the same distance on the upper arm; no.5 on the most proximal point of the caput humeri.*

3.4.4 Weights

The handle in the isometric measurements was a cylinder with a diameter of 30 mm and a length of 130 mm, with pads at both ends which enclosed the hand. This shape corresponds with regular weights used in weightlifting and fitness training, so these weights can be used in isoinertial measurements. Figure 3.4.5 shows examples of the weights that were used. The subject was instructed to move a weight of one kilogram and a weight that represented one-third of their isometric peak force.

Between the two measurements there was time to analyse the results from the isometric session and to decide on the subject-specific weight. The method of analysis and the decision on the weight given to a subject will be described in section 3.6.2.

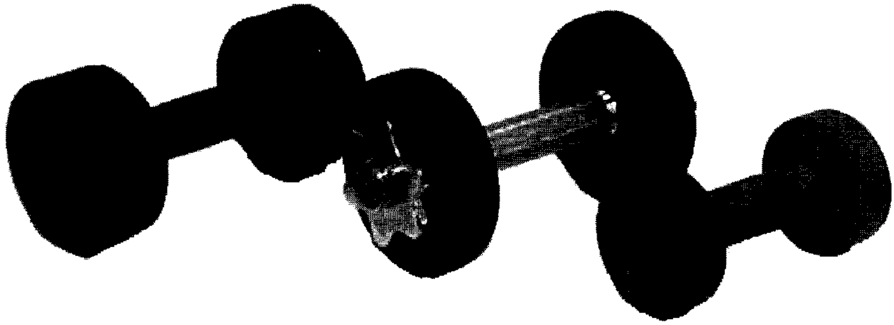


Figure 3.4.5 Three examples of weights that were used in the isoinertial measurements.

On the basis of the results of a pilot study we expected the results of the actual study to vary between 1.5 and 8 kilograms We decided to limit the amount of weights and apply steps (confer with 3.2.6). We chose to apply steps of half a kilogram (one kilogram upward) because then the lowest weight would have a maximal deviation of 14.2%, which we regarded as acceptable.

Consequently, the results of the peak-force measurement needed to be rounded off to round or half figures. Although normally figures can be rounded up or down, in this case it was preferable to round them down in order to minimise the risk of injury from overloading.

This risk may also appear when the results of the peak force are considerably higher than the result of the build-up force in the 140 degrees angle. If so, we would lower the weight. In that case we would use one-third of the mean of the peak and build-up forces to come to the weight.

Because we could not accurately predict the influence of these decisions, we analysed the correlation between the isoinertial results and the deviation from the ideal weight after measurements.

3.4.5 Instructions

After the subject was installed in the chair according to the posture described in section 3.3.2, they were instructed to perform a number of maximal isoinertial force exertions with the one-kilogram weight. Before the first measurement of each movement the subject was told to move the weight slowly to full flexion and then back to 140°. This procedure is always necessary to check the visibility of the markers.

All movements were performed twice in the following order:

- flexion from 140 degrees to zero
- flexion immediately followed by extension from 140 via zero back to 140 degrees
- flexion-extension from 140 via zero back to 140 degrees repeated five times

After all the measurements with one kilogram were completed, the same measurements were done with the 'one-third of the peak' weight. Here the visibility of the markers in movement was checked once again.

Before the measurements were started, the subject was asked to try to avoid flexing the wrist by gripping the weight firmly.

The subject was instructed to move the weight as fast as possible, putting all their force into it. It was thought that instructing people to 'accelerate' as hard as possible would cause some confusion, as not everyone is familiar with this term. By using the words 'fast' and 'force' the same intentional meaning is created.

3.5 *Combining isometric and isoinertial force exertion in the analysis*

Isoinertial force originates from acceleration. Because the gravitation of the earth is always present, isoinertial force is exerted as soon as a weight is placed on the human body. In this study isoinertial force in movement was the main interest, as it most resembles product use. In contrast, isometric force exertion lacks movement and is therefore static by nature. To make a comparison between the two force types, the movement from the isoinertial research has to be interpreted as a sequence of static, frozen positions.

Assuming that a satisfactory separate analysis of both force types could be done, there remained some considerations on the combination of the results. Because of the essential differences in the nature of the results, a number of precautions and preliminary steps were required to allow for good analyses. Two ways of analysis were possible in this study.

One way of making the data sets comparable was to consider only those isoinertial results that corresponded with the elbow angles measured in the isometric session. Each individual reached these elbow positions at a specific time in the movement. Knowing this point in time, the isoinertial force exerted in this position could be determined from the movement time-force curve. This was most easily done after the isoinertial measurements, when the force curves were available.

With this method of analysis the outcomes of the isoinertial and isometric measurements were of a comparable magnitude.

An analysis of the combination is also possible by composing a force curve from the successive results of the isometric measurements. To do so, the results of the isometric force measurements, according to the angle, have to be arranged in the same order as in the movement of the isoinertial measurement. Then it is possible to fit a curve on the measured results and to construct a force curve.

This fitted curve can simply be a fluid line over the results, but it is also possible to use the curve of the isoinertial force measurements as a basis to find a reference for comparison with the measured isometric values. Both types of fitting are of interest.

To make a meaningful curve, fitted to the isometric forces measured in different angles, there must be a sufficient number of measuring points. The number of measuring points needed depends on the form of the expected force curve. To explore the type of curvature, a pilot study was performed for the isoinertial part. The results of this study showed basically sinusoidal shapes, with no irregular oscillations or sharp peaks in the force curves. To reproduce the tops in a sinusoidal pattern, four measuring points are needed (three for shape and one for vertical displacement). It was therefore decided that the four angles that we planned to study in the isometric measurement would be sufficient.

The first method of analysis results in numbers, which makes it possible to compare the results of the two force type measurements with the help of statistics. In the second method the differences in the curves needs to be drawn, or quantitatively described. This study concentrates on the first method of analysis.

3.6 Results

All statistical results were calculated with SPSS for Windows version 7.5 (SPSS Inc.). The results presented in this section are discussed in chapters 4 and 5. To simplify the notification of the two different weights in this section, the one kilogram weight is referred to as OKW and the 1/3 peak-force weight as PFW.

It should be noted that, because the subjects were supported as lightly as possible and the movements were not guided externally, a number of the subjects did not always make the complete movement through all the angles. In the flexion-extension movement repeated five times the 35°-elbow angle was often missing, because subjects returned at too large an elbow angle.

Reproducibility

Because of the explorative nature of this study, expectations of an accurate reproducibility were not high. We were not able to control the influences, as we did not know what these were going to be.

Kanis (1997) presents three conditions that should be studied when judging the reproducibility of a measurement:

- The measurement should be of the same type in all subjects.

- The results per subject in a test-retest can be reversed.
- The differences within subjects should be randomly distributed.

For acceptable reproducibility all these conditions must be met. In the field of force exertion, reproducibility is often evaluated by means of T-tests. A T-test performed with SPSS contains the correlation coefficient and a comparison of the means and variance of two variables. We incorporated the results of all subjects in these tests.

When a difference in means between the first and second results was found to be significant (p>0.05), we concluded that the reproducibility was unacceptable. If the differences in mean and variance were not significant and the correlation coefficient was lower than 0.71, we felt that reproducibility was limited. With a correlation coefficient of 0.71 or higher there is at least 50% communality. We did not distinguish between categories of reproducibility other than sufficient or insuffient.

We did not exclude variables with poor reproducibility from further analysis, because we wanted to study the characteristics of these variables too.

Comparison of different measurements and force types

The relations between different variables were studied on the entire sample using T-tests with a significance level of 0.05. We distinguished three categories of relationships. Correlation coefficients above 0.71 indicate a strong relation, between 0.3 and 0.71 a moderate relation and under 0.3 a poor relation between the variables studied (Arisz, 1996).

Sex and age effects

Differences between the two sexes or the two age groups were established using T-tests. The significance level was 0.05.

3.6.1 *Subject characteristics*

Fifty-two subjects participated in the measurements. The number of people per sex, age group and prior participation are presented in table 3.6.1. Our plan was to measure people who had also participated in the Gerontechnology project. Although we measured 750 subjects in that project, we were not able to collect more than 10 subjects in the youngest age group (20-30 years of age). In order to find a sufficient number of subjects to make statistical comparison possible, we decided to take extra subjects from the other age group (60-65) and also to make up numbers in the younger age group with subjects who had not participated in the Gerontechnology project. In the end, we measured 20 subjects of 20-30 years of age and 32 of 60-65 years of age. Twenty-two women had originally joined the Gerontechnology project and 20 men. In total 25 women and 27 men participated in the Stadyn project.

Table 3.6.1 Subject information about participation in Gerontechnology project.

Age group	Gerontechnology participation	Sex men	Sex women
20-30	yes	5	5
20-30	no	5	5
60-65	yes	17	15

Because one of the new subjects had an accident and sustained a whiplash injury in the time between the isometric and isoinertial measurements, 51 subjects joined the isoinertial measurement.

In table 3.6.2 information on mean body mass and stature is presented per age group per sex.

Table 3.6.2 Subject information on stature and body mass.

	stature [cm]		body mass [kg]	
Age group	men $\bar{x}$ (s)	women $\bar{x}$ (s)	men $\bar{x}$ (s)	women $\bar{x}$ (s)
20-30	181.2 (7.3)	167.0 (6.9)	70.8 (7.9)	66.1 (9.7)
60-65	176.5 (6.2)	164.2 (6.5)	82.4 (7.0)	68.7 (9.4)

The subjects who joined the Gerontechnology measurements had not received treatment from a medical specialist for any new complaint in the three months prior to the measurements. For the Stadyn project we asked the subjects whether they could flex and extend their elbow without difficulty. None of the subjects had problems with their right wrist, hand or shoulder.

3.6.2 Isometric force in elbow flexion

Reproducibility

In figure 3.6.1 a scatterplot of the first and second measurement of the peak force exerted is presented.

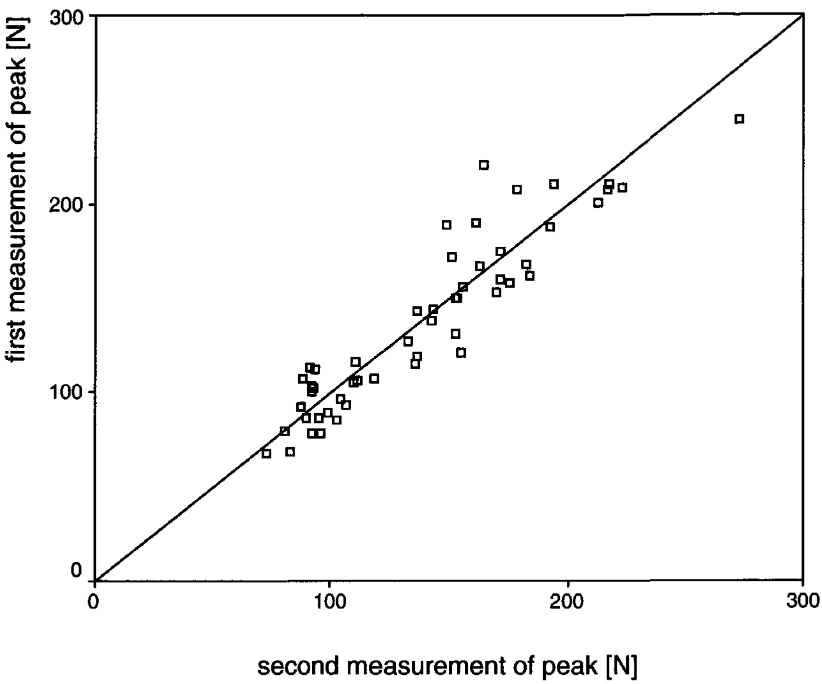


Figure 3.6.1 Scatterplot of the results from the first and second measurement of isometric peak force in elbow flexion.

A paired T-test showed no significant difference between the first and second result of the peak force exertion. The correlation coefficient was 0.93 ($p<0.05$). We concluded that the reproducibility of the peak force was acceptable.

Isometric build-up force was measured twice in four different angles (see section 3.3.2). In figure 3.6.2 the results of test and retest are presented in a scatterplot. In all the angles the mean of the first result was lower than the mean of the second result, but according to T-tests there was only a statistically significant difference ($p<0.05$) between the first and second measurement in the 35 degrees elbow position (means are 89.2N and 94.5N respectively). The isometric build-up force at the 35° angle was therefore judged to be poorly reproducible.

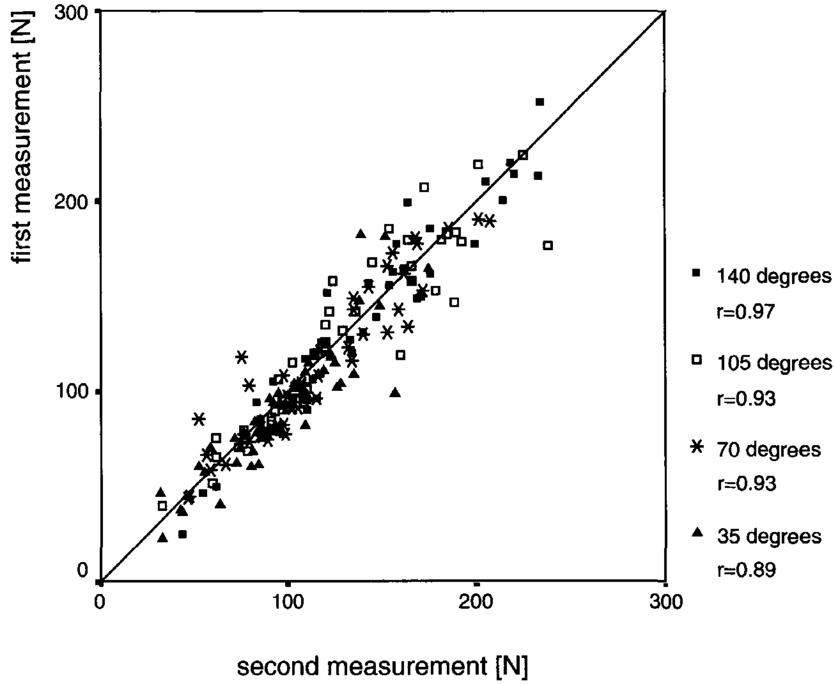


Figure 3.6.2 Scatterplot of first and second measurement in the four different angles of measurement and the standard deviations. The differences in the means in the 35° elbow angles were significant (p>0.05) and the results are therefore not sufficiently reproducible.

The correlation coefficients of the first and second measurements are also included in figure 3.6.2.

From 1/3 peak force to a weight

As mentioned in section 3.2.6 and 3.4.4, the weights applied in the measurements were calculated from the peak force that was exerted at an angle of 140 degrees. We mainly used one-third of the mean of two peak force exertions to come to a decision on the weight. However, because of large differences between peak and build-up force in 6 cases, we used the mean of the mean peak and the mean build-up force (see section 3.2.6).

The largest and smallest weights were in accordance with the prognosis (1.5 to 8 kg, see 3.4.4) and we therefore used several weights that were approximately half a kilogram apart.

Figure 3.6.3 shows a scatterplot of the mean peak force and the weight handed to the subject.

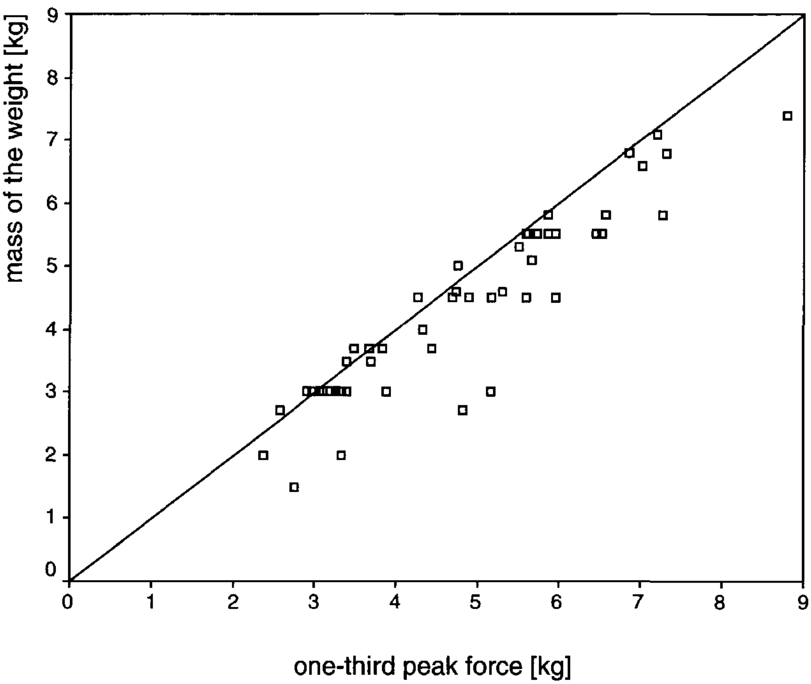


Figure 3.6.3 Scatterplot of mean peak force vs. weight. The weight that was given to the subject was in most of the cases somewhat lower than one-third of the peak force. This was to minimise the risk of injury.

Sex and age effects

The maximal peak force found was 258.98N and was exerted by a 23-year-old man, while the minimal peak force was 69.65N exerted by a 24-year-old woman. Table 3.6.3 shows the mean peak force per sex and per age group. A T-test showed that the difference between men and women is significant ($p<0.05$).

Table 3.6.3 Mean and standard deviation for peak force per sex per age group. The mean peak force of the males is significantly higher than the mean peak force of the females. The differences between the two age groups are not significant.

Age group	peak force [N] men $\bar{x}$ (s)	peak force [N] women $\bar{x}$ (s)
20-30	182.0 (39.9)	98.3 (15.2)
60-65	164.9 (33.0)	107.4 (24.0)

The mean and standard deviation of build-up force per sex and age group of the force exertion in the 140, 105, 70 and 35 degree angles respectively are presented in table 3.6.4 – 3.6.7.

Table 3.6.4 Mean and standard deviation of isometric build-up force at a 140 degree angle per sex per age group. Males are stronger than females. The differences between the age groups are not significant

Age group	140 degrees build-up force [N]	
	men $\bar{x}$ (s)	women $\bar{x}$ (s)
20-30	175.1 (40.2)	92.0 (16.5)
60-65	155.5 (40.8)	94.1 (25.7)

Table 3.6.5 Mean and standard deviation of isometric build-up force at a 105 degree angle per sex per age group. Males are stronger than females. The differences between the age groups are not significant.

Age group	105 degrees build-up force [N]	
	men $\bar{x}$ (s)	women $\bar{x}$ (s)
20-30	167.3 (39.2)	89.9 (21.1)
60-65	145.3 (35.5)	96.1 (25.9)

Table 3.6.6 Mean and standard deviation of isometric build-up force at a 70 degree angle per sex per age group. Males are stronger than females. The differences between the age groups are not significant.

Age group	70 degrees build-up force [N]	
	men $\bar{x}$ (s)	women $\bar{x}$ (s)
20-30	151.8 (34.9)	85.5 (18.7)
60-65	132.7 (32.8)	86.8 (20.9)

Table 3.6.7 Mean and standard deviation of isometric build-up force at a 35 degree angle per sex per age group. Males are stronger than females. The differences between the age groups are not significant.

Age group	35 degrees build-up force [N]	
	men $\bar{x}$ (s)	women $\bar{x}$ (s)
20-30	121.2 (32.9)	72.0 (20.7)
60-65	104.3 (27.9)	71.9 (21.0)

For women the mean isometric build-up force of the 60-65 year old is, except in the 35°, higher in all the angles than the mean of the 20-30 year old. For men the young are stronger than the old in all the angles. None of the differences in build-up force in the two age groups are significant.

The mean isometric build-up force of the men is significantly higher than that of the women ($p<0.05$).

Relationships between isometric build-up forces in different angles

The correlation coefficients that describe the relation between the build-up forces in the different angles are presented in table 3.6.8. All coefficients are statistically significant ($p<0.05$). In the same table we implemented the significance of the differences between the means. A large dot (•) indicates a significant difference while a small dot (·) indicates an insignificance.

Table 3.6.8 Correlation coefficients build-up forces in different angles and the significance of the differences in the means. (•=significant, -=insignificant)

elbow angle	140 degrees	105 degrees	70 degrees	35 degrees
140 degrees		0.92	0.90	0.79
105 degrees	-		0.95	0.82
70 degrees	•	•		0.87
35 degrees	•	•	•	

Because all correlation coefficients are above 0.71 we conclude that the results in the different angles are strongly related.

3.6.3 *Isoinertial elbow flexion force*

As mentioned in previous sections, isoinertial force was established in three different movements with two different weights.

To maintain a proper overview of the results concerning reproducibility, the results on reproducibility with OKW (one-kilogram weight) are presented separately from the results with PFW (1/3 peak-force weight).

Reproducibility with OKW

The force exertions in the two single flexion movements with the OKW (one-kilogram-weight), which are presented in figure 3.6.4, showed rather low correlation coefficients (0.65 to 0.37).

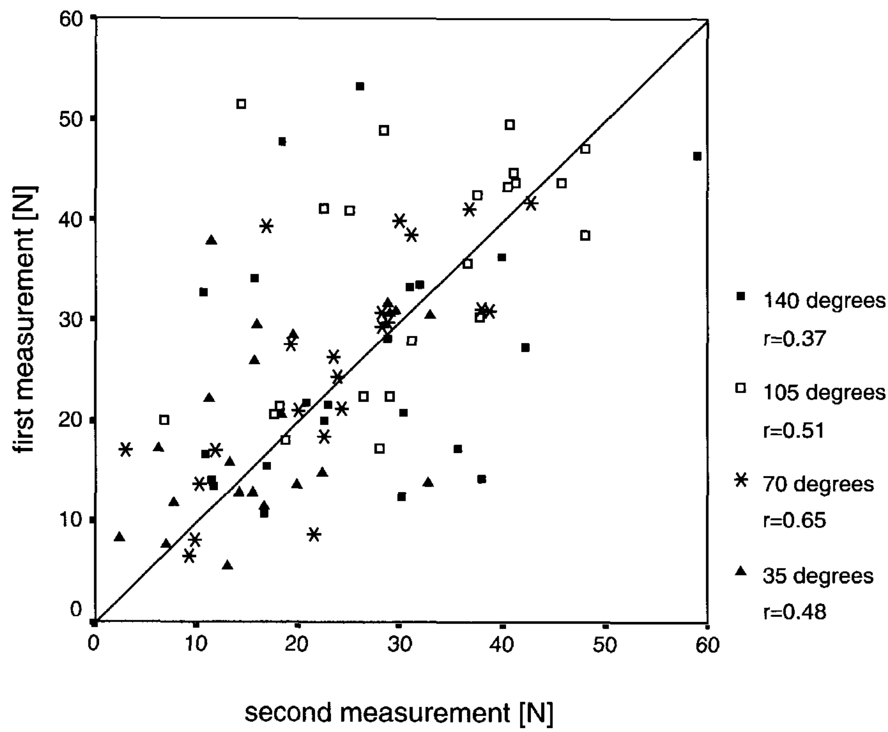


Figure 3.6.4 Scatterplot of first and second result in the single flexion movement with the OKW. The correlation coefficients are lower than 0.71, which indicates poor reproducibility.

According to T-tests, there were no significant differences between the means of the first and second force exertion at the different angles in the movement. On the basis of the low correlation coefficients we concluded that the reproducibility of the single flexion movement with the OKW was not so good.

The reproducibility of the flexion-extension movement with the OKW (one-kilogram-weight) was not good. The correlation coefficients between first and second measurement varied between 0.38 and 0.65 (all $p < 0.05$) which is low, but in combination with the absence of significant differences between the means of results of the first and second attempt we concluded that the reproducibility allows further consideration. The results are presented in figure 3.6.5.

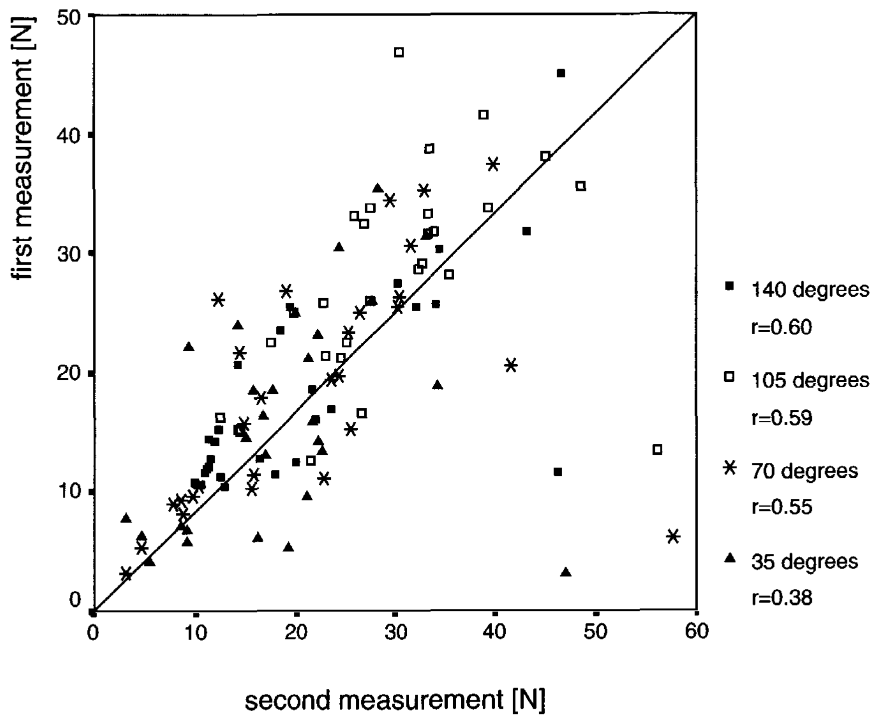


Figure 3.6.5 Scatterplot of first and second result in the flexion-extension movement with OKW. Although the differences in the means are not significant, the correlation coefficients are lower than 0.71, which indicates rather poor reproducibility.

The last measurements in the isoinertial sessions with the OKW concerned repeated elbow flexion-extension movements. To study the reproducibility of the total movement, the results were described in force per angle per movement number.

The reproducibility of the results at 140°, 105° and 70° elbow angle in the first flexion-extension movement was acceptable, with correlation coefficients between 0.66 and 0.79 and no significant differences between the means. Reproducibility at the 35° elbow angle ($p<0.05$) was insufficient because there was a significant difference between the means of test and retest. The results of the first flexion-extension movement are presented in figure 3.6.6.

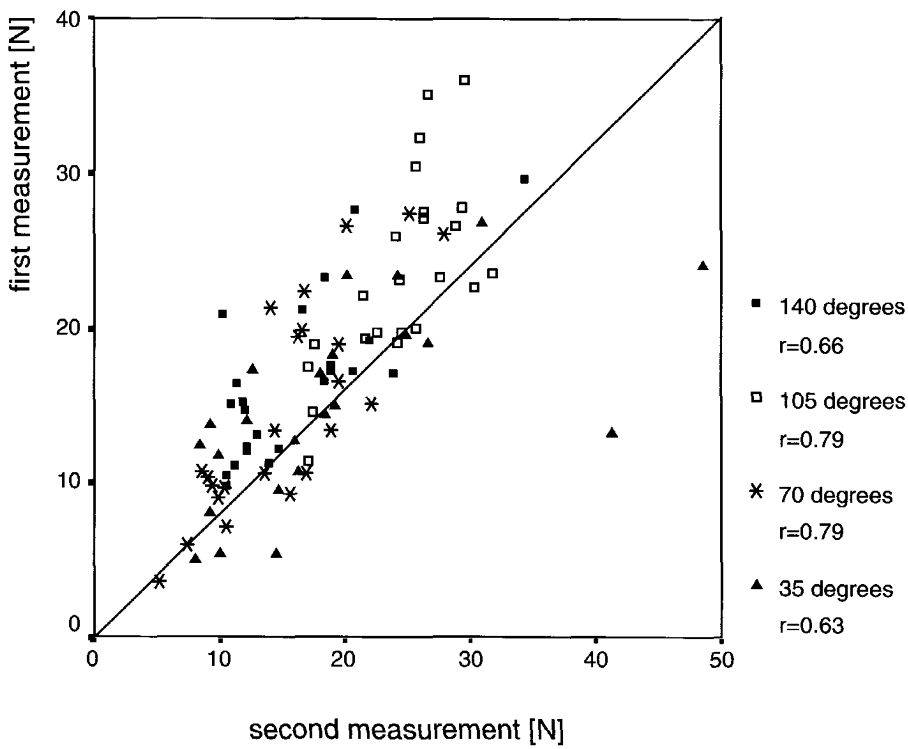


Figure 3.6.6 Scatterplot of first and second result in the first flexion-extension in the repeated flexion-extension movement with OKW. The differences in the means in 140°, 105° and 70°were not significant. In combination with the correlation coefficients this indicates acceptable reproducibility. The results in the 35 degrees angle are not sufficiently reproducible according to the significant differences in the means of the first and second results.

The reproducibility of the second flexion-extension movement was worse than the first. The correlation coefficients between the first and second measurement varied from 0.38 to 0.69. Here the smaller angles of 70° and 35° were the most reproducible. In the elbow angle of 140° the difference between the mean of the first and second measurement (respectively 22.9 (6.4) and 26.3 (9.9)) was significant according to a T-test. The results are presented in figure 3.6.7.

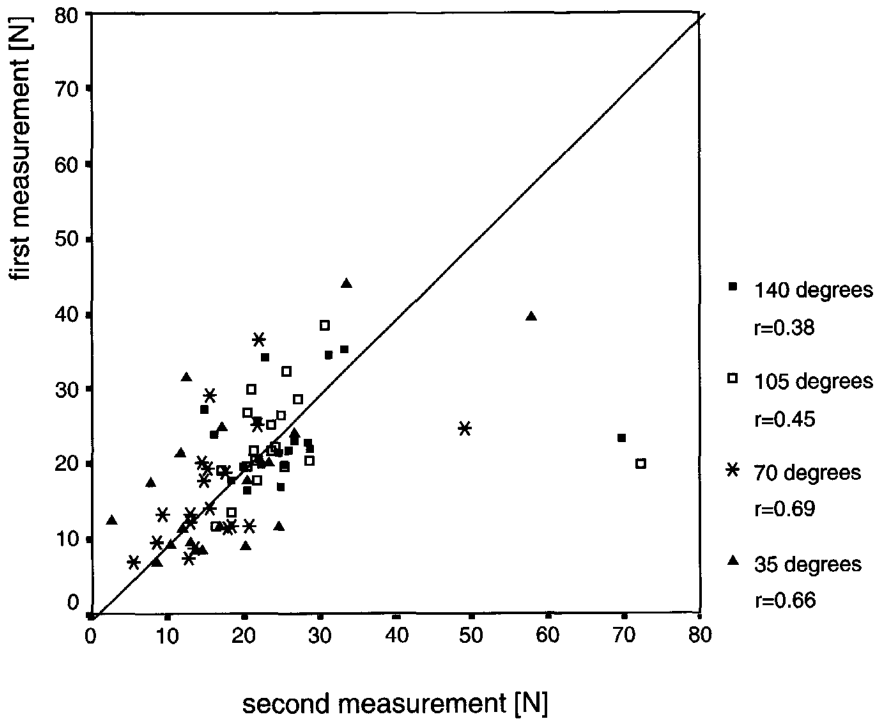


Figure 3.6.7 Scatterplot of first and second result in the second flexion-extension in the repeated flexion-extension movement with OKW. The differences in the means in 105°, 70° and 35° are not significant. In combination with the correlation coefficients this indicates acceptable reproducibility for the 70° and 35° angle, but poor reproducibility for 105. The results in the 140° angle are not sufficiently reproducible according to the significant differences in the means of the first and second results. We therefore conclude that the reproducibility of these results is also poor.

The reproduction of the <u>third</u> movement was, according to the results of a T-test, better than that of the second. The correlation coefficients ranged from 0.46 to 0.63 and there were no significant differences between the means (figure 3.6.8).

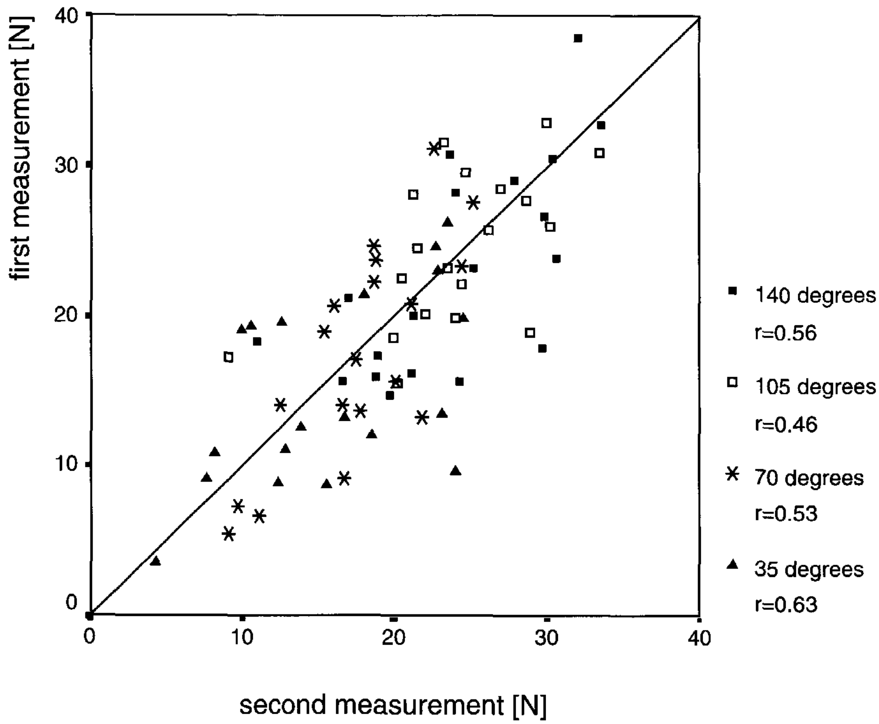


Figure 3.6.8 Scatterplot of first and second result in the third flexion-extension in the repeated flexion-extension movement with OKW. The differences in the means are not significant. The correlation coefficients, however, are lower than 0.71. We therefore conclude that the reproducibility of these results is not good.

The reproducibility of the fourth movement was not good. The correlation coefficients varied between 0.49 and 0.72. It was, however, impossible to find a significant correlation coefficient for the results at the 35° elbow angle. Furthermore, the means of the isoinertial force at 140° were not reproducible according to the describing t-value. The latter lowered the reproducibility of the fourth movement.

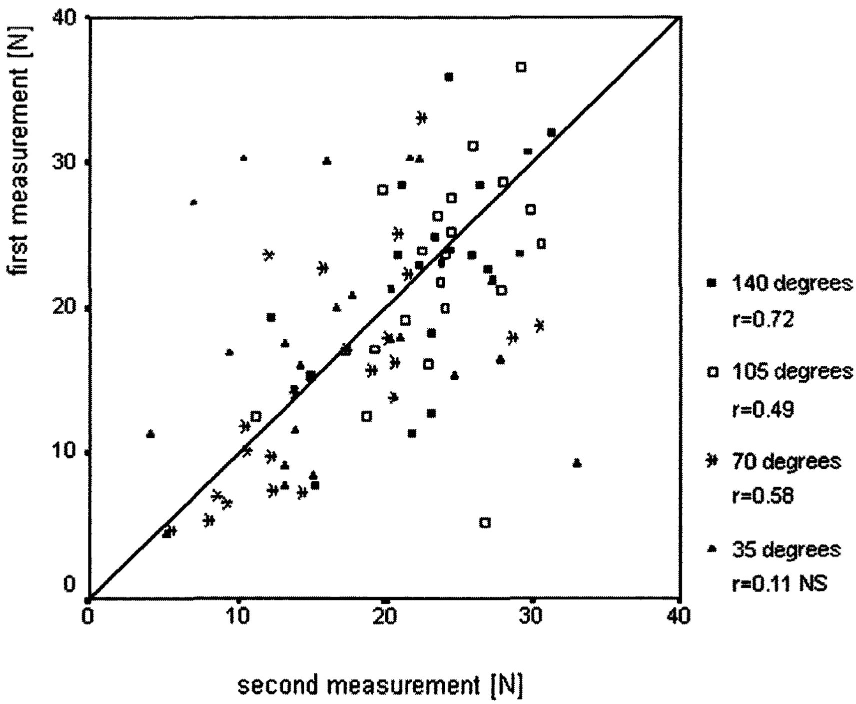


Figure 3.6.9 Scatterplot of first and second result in the fourth flexion-extension in the repeated flexion-extension movement with OKW. The differences in the means at 140° were significant and the results at this angle are therefore not sufficiently reproducible. The correlation coefficients in 105° and 70° are lower than 0.71, which hampers reproducibility. For the results in the 35° angle a significant correlation coefficient could not be found. We therefore conclude that the reproducibility of the fourth movement with OKW is not good.

The fifth movement had correlation coefficients between 0.54 and 0.65 but no significant coefficient for the 70°elbow angle. The differences between the means were found not to be significant. The low correlation coefficients and the lack of a significant coefficient for the 70° angle diminished reproducibility.

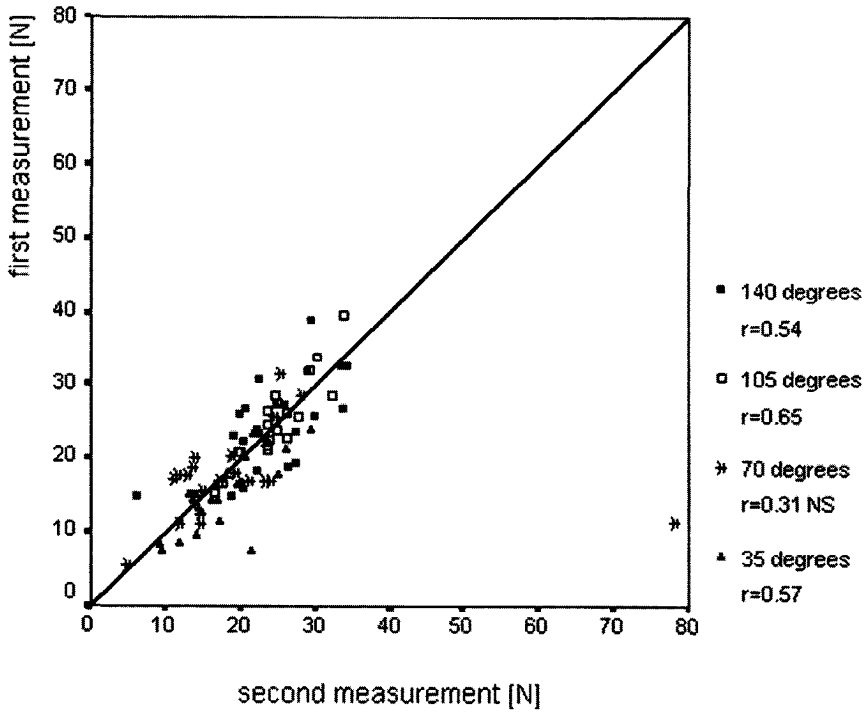


Figure 3.6.10Scatterplot of first and second result in the fifth flexion-extension in the repeated flexion-extension movement with OKW. The differences in the means are not significant. The correlation coefficients in 140°, 105 and 35° were lower than 0.71, which hampers reproducibility. For the results in the 70° angle a significant correlation coefficient could not be found. We therefore conclude that the reproducibility of the fifth movement with OKW is not good.

On the basis of the correlation coefficient and T-values we concluded, that in the repeated flexion-extension movement with the OKW, the first movement of the five was the most reproducible, but overall reproducibility was poor.

On the whole reproducibility with the OKW was unacceptable. We suspect that this was due to the fact that the weight to be moved was quite light. This could indicate submaximal force exertion, which is less well reproducible.

Reproducibility with PFW

The single flexion movement with the PFW (1/3 peak-force weight) resulted in very diverse correlation coefficients at the different angles for the first and second attempt(figure 3.6.11). The coefficients for maximal force at 140° and 105° ranged from 0.92 to 0.82, but at the 70° and 35° angles these were much lower (respectively 0.26 and 0.41) and not statistically significant ($p>0.05$). The differences between each two comparative means were, however, not significant.

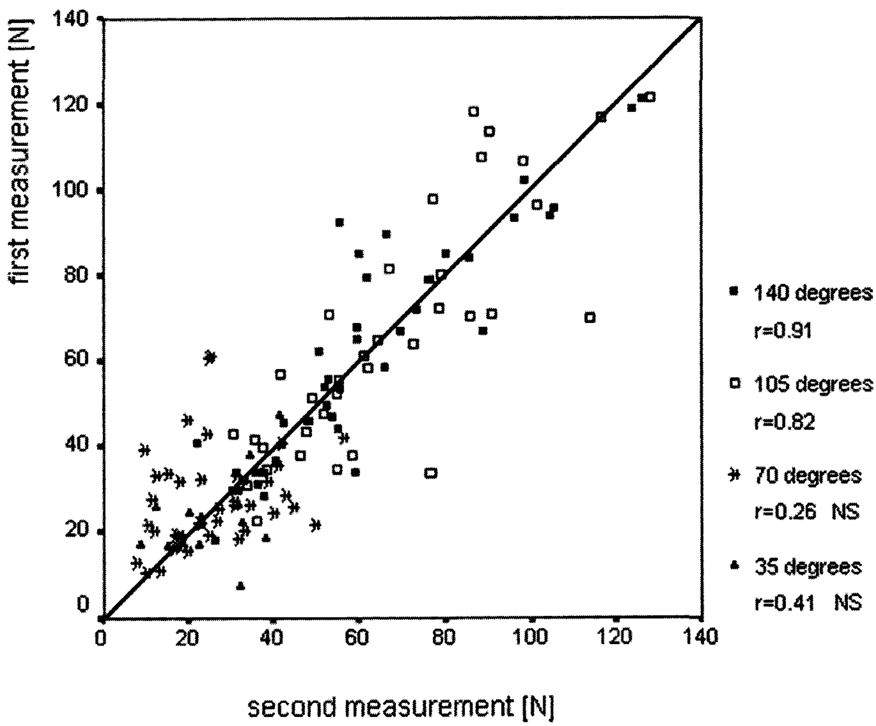


Figure 3.6.11Scatterplot of first and second result in the single flexion movement with PFW. Reproducibility in 140° and 105° was good but in 70° and 35° the correlation coefficients were not significant.

The correlation coefficients between the first and second results of the flexion-extension movement with PFW at 140°, 105° and 35° were above 0.71 (figure 3.6.12). The lowest correlation coefficient was 0.46, which was found at the 70° angle. We found no significant differences between the means of first and second measurement at the different angles. We therefore conclude that the results at 140°, 105° and 35° are sufficiently reproducible, but reproducibility of the results at the 70° angle is hampered.

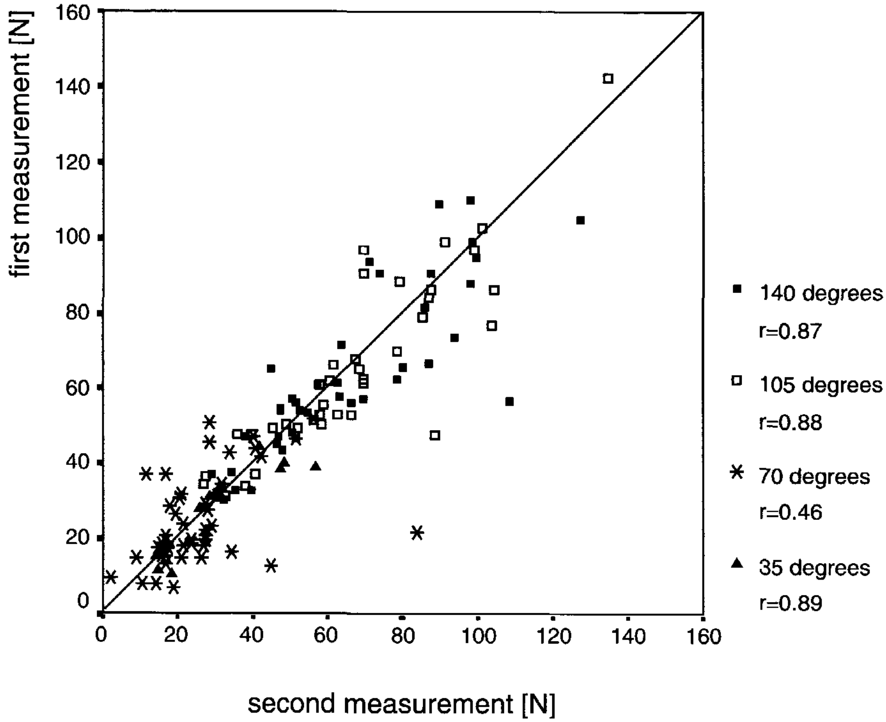


Figure 3.6.12Scatterplot of first and second result in the flexion-extension movement with the PFW. Reproducibility of 140°, 105° and 35° is sufficient, but of 70° is hampered by means of a low correlation coefficient.

For the repeated movements with the larger PFW reproducibility was studied in the same way. Correlation coefficients between first and second attempt in the first of five movements (figure 3.6.13) ranged from 0.56 to 0.95. However, the correlation coefficient for 35° was not significant which was also due to the small number of subjects (n=7). For this first flexion-extension movement the means at the different angles did not vary significantly. Because of the insignificance of the correlation coefficient at 35° and the low correlation coefficient at 70°, we argue that these angles are not acceptably reproducible.

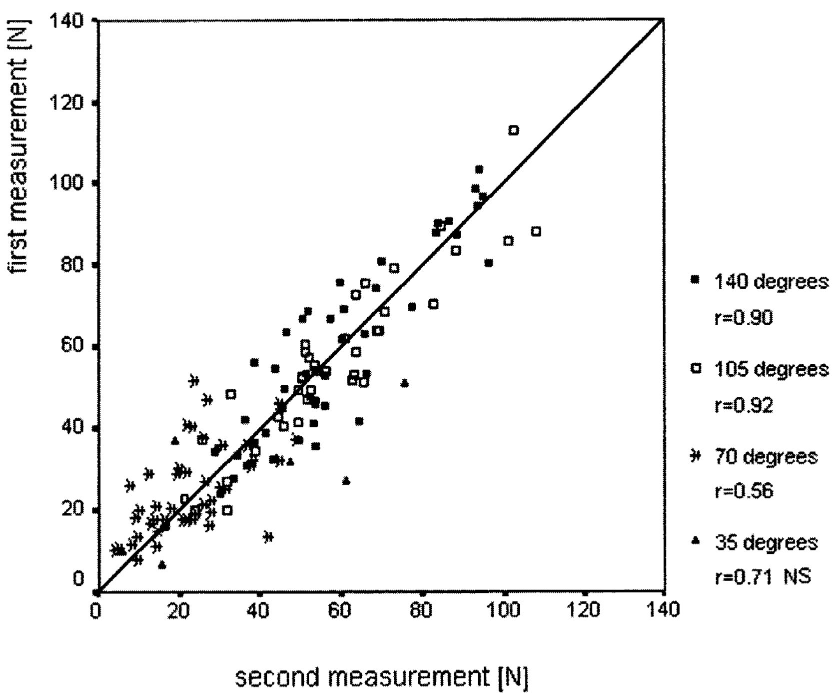


Figure 3.6.13Scatterplot of first and second results in the first flexion-extension movement in the repeated flexion-extension movement. The differences between the means were all found to be insignificant. On the basis of the correlation coefficients we argue that the results in 140° and 105° can be sufficiently reproduced, while the results in 70° and 35° cannot.

The reproducibility of the second movement in the repeated flexion-extension movement was good for the angles of 140°, 105° and 35°, but hampered for the 70° angle (figure 3.6.14). The correlation coefficient at the 70° angle was 0.46. The other correlation coefficients ranged from 0.82 to 0.92. Differences in the means were found to be insignificant. So, apart from the 70° angle, reproducibility was sufficient.

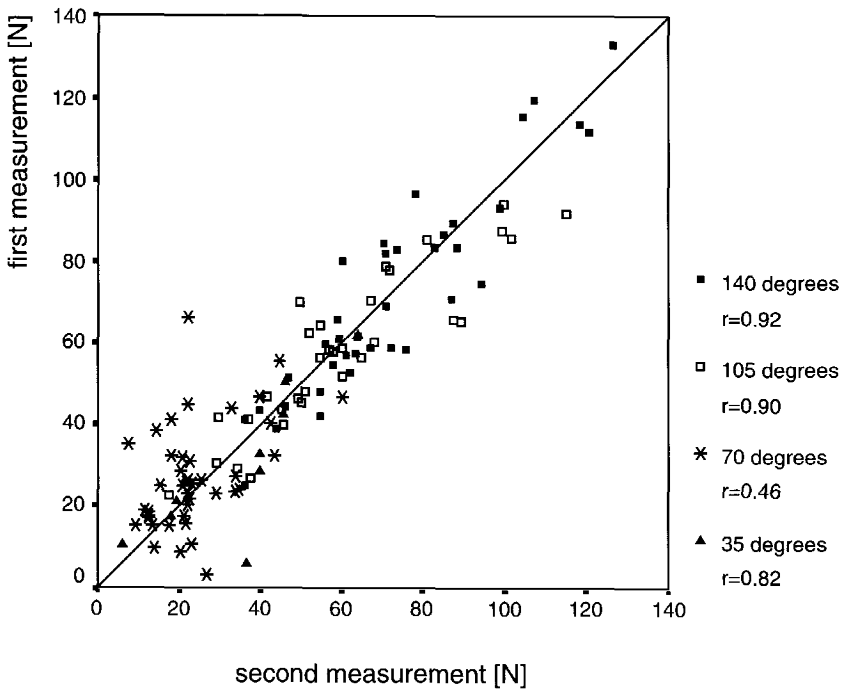


Figure 3.6.14 Scatterplot of first and second result in the second movement in the repeated flexion-extension movement with the PFW. The correlation coefficient in the 70° angle is low, which indicates insufficient reproducibility. Due to the insignificant differences in the means the reproducibility of the other angles is considered to be quite sufficient.

The correlation coefficients between the first and second repetition of the third movement in the repeated movement were all significant and varied between 0.47 and 0.96 (figure 3.6.15). The differences in the means of the maximal force and the force at 105° were significant and the results in this angle are therefore not sufficiently reproducible. The correlation coefficient of 0.47 at the angle of 70° indicates limited reproducibility.

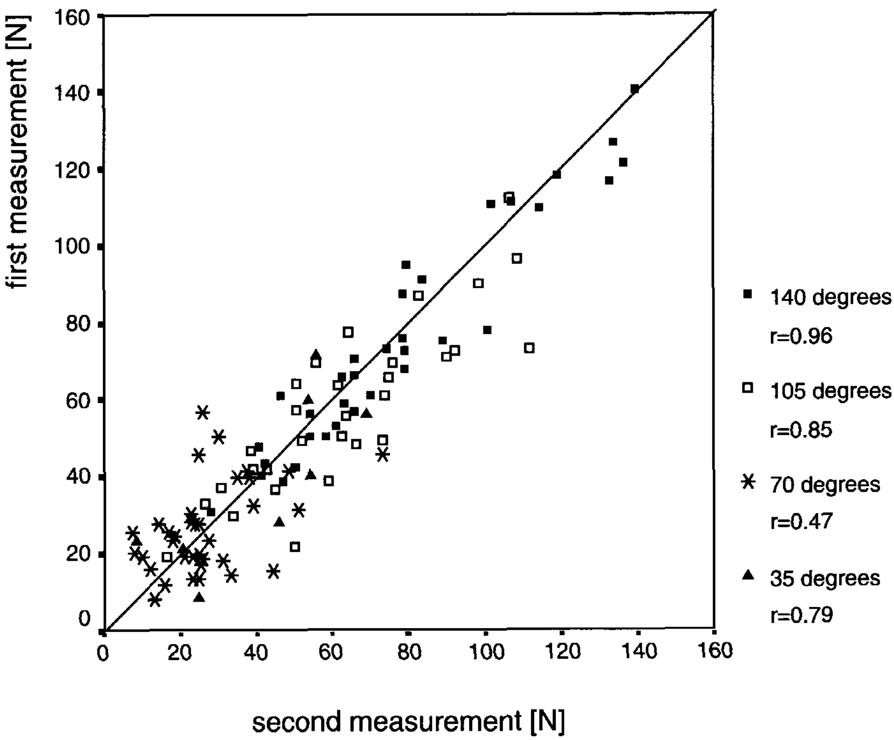


Figure 3.6.15 *Scatterplot of first and second result of the third movement in the repeated flexion-extension movement. The high correlation coefficients in combination with insignificant differences between the means indicate that the results in the 140° and 35° angle are sufficiently reproducible. However, because of a significant difference between the means of test and retest, the results in the 105° angle are considered not to be convincingly reproducible, as are the results at 70° due to a low correlation coefficient.*

The reproducibility of the <u>fourth</u> movement was determined from the insignificance of the differences between the means of the first and second repetition of the fourth movement, and from the correlation coefficients that lay between 0.55 and 0.94. The correlation coefficient of 0.55 at the 70° angle causes the reproducibility in this angle to be limited.

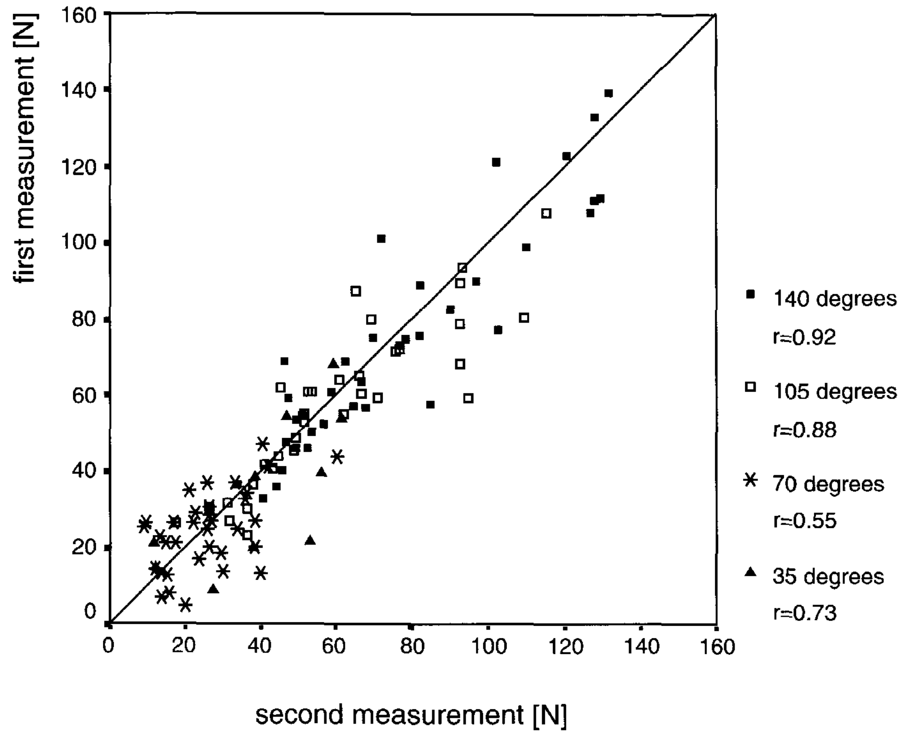


Figure 3.6.16Scatterplot of first and second result in the fourth movement of the repeated flexion-extension movement. Apart from the results at the 70° angle, which has a correlation coefficient under 0.71, all results are sufficiently reproducible.

Establishing the reproducibility of the 35° elbow angle in the fifth and last flexion-extension movement was hampered by the fact that only 3 subjects reached this angle. It was therefore not feasible to calculate a significant correlation coefficient in this angle. The correlation coefficients of the forces in the other angles and the maximal force ranged from 0.39 and 0.96. The means of the forces exerted in the elbow angle of 140° did differ significantly according to the T-value. Therefore, it is concluded that the reproducibility at the 70° and 140° is insufficient.

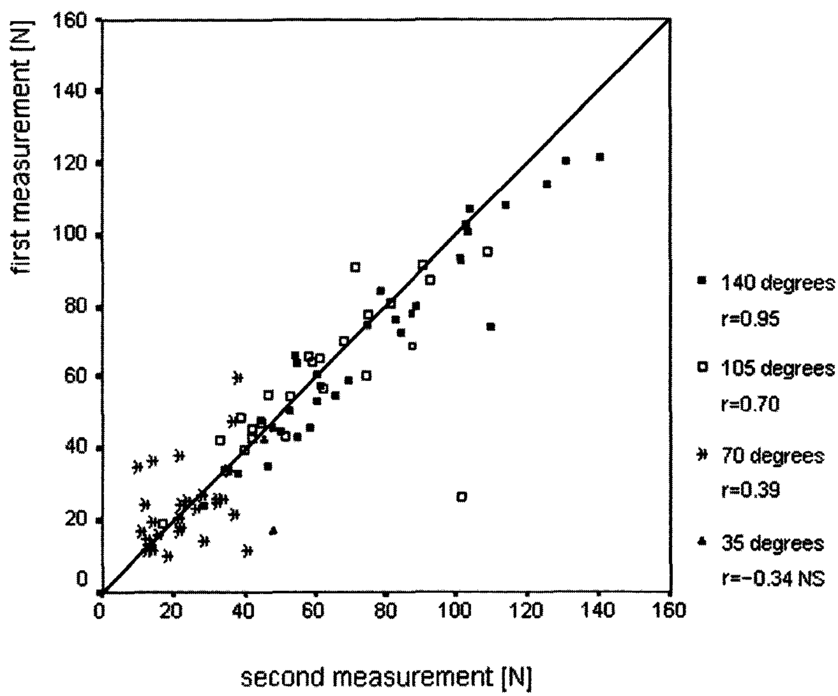


Figure 3.6.17 Scatterplot of first and second result in the fifth movement of the repeated flexion-extension movement. The results at the 140° and 70° angle are not sufficiently reproducible, the other two angles are.

The reproducibility of the repeated movements with the PFW is acceptable at some angles. Many of the correlation coefficients found were above 0.9, which is very high and indicates good repeatability. However, some other correlations were below 0.5, which indicates a difference in repetition, especially at the 70° angle where the correlation coefficient was low in each movement. The fourth flexion-extension movement was the most reproducible.

Overall, in the movements with the PFW the degree of reproducibility depended mainly on the elbow angle. The angles of 140 and 105° are sufficiently reproducible in most movements, but in the angle of 35° it is often limited, while at 70° reproducibility is poor in all movements.

Sex and age effects

When comparing the results of males and females we found that in all movements and at all angles males were generally stronger than females. The mean isoinertial forces of the males were somewhat higher in the movements of the OKW, and much higher in the movements of the PFW, than those of the females. With the OKW only a few of the differences in means were significant, while in the movement of the PFW all means of the males were significantly higher. The equality of the variances was tested and according to Levene's test the variances of the results in the movement of the OKW are generally similar, but the variance of the results in the movement of the larger PFW are generally different. The means and standard deviations of males and females are presented in tables $3.6.8^{A+B}$ (single flexion movement) $3.6.9^{A+B}$ (flexion-extension movement) and 3.6.10 (repeated flexion-extension movement). An asterisk (*) between the means indicates a significant difference in means and an asterisk between the standard deviations a significant difference in variance.

Table $3.6.8^{A}$ The mean and standard deviation of force exerted by males and females in the single flexion movement of the OKW. According to the means, males are generally stronger than females. The standard deviations, however, are similar.

force [N]	max. force	140°	105°	70°	35°
	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
males	41.0 (8.9)	24.3 (10.7)	31.3 (9.7)	23.0 (8.7)	19.9 (8.3)
	*	*	*	*	*
females	29.9 (9.4)	16.9 (6.6)	23.4 (9.4)	14.4 (10.2)	14.9 (6.6)

Table $3.6.8^{B}$ The mean and standard deviation of force exerted by males and females in the single flexion movement of the PFW. The means of the results of the males are higher than those of the females, and also the standard deviations are dissimilar (apart from those at 70°).

force [N]	max. force	140°	105°	70°	35°
	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
males	101.1 (22.4)	77.4 (21.4)	79.1 (21.6)	29.6 (8.7)	40.2 (19.3)
	* *	* *	* *	*	* *
females	58.1 (9.4)	42.9 (11.2)	46.5 (9.4)	20.9 (10.2)	24.0 (7.5)

Table 3.6.9^A For the movement with the OKW: the means of the isoinertial forces exerted by males and females in the different elbow angles and of their maximal isoinertial force. The means of the males are higher than of the females but the difference in variances is not significant.

force [N]	max. force	140°	105°	70°	35°
	x̄ (s)	x̄ (s)	x̄ (s)	x̄ (s)	x̄ (s)
males	37.9 (10.3)	21.1 (9.6)	29.5 (7.9)	20.8 (8.5)	18.9 (8.7)
	*	*	*	*	*
females	29.2 (8.9)	17.1 (7.4)	23.3 (8.9)	15.5 (9.1)	15.8 (6.9)

Table 3.6.9^B For the movement with the PFW: the means of the isoinertial forces exerted by males and females in the different elbow angles and of their maximal force. The means of the males are higher than of the females, and for the force exerted at 140° and for the maximal force there is also a significant difference in variance.

force [N]	max. force	140°	105°	70°	35°
	x̄ (s)	x̄ (s)	x̄ (s)	x̄ (s)	x̄ (s)
males	99.8 (20.9)	76.1 (20.4)	77.8 (19.9)	30.2 (10.7)	44.2 (17.9)
	* *	* *	*	*	*
females	58.2 (11.4)	43.0 (11.7)	47.5 (11.7)	21.4 (10.1)	27.1 (10.3)

Table 3.6.10 Means and standard deviations of isoinertial force exertion of males and females. Males are generally stronger than females, but this difference is most pronounced in the movement with the PFW. All significant differences are marked with **an** *asterisk between the significantly different results. An asterisk between two standard deviations indicates a significantly different variance.*

OKW force [N]	max. force	140°	105°	70°	35°
	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
flexion 1					
males	31.8 (7.4)	20.5 (8.4)	25.4 (6.3)	16.1 (7.8)	23.7 (10.1)
		* *			* *
females	27.7 (10.8)	15.2 (4.4)	22.6 (11.2)	13.0 (12.0)	14.7 (6.4)
flexion 2					
males	30.7 (6.1)	25.2 (7.3)	25.6 (7.2)	17.2 (7.7)	24.1 (16.1)
					*
females	27.2 (7.9)	23.3 (6.4)	21.2 (7.8)	14.1 (7.5)	16.8 (9.3)
flexion 3					
males	31.0 (6.1)	25.7 (6.1)	26.4 (7.5)	20.3 (7.8)	23.3 (15.2)
				*	
females	27.9 (10.5)	22.7 (5.6)	22.8 (9.3)	14.9 (9.0)	17.8 (13.1)
flexion 4					
males	32.1 (6.3)	26.4 (7.7)	27.1 (6.5)	20.1 (6.7)	18.2 (6.4)
		*	*	*	
females	27.5 (9.9)	22.4 (5.1)	21.7 (9.3)	13.7 (10.8)	16.3 (10.2)
flexion 5					
males	33.0 (8.0)	26.5 (7.3)	27.5 (6.7)	20.9 (7.2)	16.5 (7.0)
			*	*	
females	27.9 (10.7)	24.4 (13.8)	22.9 (8.5)	15.4 (10.2)	15.6 (4.9)

PFW force [N]	max. force	140°	105°	70°	35°
	x̄ (s)	x̄ (s)	x̄ (s)	x̄ (s)	x̄ (s)
flexion 1					
males	96.0 (21.8)	74.9 (18.0)	71.6 (19.7)	28.2 (10.0)	46.4 (9.6)
	* *	* *	* *	*	*
females	56.7 (11.7)	42.2 (10.4)	45.9 (13.2)	19.6 (7.6)	23.4 (12.4)
flexion 2					
males	104.1 (25.7)	95.9 (25.1)	71.5 (18.7)	32.1 (11.8)	46.6 (20.5)
	* *	* *	*	* *	*
females	61.4 (14.2)	56.8 (14.0)	46.5 (14.0)	20.6 (6.4)	25.9 (12.7)
flexion 3					
males	103.4 (25.3)	94.4 (26.0)	74.1 (19.7)	32.8 (12.5)	49.3 (18.4)
	* *	* *	*	* *	* *
females	62.8 (14.3)	57.5 (13.6)	47.3 (14.0)	21.9 (8.2)	26.7 (6.3)
flexion 4					
males	98.3 (23.0)	92.7 (23.6)	70.9 (19.2)	30.9 (8.7)	45.5 (14.2)
	* *	* *	*	*	* *
females	61.0 (12.9)	57.0 (13.7)	45.1 (12.9)	19.2 (6.3)	19.8 (6.3)
flexion 5					
males	101.0 (21.7)	95.1 (22.1)	72.5 (20.7)	32.4 (12.0)	51.3 (20.8)
	* *	* *	*	* *	*
females	58.3 (15.5)	54.5 (13.6)	47.5 (15.5)	18.8 (6.2)	28.1 (13.8)

The means of the subjects between 60 and 65 years of age in the movement of the OKW were similar to the means of the younger subjects (aged between 20 and 30 years) and there were hardly any significant differences in variance. For the larger weight the differences in the means were more pronounced and the elderly subjects were generally weaker than the young. The results from both age groups in the different angles with the two weights are presented in tables $3.6.11^{A+B}$ (single flexion), $3.6.12^{A+B}$ (flexion-extension) and 3.6.13 (repeated flexion-extension).

Table 3.6.11^A The means of the force exerted in the single flexion movement at the different angles and the maximal force exerted, in combination with the standard deviation for the movement with the OKW. The subjects over 60 have similar strength to the subjects under 30 years of age.

force [N]	max. force	140°	105°	70°	35°
	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
20-30	36.5 (10.2)	22.7 (8.2)	27.5 (9.8)	17.6 (9.8)	16.8 (8.8)
60-65	35.1 (10.2)	19.5 (10.5)	27.6 (11.1)	19.7 (10.7)	18.7 (7.3)

Table 3.6.11^B The means of the force exerted in the single flexion movement at the different angles and the maximal force exerted, in combination with the standard deviation for the movement with the PFW. With the exception of the 70° elbow angle, the subjects over 60 generally have less strength than the subjects under 30 years of age.

force [N]	max. force	140°	105°	70°	35°
	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
20-30	87.6 (33.3)	69.9 (26.0)	70.2 (29.1)	24.5 (10.2)	39.4 (19.9)
60-65	75.2 (22.7)	54.6 (21.7)	59.9 (19.5)	25.8 (9.6)	25.8 (9.9)

Table 3.6.12^A The means of the flexion force exerted in a flexion-extension movement at the different angles and the maximal force exerted, in combination with the standard deviation for the movement with the OKW. The subjects over 60 have similar strength to the subjects under 30 years of age.

force [N]	max. force	140°	105°	70°	35°
	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
20-30	33.7 (9.1)	20.1 (7.2)	27.5 (9.0)	18.2 (8.7)	16.7 (7.5)
60-65	33.9 (11.5)	18.7 (9.8)	25.9 (8.9)	18.3 (9.5)	17.9 (8.4)

Table 3.6.12^B The means of the flexion force exerted in a flexion-extension movement at the different angles and the maximal force exerted, in combination with the standard deviation for the movement with the PFW. With exception of the 70° elbow angle, the subjects over 60 generally have less strength than the subjects under 30 years of age.

force [N]	max. force	140°	105°	70°	35°
	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
20-30	85.7 (32.6)	67.0 (24.9)	70.9 (26.6)	23.0 (10.8)	38.1 (21.8)
60-65	75.5 (22.2)	54.7 (21.5)	59.6 (18.5)	27.7 (11.3)	33.6 (14.1)

In the repeated movement with the PFW, the subjects over 60 years of age generally generated a lower maximal force and less force in the 105° and 140° angle than the subjects under 30 years of age. This difference in mean force in the repeated movement is, however, rarely significant. In the movement of the OKW the elderly subjects were not weaker than the young, but had similar strength.

Comparison of the results with the one-kilogram-weight (OKW) and with the 1/3 peak-force weight (PFW)

To compare the results of the movements with the two weights the mean of the first and second result were used.

In the single flexion movement the means showed moderate correlations. The coefficients ranged from 0.48 to 0.56. The results at the 35° angle could not be correlated significantly. According to T-tests the results from the PFW were, at all angles, significantly higher than those from the one-kilogram weight ($p<0.05$). Table 3.6.13 contains the means and standard deviation for the forces at all angles and the maximal force for each weight.

Table 3.6.13 Means and standard deviation of maximal force exerted and forces exerted at 140°,105°,70° and 35° angle between upper and forearm, in a single elbow flexion movement with two different weights. The mean forces in the movement with the 1/3 peak-force-weight (PFW) were significantly higher at all angles than those exerted with the one-kilogram-weight (OKW).

Forces [N]	1 kilogram-weight $\bar{x}$ (s)	1/3 peak-force-weight $\bar{x}$ (s)
Maximal force	36.2 (10.3)	80.3 (28.1)
Force at 140°	20.9 (9.7)	60.6 (24.5)
Force at 105°	27.9 (9.9)	64.1 (24.4)
Force at 70°	19.1 (10.3)	25.2 (9.9)
Force at 35°	17.4 (8.4)	33.6 (17.3)

When comparing the means of the different weights in the flexion-extension movement we did find significant differences (all $p<0.05$). The mean isoinertial force was higher at all angles with the larger PFW. The mean and standard deviations of the movement with both weights are presented in table 3.6.14.

Table 3.6.14 Means and standard deviation of maximal isoinertial force exerted and isoinertial force exerted in an elbow angle of 140°, 105°, 70° and 35° moving a weight of 1kilogram (OKW), or of 1/3 of the maximal isometric peak force (PFW). The means exerted in moving the larger PFW are significantly higher than with the OKW ($p<0.05$).

Forces [N]	1 kilogram-weight $\bar{x}$ (s)	1/3 peak-force-weight $\bar{x}$ (s)
Maximal force	33.3 (10.8)	79.5 (27.1)
Force at 140°	18.3 (8.3)	60.0 (23.6)
Force at 105°	26.7 (8.5)	63.9 (22.8)
Force at 70°	18.1 (9.2)	25.3 (10.8)
Force at 35°	16.6 (7.9)	36.1 (17.2)

The means and standard deviations of all forces at different elbow angles in different numbers of flexion-extension movements are presented in table 3.6.15. The results of the paired T-test show that there is little relationship between the forces in the movement of the two weights.

Table 3.6.15 Maximal isometric flexion force and forces exerted in elbow angles of 140°, 105°, 70° and 35°. Because the movement of elbow flexion-extension was performed five times in a row the table contains information on force in five flexion movements. The means of the force exerted in the movement of the OKW are lower than the forces in the movement of the PFW. The differences in the means are significant and correlations between the same number of flexion movement with the OKW and the PFW are low and vary between –0.33 and 0.40.

force [N]	max. force	140°	105°	70°	35°
	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)	$\bar{x}$ (s)
flexion 1					
OKW	29.8 (9.3)	17.9 (7.3)	24.0 (8.7)	14.3 (10.0)	16.9 (8.1)
PFW	77.1 (26.4)	59.2 (22.1)	59.3 (21.2)	23.9 (9.8)	31.6 (16.6)
flexion 2					
OKW	29.0 (7.2)	24.1 (6.8)	24.1 (7.6)	15.3 (7.4)	17.6 (11.1)
PFW	83.6 (30.0)	76.8 (28.2)	61.2 (20.5)	26.2 (11.1)	35.2 (20.1)
flexion 3					
OKW	29.6 (8.7)	23.8 (5.7)	25.1 (8.4)	17.8 (8.8)	15.5 (5.3)
PFW	82.9 (28.5)	74.8 (26.5)	61.4 (21.6)	27.4 (11.9)	35.8 (17.2)
flexion 4					
OKW	29.8 (8.3)	24.4 (6.3)	25.3 (7.3)	17.0 (8.9)	18.7 (10.3)
PFW	80.0(25.7)	75.3 (25.5)	59.3 (20.9)	25.2 (9.9)	35.3 (17.3)
flexion 5					
OKW	30.7 (10.0)	26.3 (11.0)	25.5 (7.9)	18.0 (9.4)	17.3 (5.5)
PFW	80.3 (28.1)	75.3 (26.8)	60.9 (21.5)	25.8 (11.9)	41.7 (19.1)

From the results in 3.6.3 we concluded that the reproducibility of the movements with the one kilogram weight (OKW) was not as good as the reproducibility of the movements with the 1/3 peak-force weight (PFW). In the same section we argued that the isoinertial force exerted in the movements with the OKW seemed to be submaximal force exertions.

The relations between the forces exerted in the movements of the two different weights are not strong, as correlation coefficients are rather low. To give an idea of the correlation coefficients, the coefficients that describe the relation between the maximal forces in all movements are presented in table 3.6.16.

Table 3.6.16 Correlation coefficients between maximal isoinertial force exerted with the two weights in the three different movements. The coefficients are significant but lower than 0.71.

maximal force in:	correlation coefficient between OKW and PFW
single flexion	0.56
flexion-extension	0.43
repeated flexion-extension	0.35

The relation between submaximal isoinertial force and maximal isometric force is also not strong according to the correlation coefficients. None of the correlations between the isoinertial forces during flexion-extension and repeated flexion extension and the isometric forces in the different angles were significant. The correlations coefficients between isometric force exerted at elbow angles of 140°, 105° and 70° and the isoinertial force in the single flexion movement were significant and are presented in table 3.6.17. The coefficient for 35° was not significant (NS).

Table 3.6.17 Correlation coefficients between maximal isoinertial force exerted with OKW during single elbow flexion and maximal isometric force in four different angles. The correlation coefficients are rather low, the coefficient for the forces in 35° is not significant ($p>0.05$).

elbow angles	correlation coefficient between maximal isometric force and submaximal isoinertial force
140°	0.41
105°	0.37
70°	0.43
35°	0.30 NS

Because of the magnitude of the correlation coefficients we concluded that a comparison of maximal isometric force exertion and submaximal isoinertial force exertion would not substantially contribute to an improved understanding of the differences between isometric and isoinertial force exertion. We therefore decided to exclude the results with the OKW from theanalysis presented in the article in section 4.2.

Comparison of the results with 1/3 peak-force weigth (PFW) in different angles

Tables 3.6.18 to 3.6.24 contain, for each movement with the PFW, the correlation coefficients between the different angles and an indication of the significance of the differences in the means. A dot (•) indicates a significant difference and a dash (-) an insignificance.

Table 3.6.18 Within angle correlation coefficients and marks on differences in means for the single flexion movement with PFW.

elbow angle	140 degrees	105 degrees	70 degrees	35 degrees
140 degrees		0.84	0.48	0.57
105 degrees	-		0.59	0.56
70 degrees	•	•		0.33NS
35 degrees	•	•	•	

Table 3.6.19 Within angle correlation coefficients and marks on differences in means for the flexion-extension movement with PFW.

elbow angle	140 degrees	105 degrees	70 degrees	35 degrees
140 degrees		0.82	0.32	0.74
105 degrees	-		0.49	0.64
70 degrees	•	•		0.07NS
35 degrees	•	•	-	

Table 3.6.20 Within angle correlation coefficients and marks on differences in means for first movement in the repeated flexion-extension movement with PFW.

elbow angle	140 degrees	105 degrees	70 degrees	35 degrees
140 degrees		0.83	0.48	0.79
105 degrees	-		0.44	0.74
70 degrees	•	•		0.56
35 degrees	•	•	-	

Table 3.6.21 Within angle correlation coefficients and marks on differences in means for second movement in the repeated flexion-extension movement with PFW.

elbow angle	140 degrees	105 degrees	70 degrees	35 degrees
140 degrees		0.82	0.49	0.71
105 degrees	•		0.64	0.68
70 degrees	•	•		0.37
35 degrees	•	•	-	

Table 3.6.22 Within angle correlation coefficients and marks on differences in means for third movement in the repeated flexion-extension movement with PFW.

elbow angle	140 degrees	105 degrees	70 degrees	35 degrees
140 degrees		0.78	0.54	0.84
105 degrees	•		0.63	0.72
70 degrees	•	•		0.35
35 degrees	•	•	•	

Table 3.6.23 Within angle correlation coefficients and marks on differences in means for fourth movement in the repeated flexion-extension movement with PFW.

elbow angle	140 degrees	105 degrees	70 degrees	35 degrees
140 degrees		0.83	0.49	0.80
105 degrees	•		0.61	0.72
70 degrees	•	•		0.53
35 degrees	•	•	-	

Table 3.6.24 Within angle correlation coefficients and marks on differences in means for fifth movement in the repeated flexion-extension movement with PFW.

elbow angle	140 degrees	105 degrees	70 degrees	35 degrees
140 degrees		0.82	0.62	0.90
105 degrees	•		0.62	0.71
70 degrees	•	•		0.32NS
35 degrees	•	•	•	

On the basis of the tables we concluded that the inter-angle differences were mostly significant and that the correlation coefficients range was from moderate to good. The highest correlations were found between the results in 140° and 105° and between those in 140° and 35°. The lowest correlations were found between the results in 70° and the other angles.

In figures 3.6.18 to 3.6.20 boxplots are presented for all movements with PFW. Extreme results are marked with a circle or a star. For the boxplot of the repeated movement we included all results in each angle, therefore the number of cases mentioned under the horizontal axis is far higher than the number of subjects.

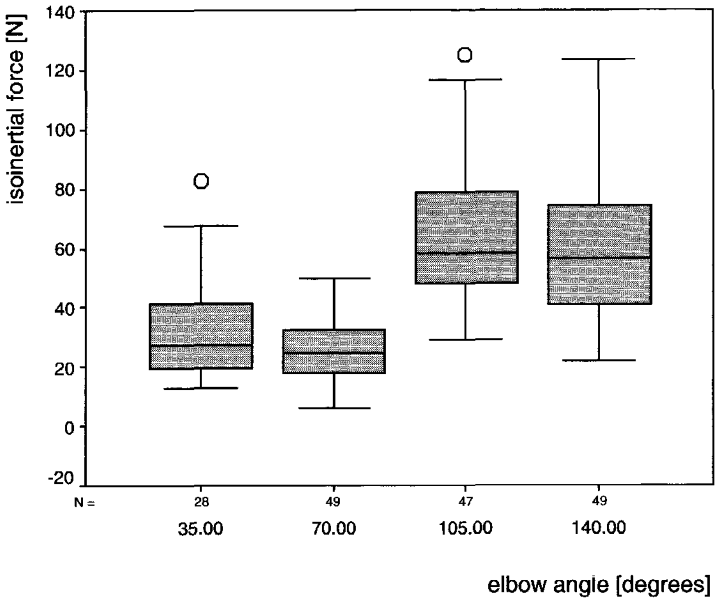


Figure 3.6.18 Boxplot of the isoinertial force exerted with the PFW at the different elbow angles of 140°, 105°, 70°and 35° in a single flexion movement.

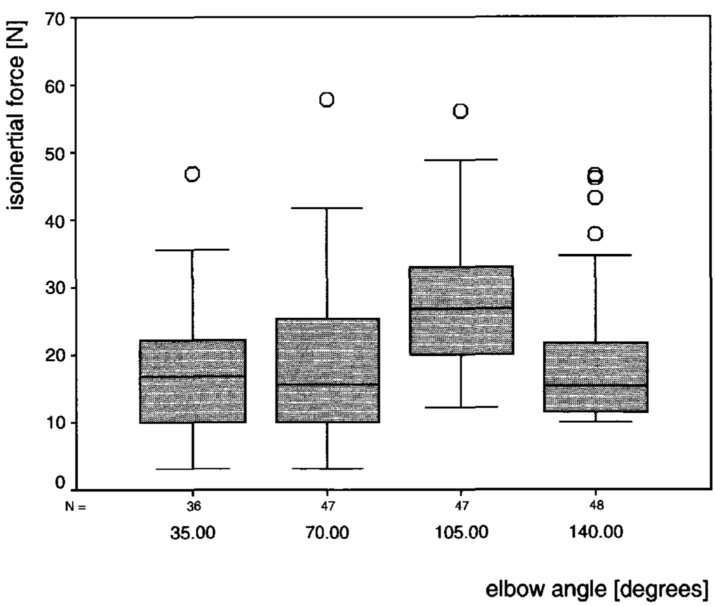


Figure 3.6.19 Boxplot of the isoinertial force exerted with the PFW in the different angles in a flexion-extension movement.

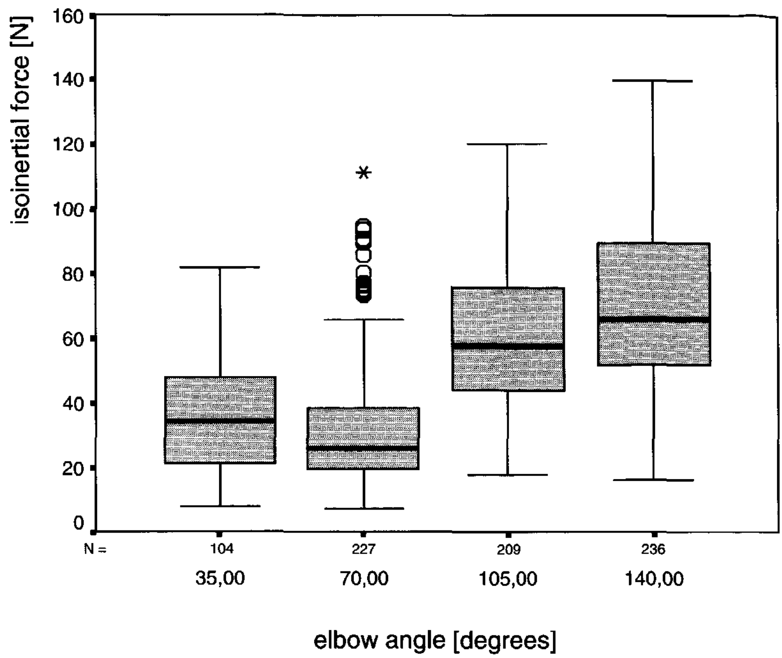


Figure 3.6.20Boxplot of isoinertial force exerted in the different angles with PFW in the repeated flexion-extension movement. All results of all subjects in all movements are combined in this boxplot.

We concluded that isoinertial force was highest at the beginning of a movement. The type of movement is not so relevant.

3.6.4 *Influence of movement type and moved weight on isoinertial force*

All results show that isoinertial force exertion depends largely on the individual capacity interacting with the heaviness of the weight that is moved. In general, the forces in the movement of the PFW (1/3 peak-force weight) are significantly higher than in the movement of the OKW (one-kilogram weight).

On the basis of the correlation coefficients it is clear that the forces exerted with the PFW are much more reproducible than the forces exerted with the OKW. According to the correlation coefficients, the relationships between the different movement types (e.g. single elbow flexion, single elbow flexion-extension and five times repeated elbow flexion-extension) were strongest for the results with the PFW.

As explained in section 3.2.6, we expected that with a weight that was too light it would not be possible to gain maximal acceleration. Therefore, the movements with OKW can be seen as submaximal force exertions, which are known to be less reproducible. Furthermore, submaximal force is always lower than maximal force.

Some influences were found that seemed to be caused by the type of movement. The results of the five times repeated flexion-extension movement differ significantly from the other two movements in the elbow angles of 140 and 105 degrees and in maximal force. The differences found are, however, also dependent on the heaviness of the weight that is moved. Roughly speaking, the results in the repeated movement with the OKW are lower than in the single movements, and the results in the repeated movements with the PFW are higher than in the single movements. Significant differences between the single flexion movement and the single flexion-extension movement were only found at the 35° elbow angle in the movement of the PFW.

The main reason for studying repeated elbow flexion-extension was to find out whether the isoinertial force exertion changes after a number of movements. We therefore compared the forces exerted in the different numbers of movements. We used a oneway-ANOVA to find significant differences in the results, depending on movement number. We found hardly any difference in force exertion, in all angles, for the different movements. Only the force exerted in an elbow angle of 140° showed differences between the first and fifth movement. Although other statistical tests show a very poor relationship between the results of the two weights, this difference was found in the movements of both weights. In the movement of the PFW we also found a significant difference between the force in the first and second movement at the 140°elbow angle.

4 Interpretation and combination of results of the Stadyn project

In this chapter some of the results from the Stadyn project are presented in the form of articles. Section 4.1 contains the results from the sub-study on the effect of the angle of the wrist on elbow flexion strength. It should be noted that the subject sample used in this sub-study is different from that used in the main study.

4.1 The relationship between elbow flexion strength and wrist angle

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(Submitted to The European Journal of Applied Physiology, Februari 2000)

Summary

This study concerns the influence of the angle of the wrist on maximal isometric elbow flexion strength. We measured 15 subjects aged between 25 and 63 years. They exerted maximal elbow flexion force while their elbow was flexed to 70° and their wrist was held either in a neutral position, or in flexion or extension of 30 degrees.

We found the highest results when the wrist was in the neutral position, but at 30° flexion the results were not significantly lower. When the wrist was extended 30° the results were significantly lower than in the neutral or the flexed position.

Introduction

Force exertion in sport, work and the activities of daily life is studied in order to understand the aetiology of musculoskeletal disorders, or to optimise performance. For the latter, joint position and range of motion are major issues because of their effect on muscle dynamics. Combinations of actions in different joints have been studied. For instance, grip force as a function of elbow position (Mathiowetz et al., 1985; Marley and Wehrman, 1992) and grip force as a function of wrist position (Kraft and Detels, 1972; Terrell and Purswell, 1976). Tests are conducted in laboratory conditions or in practical situations such as playing tennis or the handrim propulsion of wheelchairs (Veeger et al., 1998).

In situations where small effects are studied, it is necessary to eliminate disturbing effects from movement in co-acting joints from the same kinematic chain. Therefore the movement of those joints needs to be controlled, and force application has to be isometric. Although many interactions of upper extremity joints have been studied, there has been no study of the combination of wrist angle and maximal elbow flexion. We therefore decided to measure elbow flexion performance at different elbow and wrist angles.

Method and materials

Fifteen subjects joined the project, eight men and seven women. They were aged between 27 and 63 years. All subjects were healthy volunteers who did not practise a sport involving heavy arm loading (such as tennis or boxing) on a professional level. Subjects who had previously undergone arm surgery or had recently injured their arms were excluded from the tests.

In Table 4.1.1, subject information can be found on body mass, stature and sex.

Table 4.1.1 Subject information.

	Men $\bar{x}$ (s)	Women $\bar{x}$ (s)
body mass [kg]	81.3 (15.2)	77.0 (13.4)
stature [cm]	179.5 (9.0)	166.6 (6.6)

All measurements were done in our biomechanics laboratory. Body mass was established using an electronic scale. Body sizes were measured with an anthropometer in the following order: stature, elbow-grip length, elbow-shoulder length. Apart from the first, all measurements were taken while the subject was seated on an adjustable chair.

The same chair was used in the experiment. The length of the seat was adjusted to the length of the upper leg , while the feet were left unsupported. The subject sat upright with the back against a vertical support. The left arm, with the elbow bent at a 90° angle, was supported by an adjustable armrest (see figure 4.1.1).

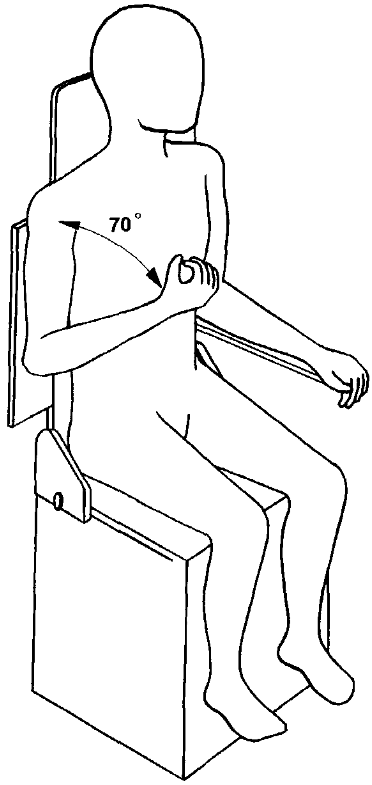

Figure 4.1.1 Subject position.

All measurements were performed on the right arm. The right upper arm was held vertically against a support. The hand exerted force on a handle with the elbow bent to a 70° angle. The handle was a cylinder with a diameter of 30 mm and a width of 130 mm. This is shown in figure 4.1.2. The handle could be adjusted in four directions: rotation around the hinge near the horizontal rail[A], sliding vertically along a rail[B], sliding horizontally along the side of the subject[C] and sliding in the direction of the handle[D].

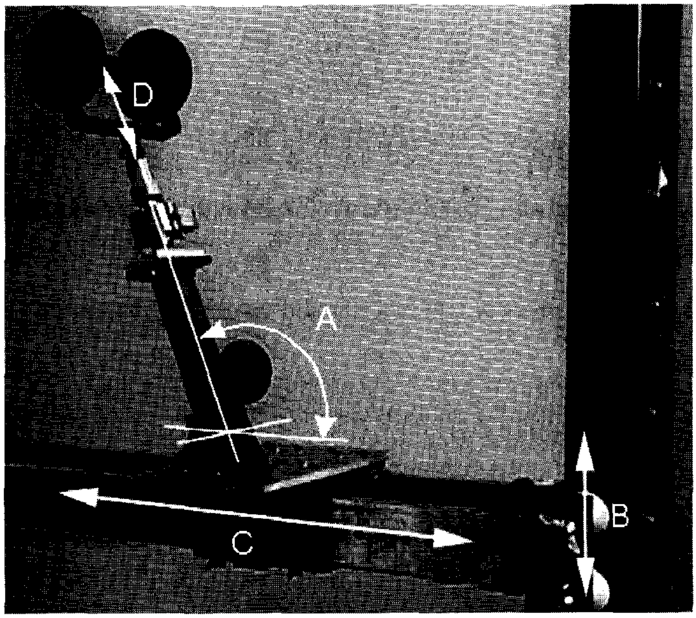

Figure 4.1.2 The moveability of the handle.

Two experimenters carried out the measurements. One instructed the subject and made the adjustments to the equipment. These were made with the subject in test position. To decide on the correct elbow angle the arm segments of the subject were held against a metal template.

The other attendant monitored the computer and gave the command to start force exertion. This person also checked on the force curve and gave correcting instructions when necessary.

During the measurements the subjects looked straight ahead. Before the actual measurement the subject was instructed what to do and was given the opportunity to try the equipment. During the actual measurement no verbal encouragement was given.

The force was build-up by the subject and measured isometrically. This was recorded with a strain gauge that was linked to a PC (Quick Log, Strawberry Tree Inc.) via an amplifier and data-acquisition system.

Maximal elbow flexion force was measured at the angle of 70° between upper arm and forearm. The handle was oriented perpendicularly to the forearm. The subjects were asked to flex and extend their wrist to three angles, in the following order: neutral, 30° flexion and 30° extension (see figure 4.1.3). In neutral position the axis of the forearm was aligned with the line between thumb and forefinger. The degrees of flexion and extension were determined on the basis of the neutral position.

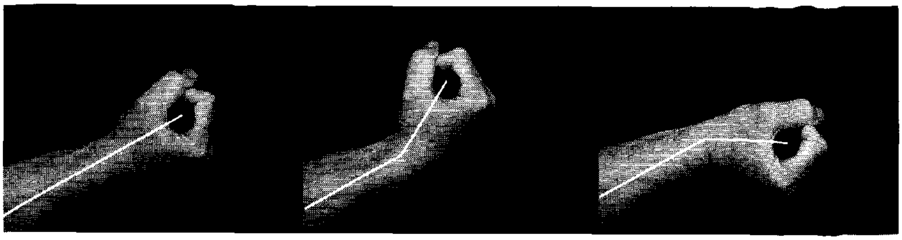

Figure 4.1.3 Wrist positions.

All measurements were repeated once. In this way isometric elbow flexion strength was measured twice in three different settings (see figure 4.1.3).

The results of the force exertions are presented as moment of force about the elbow joint. We therefore multiplied the handle force with the elbow-grip length.

All statistical results were calculated with SPSS for Windows NT (SPSS Inc.).

Results

Because of the small number of subjects we tested significance to a level of 0.05.

The correlation coefficients between all first and second measurements in each wrist position were calculated. The results are presented in table 4.1.2.

Table 4.1.2 Correlation coefficients between all first and second measurements.

wrist position	correlation coefficient
neutral	0.94
30° flexion	0.95
30° extension	0.96

All these correlation coefficients were significant ($p<0.05$). The differences in mean of first and second measurement regarding the t-tests were not significant

In table 4.1.3 the mean and standard deviation of all the wrist angles are presented. The mean elbow flexion force with the wrist in neutral position is a bit higher than the mean in 30° flexion. This difference is not significant according to the result of a t-test. The mean elbow flexion force is lowest with the wrist extended 30°; this mean is significantly lower than the other means ($p<0.05$).

Table 4.1.3 Mean and standard deviation of elbow flexion force in all three wrist positions per sex.

wrist position	$\bar{x}$ (s)
neutral	126.5 (35.7)
30° flexion	122.5 (40.3)
30° extension	108.3 (30.2)

The relation between the magnitude of the elbow flexion force is judged with the correlation coefficients between the means of force in each wrist position. The correlation coefficients are presented in table 4.1.4. All coefficients are significant ($p<0.05$).

Table 4.1.4 Correlation coefficients between elbow flexion forces in different wrist angles.

wrist position	neutral	30° flexion	30° extension
neutral	*	0.91	0.90
30° flexion		*	0.95
30° extension			*

Discussion and conclusions

Contrary to what we expected, wrist extension decreased elbow flexion force. Our expectation was based on the concept that pre-tension of the agonist flexor muscle at wrist extension contributes to maximal strength performance. Our interpretation is that the pre-tension effect of wrist extension in our experiment was not sufficient for force enhancement, because the elbow was flexed to the small angle of 70°. In this position the biarticular muscles, such as m. extensor carpi radialis and the m. brachio radialis, are shortened. We measured flexion force at 70°, because at this angle the wrist may flex or extend under load in a flexion movement from 140° to 35°. In the case of flexing acceleration, the mass inertia of the hand-held weight forces the wrist into extension, while the opposite occurs in the case of flexion deceleration. We observed both wrist positions in our subjects. In the majority of cases slight wrist flexion occurred at the 70° elbow angle. This was more pronounced with a larger weight, which can be ascribed to the greater effect of mass inertia during deceleration.

In the literature the 90° isometric elbow flexion force is the one most often studied, because of maximal possible isometric performance. The joint moment increases from full extension to 90° of elbow flexion, and then decreases with further elbow flexion (Chang et al. 1999). Our study at 70° is exceptional. The relevance of this angle is therefore primarily dynamic.

Literature on the influence of the wrist position on grip force mentions that 30° excursion of the wrist, in extension or in flexion, is a threshold (Gast, 1991), i.e. that larger angles produce lower results. In combination with the fact that we observed only slight deviations of wrist position from neutral, we decided to choose 70° extension for our measurements.

Because strong people performed well in both wrist flexion and extension and weaker people performed less well in the same proportion, it is interesting to develop an algorithm which relates to the force in a neutral position with other wrist angles.

Based on our measurements with the elbow flexed to 70° we conclude the following:

- Elbow flexion force is significantly lower at 30°-wrist extension.
- Wrist flexion of 30° does not result in different force exertions compared to neutral wrist position.

4.2 The difference between peak force and build-up force exertion in elbow flexion

A.I.M. Voorbij and C.J. Snijders

(Submitted to Occupational Ergonomics, Februari 2000)

Summary

This study concerns design relevant information on elbow flexion. We measured the maximal peak and build-up force in elbow flexion of 52 subjects, aged between 20 and 65 years. Our method deviates from other studies only because we did not immobilise the wrist with a cuff but left it free. We measured elbow flexion force in an angle of 140 degrees. In agreement with the literature, we found that peak force is higher than build-up force. We further established that peak force is more easily reproducible than build-up force. This deviates from findings presented in the literature. We also found that in women the force studied does not decrease with age.

The results of this study can be used by product designers to more accurately adjust the characteristics of their products to cope with the loads exerted by users in peak exertion.

Introduction

In studies on maximal isometric force, the force presented can be exerted in several ways. With respect to methods of exertion, the literature discriminates between build-up force and peak force (Daams, 1994; Kroemer, 1970; Caldwell et al. 1974). When force is exerted in a peak the time taken to reach maximum force is minimised, while in build-up force the force is gradually built up to maximum in a given time. Build-up force is known to be fairly reproducible and is the most common in the field of force measurements (Daams, 1994). The number of studies on peak force is limited because its reproducibility is not as good. Furthermore, this method of force exertion is more difficult for the subjects to control. Understandably, very few studies were performed on the relation between peak and build-up force (Daams 1994).

Studies on elbow-flexion force, as published by De Koning (1984), McDonagh et al. (1984), Hagberg (1981) and Lagassé (1979), concentrate on build-up force and not on peak force. The relation between peak and build-up force in elbow flexion has yet to be described.

We believe that this relation is of interest for industrial design engineers. Designers are co-responsible for the functioning of their products. They need to prevent the product from collapsing under the force of its user, thereby injuring the user. A designer will take precautions based on figures on maximal force. In most cases these figures are based on build-up forces, although Berg et al. (1988) found that for finger strength peak force is 7% higher than build-up force. For this purpose information on peak force would therefore be more valuable to a designer. We therefore decided to study the difference between build-up force and peak force in elbow flexion.

Method and materials

This study was part of a study on the relation between isometric and isoinertial force exertion in elbow flexion. As well as build-up flexion force at 140 degrees we also measured this force at three other angles. Peak force was only measured at 140 degrees.

In this study 52 subjects were measured. Two age groups were compared: 20 subjects of 20-30 years of age and 22 of 60-65 years of age. In table 1 the numbers of subjects per sex and per age group are presented.

Table 4.2.1 Number of subjects.

Age group	number men	number women
20-30	10	10
60-65	17	15

In table 2 information on sex, body mass, stature and grip force (mean of both hands) is presented.

Table 4.2.2 Information on stature, body mass and grip force.

Age group	stature [cm] men $\bar{x}$ (s)	stature [cm] women $\bar{x}$ (s)	body mass [kg] men $\bar{x}$ (s)	body mass [kg] women $\bar{x}$ (s)	grip force [N] men $\bar{x}$ (s)	grip force [N] women $\bar{x}$ (s)
20-30	181.2 (7.3)	167.0 (6.9)	70.8 (7.9)	66.1 (9.7)	50.9(8.4)	32.2(5.6)
60-65	176.5 (6.2)	164.2 (6.5)	82.4 (7.0)	68.7 (9.4)	43.1(6.8)	29.6(5.4)

The subjects were selected for their ability to flex and extend their elbow without difficulty. None of the subjects had serious problems with wrist, hand or shoulder. All measurements were done on the right arm.

There was a constant order of measurement. The session started with the measurement of elbow-grip length, upper arm length, stature and body mass. After that grip force was measured twice for both hands. Peak force was then measured twice at 140 degrees, followed by build-up force at the same angle (also twice). After that the remaining build-up force exertions were performed.

Between each force exertion there was a one-minute rest period.

Flexion forces were measured while the subject was sitting on an adjustable chair (see figure 4.2.1). The upper legs and the back were fully supported. The seat of the chair was fairly high and the soles of the feet were left unsupported. The left arm was supported by an adjustable rest.

The right upper arm was held in a vertical position by an adjustable plate. This plate prevented the upper arm from moving backward during force exertion.

The right hand held a handle which was connected to a force transducer (Hottinger Baldwin Messtechnik, typeU2A). The axis of this transducer was perpendicular to the forearm.

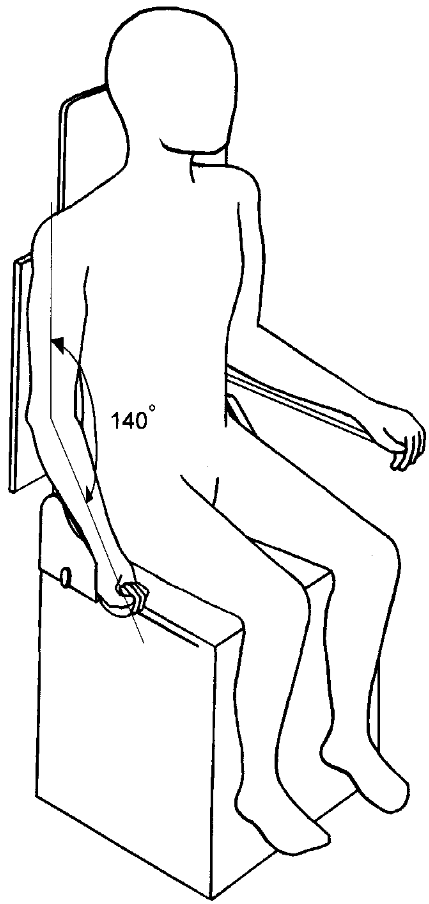

Figure 4.2.1 Subject position.

The wrist was not secured by a cuff but was left free to move. The subject was instructed to grip the handle firmly during the exertion of elbow flexion force.

The force transducer was connected to a strain indicator that was linked to a PC via a data shuffle.

Two attendants were present during the measurements. One attendant gave instructions while the other monitored the results of the force exertion.

The subject was instructed to exert maximal force. The principles of peak force and build-up force were explained prior to the measurements. During the measurements the attendants made no comments.

Statistical analysis was performed with SPSS (SPSS Inc. version 7.5)

Results

A paired t-test showed no significant difference between the first and second result of the peak force exertion. The correlation coefficient is 0.929 (p=0.000). In figure 4.2.2 the results of both measurements are presented as a scatterplot. Most dots are placed around the line that represents the position of equal results. The mean of the first attempt is 137.7N (s=46.3) and of the second 139.5N (s=45.4).

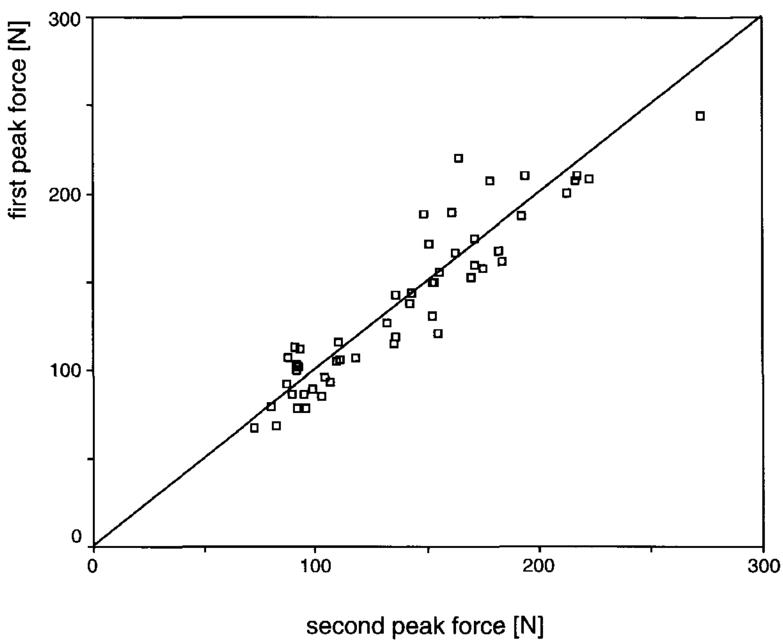

Figure 4.2.2 First and second peak force.

The difference between the first and second result of the build-up force exertion is somewhat larger than the difference between the peak forces, but in a paired t-test it was shown not to be significant (p>0.05). The mean of the first attempt was 260.5 (s=103.3), while the mean of the second attempt was 266.8 (s=97.1). The result of both attempts is presented in figure 4.2.3. The correlation coefficient for those results is 0.967 (p=0.000).

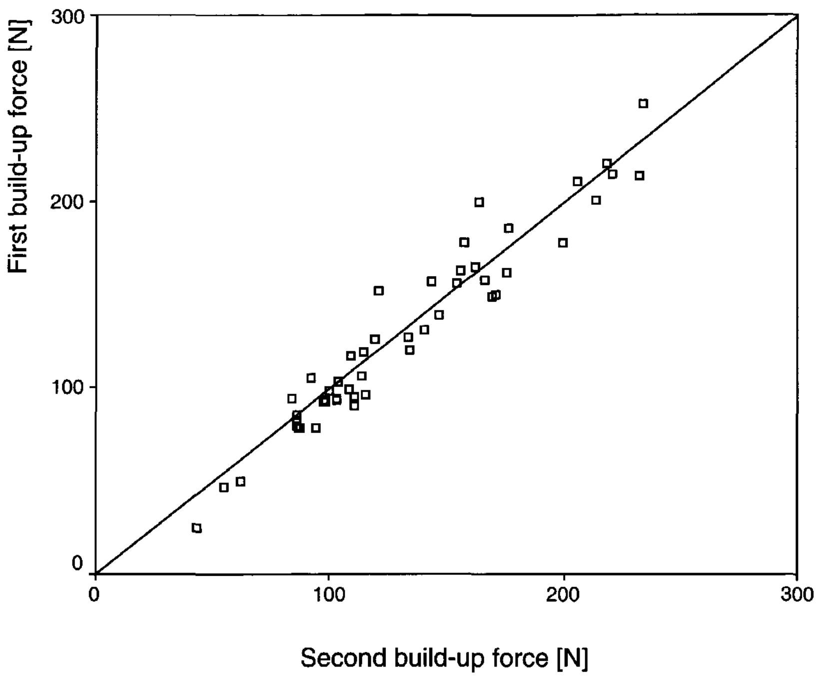

Figure 4.2.3 First and second build-up force.

Judging by the skewness and kurtosis, the results of the two force types are normally distributed.

According to the results of a paired t-test, the difference between the mean peak force and the mean build-up force is significant ($p=0.001$). The mean peak force is 138.8 N ($s=45.0$) while the mean build-up force is 129.3 N ($s=48.1$). The correlation coefficient for this relation is 0.913 and is significant ($p<0.05$). In the scatterplot in figure 4.2.4 the mean of the peak and of the build-up force are presented.

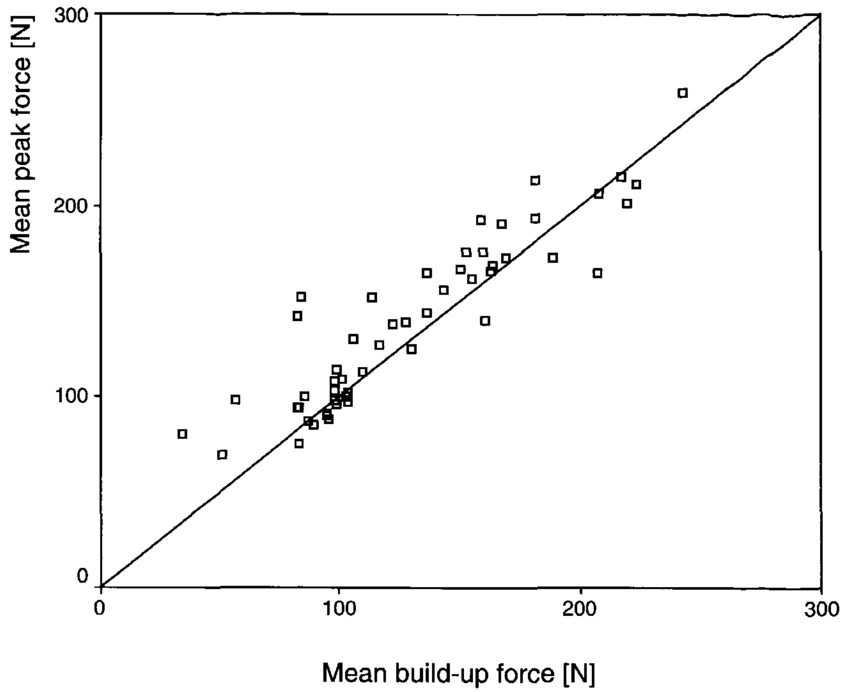

Figure 4.2.4 Mean peak force and mean build-up force.

In terms of percentage the mean peak force is 7.3% higher than the build-up force. In Newton the mean difference was 15.5. There are, however, large inter-individual differences in the relation between peak force and build-up force. One subject had a 42.2N higher build-up force than peak force, while another subject had a peak force that was 67.7N higher than his build-up force. In terms of percentage (of build-up force), the extreme differences were -20% and 138%.

A partial correlation (controlled for age) shows that the fact that there are two age groups does not affect the correlation coefficient. When controlled for sex, the correlation coefficient between peak and build-up force drops to 0.81.

In table 4.2.3 the results for mean peak and build-up elbow flexion force and the standard deviations are presented per age group per sex.

Table 4.2.3 Mean and standard deviations of peak and build-up force.

Age group	peak force [N] men $\bar{x}$ (s)	peak force [N] women $\bar{x}$ (s)	build-up force [N] men $\bar{x}$ (s)	build-up force [N] women $\bar{x}$ (s)
20-30	182.0 (39.9)	98.3 (15.2)	175.1 (40.2)	92.0 (16.5)
60-65	164.9 (33.0)	107.4 (24.0)	155.5 (40.8)	94.0 (25.7)

When force is exerted with the hand while the elbow is kept in position, muscles in the arm have to compensate for a moment that occurs around the elbow joint. In table 4.2.4 the mean and standard deviation of the moments around the elbow joint are presented. This moment was calculated by multiplying the length of the forearm (epicondylus radialis-centre of grip) with the force exerted on the handle.

Table 4.2.4 Mean and standard deviation of peak and build-up moment.

Age group	peak moment [Nm] men $\bar{x}$ (s)	peak moment [Nm] women $\bar{x}$ (s)	build-up moment [Nm] men $\bar{x}$ (s)	build-up moment [Nm] women $\bar{x}$ (s)
20-30	61.0 (13.6)	29.7(4.3)	58.7 (13.8)	27.8 (4.8)
60-65	55.0 (11.9)	32.2(8.0)	51.9 (14.3)	28.3 (8.5)

Age does not significantly influence the results of the force exerted on the handle. However, for the females the mean of the 60-65 year old females is unexpectedly higher than the mean of the 20-30 year old females, while the younger males are stronger than the older ones.

Sex does significantly influence the results. Men are generally stronger than women, regardless of the age group.

Discussion and conclusions

We did not anticipate such remarkable results for peak and build-up force at 140 degrees elbow angle. In our method of measuring we measured only the force that is perpendicular to the forearm. Although this is arguably the most essential direction of force measurement when studying elbow flexion force, it is not guaranteed that all force is exerted in that direction. We did not, however, study other force components.

We did not immobilise the wrist with a cuff although this is common practise in other studies. We aimed at providing information on a situation that was as natural as possible, and therefore most relevant for use by product designers. An immobilised wrist is far less natural than a mobile one. The main reason that other researchers immobilise the wrist is to prevent the wrist from influencing the elbow flexion force. We limited this influence by having the subject grip the handle firmly during the exertion of elbow flexion force, thus preventing the wrist from bending away from the 'neutral' position.

We studied only peak force in elbow flexion when the elbow was held at an angle of 140 degrees. This study was part of a larger study whose aim was to compare isometric and isoinertial force measurements. For the isoinertial force exertion the starting angle of the elbow flexion movement was 140 degrees. To emphasise some aspects of the isometric force in this specific angle we studied both peak and build-up force. We did not expect to such remarkable results in the comparison of these force types and so did not study peak force in other angles.

We feel that further study into the relation between the two force types with respect to different angles of the elbow is advisable. To a product designer, however, the relation between the two force types in all angles is of equal interest because product use is not confined to one specific angle.

The results show an anticipated difference between men and women, but the fact that the elderly women were stronger than the younger ones is unexpected. However, the results in the grip forces as presented in table 4.2.2 show that the young women generally have a larger grip force. We therefore conclude that the difference in elbow flexion force is not caused by a biased sample. This difference may be caused by differences in working conditions. The elderly women may use their arms more frequently as they traditionally do more active housework.

We found the reproducibility of peak force to be better than build-up force. According to Close (1972) this is extraordinary, because muscle tension fluctuates too much to get a reliable reading in a peak.

Although we found peak force to be 7.3% higher than build-up force, this is not always the most relevant information for industrial design engineers. The inter-individual differences are large. We found one subject whose peak force was 238% of the build-up force! A product might well collapse under such a peak force if its strength were based on 'build-up' information only. If this subject is amongst the strongest users a product might collapse under a peak force when its strength is based on built up information only.

We compared peak and build-up force and got remarkable results. Although the mean difference between the two force types, in terms of percentage, is on the same level as that found by, for example, Berg et al. (1988), we found peak force to be more reproducible than build-up force. With respect to ageing, we found that the decrease in force was present in the males, but was reversed in the females, in spite of the results of the grip force measurements which show a traditional decrease.

With reference to our results we reached the following conclusions:

-Peak force is larger than build-up force.

-In elbow flexion peak force is more reproducible than build-up force.

-The decrease of peak force in elbow flexion is related to gender.

4.3 The relationship between maximal isoinertial and isometric force exertion in elbow flexion

A.I.M. Voorbij and C.J. Snijders
(Submitted to the Journal of Biomechanics, February 2000)

Summary

Human isometric force is often measured. Isoinertial force measurements are seldom taken. Product designers would benefit substantially from information about isoinertial force exertion because it represents force exertion in product use much better than isometric force exertion. This, rather explorative, study concentrates on the relation between isometric and isoinertial force exertion in elbow flexion.

In two sessions measurements were performed on 51 male and female subjects, aged between 20 and 30 or between 60 and 65 years. During both types of measurement the subjects were seated. In the isometric force measurements the force was exerted onto a handle, while in the isoinertial force measurements the subjects moved a hand-held weight. The weight moved by the subjects was one-third of their maximal isometric peak force. We compared the two force types at elbow angles of 140°, 105°, 70° and 35°.

We found that maximal isoinertial force exertion is lower than maximal isometric force exertion. The two types of force exertion are, however, strongly related particularly at the start of the movement.

This study provides information for product designers to help them improve the ergonomic fit of their design to the needs and force characteristics of their intended users.

Introduction

Much is known about the isometric forces of humans. Numerous studies have been done in this field and these data are of great value for product design. Designers use the information to enhance the ergonomics of their design. Nevertheless, several forces have not yet been studied, for example, the pushing force applied by the hip when opening a door. The most intensively studied forces are those that incorporate the hand as the surface of contact. This is, in fact, product handling and these studies are the most relevant to product use.

In real life situations force is usually exerted in combination with movements. Studies that incorporate force and motion are most often isokinetic. These data are useful in sports sciences but are hardly relevant to product design, because the constant velocity does not reflect product use. In isoinertial conditions the velocity is not relevant. Isoinertial conditions are described by the second law of Newton: a mass (m) receives acceleration (a) by a force (F) according to F=m.a. The isoinertial conditions closely mimic real life situations and are therefore most relevant for use in product design. Because, however, isoinertial measurements are much more complicated than isometric, only a few studies have been published.

In sports science isoinertial forces in bench pressing were studied by Murphy et al. (1994). Niesing et al. (1990) developed a wheel chair ergonometer to measure hand propulsion in relation to posture, joint angles and physical condition. The computer controlled the resistance. This device was also applied by Lode Instruments in a bicycle ergonometer, which allowed for adjustment of man (body and bicycle weight) and a variety of parameters like hill inclination and wind force.

We are not aware of any studies on force in motion in free space. This type of force exertion is very common in daily life and in professional activities. We therefore decided to carry out an explorative study of this field. We wanted to assess the differences between isometric and isoinertial force exertion, and to assess possibilities for the practical application of isoinertial data.

With reference to the importance of hand-applied forces to product design, we measured isoinertial elbow flexion force while the hand holds a weight. We also measured isometric elbow flexion force under the same conditions.

Method and materials

The study concentrated on the comparison of isometric and isoinertial force exertion. All subjects participated in two sessions of force exertion - an isometric session and an isoinertial session. All subjects were first measured isometrically.

Isometric session

The isometric session lasted about 45 minutes.

The session began by establishing the maximal grip force for the left and right hand in two measurements. We used a Jamar Hand Dynamometer Model 1 (Asimov Engineering Company, California, USA).

For the measurement of isometric elbow flexion the subject was positioned on an adjustable chair (figure 4.3.1). This chair supported the back and the right arm vertically and the left forearm horizontally. The feet were unsupported. The subject looked straight ahead during force exertion. The wrist was unbraced but subjects were instructed to grip the handle firmly to keep the wrist straight.

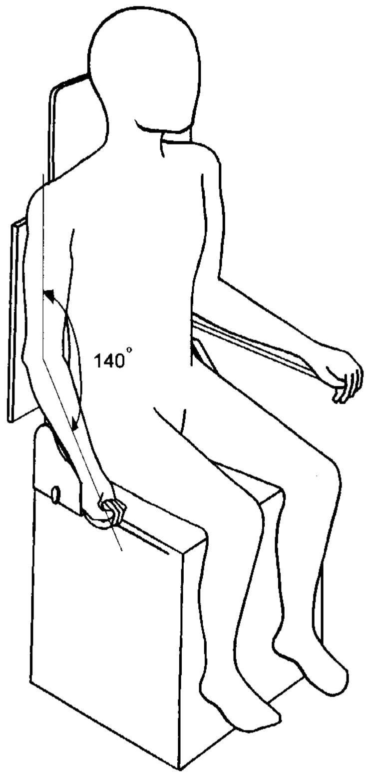

Figure 4.3.1 Subject position.

All measurements were performed on the right arm. Five types of measurements were done:

- Maximal peak force with an angle of 140 degrees between fore- and upper arm.
- Maximal build-up force in a 140 degrees elbow angle.
- Maximal build-up force in a 105 degrees elbow angle.
- Maximal build-up force in a 70 degrees elbow angle.
- Maximal build-up force in a 35 degrees elbow angle.

All types of force exertion were repeated once. Between each measurement there was a one-minute rest period.

The forces were exerted on a handle. This handle was adjusted in such a way that the axis of the force transducer (Hottinger Baldwin Messtechnik, type U2A) was perpendicular to the forearm of the subject. The force transducer was linked to a PC via a data shuttle.

The subjects were given instructions before each force exertion.

Two experimenters attended the measurements. One gave the instructions and stayed with the subject during the force exertion. The other viewed the results on-line and, if necessary, commented on the force graph afterwards.

During the actual force exertion the experimenters refrained from comments or encouragement.

Isoinertial session

Isoinertial measurements took place about two weeks after the isometric sessions.

The chair used in the isometric session was also used in the isoinertial measurements. The position of the subject was also kept the same. Four Infra Red Emitting Diodes (IREDs) were placed on the right arm of the subjects: one on the wrist near the processus styloidus, one at 12cms from the epicondylus ulnaris, one at the same distance on the upper arm and one on the most proximal point of the caput humeri (see figure 4.3.2). A fifth IRED was placed on the weight that was to be moved.

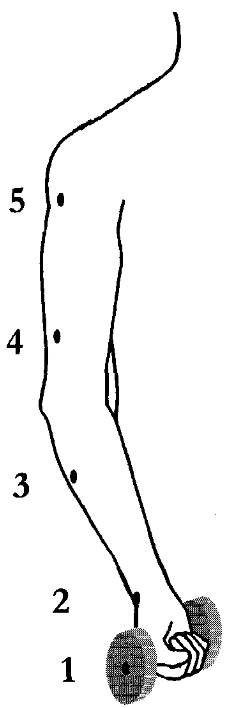

Figure 4.3.2 Position of the markers: no.1 is placed on the weight that is to be moved by the subject; no.2 is on the wrist near the processus styloideus; no.3 at 12cms from the epicondylus ulnaris on the forearm; no.4 at the same distance on the upper arm; no.5 on the most proximal point of the caput humeri.

The movement of the IREDs was monitored by an OPTOTRAK 2010-system (Northern Digital Inc., Waterloo ON, Canada) with two camera units, each containing two camera's.

The subjects were handed a weight and were instructed to move that weight as fast as possible. During force exertion they were told to grip the weight firmly to keep the wrist straight.

The subjects first moved a mass of 1kg according to three separate trajectories:

Elbow flexion from 140 degrees to zero.

Elbow flexion followed by extension from 140 via zero back to 140 degrees

Five times repeated elbow flexion-extension from 140 via zero back to 140 degrees.

After the movements with 1kg the subjects were handed a weight that represented one-third of their peak force in the isometric session. The movements were then performed with this larger weight. All movements were repeated once.

After each movement there was a rest period of one minute.

Two experimenters attended the isoinertial session. One monitored the functioning of the IREDs and gave the starting commands to the subject. The second attendant instructed the subject on the movements and the handling of the weight. In rest periods this attendant took over the weight from the subject.

During force exertion the attendants refrained from conversation and encouragement.

We measured subjects in two age groups; 60-65 and 20-30 years of age. A total of 51 subjects participated in both sessions. The subjects were selected for their ability to flex and extend their elbow without difficulty. Furthermore, they did not have problems with their wrist, hand or shoulder. Table 4.3.1 contains the number of subjects per age group per sex.

Table 4.3.1 *Number of subjects that took part in both the isometric and the isoinertial force measurements. The subjects were selected for their ability to flex and extend their elbow without complaints.*

Age group	number	
	men	women
20-30	10	9
60-65	17	15

Information on body mass, stature and grip force is presented in table 4.3.2, per sex and per age group.

Table 4.3.2 Information on stature, body mass and grip force per sex and per age group.

Age group	stature [cm] men $\bar{x}$ (s)	stature [cm] women $\bar{x}$ (s)	body mass [kg] men $\bar{x}$ (s)	body mass [kg] women $\bar{x}$ (s)	grip force [N] men $\bar{x}$ (s)	grip force [N] women $\bar{x}$ (s)
20-30	181.2 (7.3)	166.6 (7.2)	70.8 (7.9)	66.4 (10.3)	50.9 (8.4)	32.0 (5.8)
60-65	176.5 (6.2)	164.2 (6.5)	82.4 (7.0)	68.7 (9.4)	43.1 (6.8)	29.6 (5.4)

Results

All statistical tests were performed on a significance level of 0.05.

To test reproducibility the results of each first measurement of a specific position or movement were compared with the results of the second in exactly the same position or movement. Reproducibility was found to be insufficient for the movements with the one-kilogram weight. For the movements with the weight that represented one-third of the peak force, the reproducibility was hampered in the 70° and 35° for all types of measurement. Nevertheless, we decided to use the results in further analysis.

The results presented here are the means of the first and second measurements, and for the five times repeated elbow flexion the mean of these means in all five flexions.

When the results of isometric force exertion in the different elbow angles (see table 4.3.3) are compared with each other there are some differences in means. The highest mean is found in the elbow angle of 140° and the lowest in 35°. The differences between the two highest and this lowest result are significant ($p>0.05$), the other differences are not.

Table 4.3.3 Mean and standard deviation of isometric force in four different elbow angles. The differences between the means are only significant when the results in the 140° and 105° are compared with the results in the 35°-elbow angle.

elbow angle	Isometric force [N] $\bar{x}$ (s)
140°	129.8 (48.4)
105°	125.1 (43.9)
70°	114.7 (38.9)
35°	92.1 (32.6)

The isometric force that was exerted, per sex, in the four angles mentioned is presented in table 4.3.4. With a t-test on independent samples it was determined that the means of the males are significantly higher than those of the females. Furthermore it was determined that, apart from the results at 35°, the differences in variation are also significant.

Table 4.3.4 Mean and standard deviation of maximal isometric elbow flexion force in four different angles presented per sex. The means of the males are significantly higher than those of the females.

Isometric elbow flexion force [N]		
	men	women
elbow angle	$\bar{x}$ (s)	$\bar{x}$ (s)
140°	162.7 (40.9)	92.8 (22.4)
105°	153.4 (37.7)	93.3 (24.3)
70°	139.8 (34.2)	86.5 (20.1)
35°	110.5 (30.3)	71.4 (20.7)

The results of isometric force in the different elbow angles presented per age group show that the subjects under 30 are isometrically stronger than those over 60 (table 4.3.5). A t-test for independent samples indicates that this difference is neither significant ($p>0.05$) for the means nor for the variance.

Table 4.3.5 Mean and standard deviation per age group of maximal isometric elbow flexion force in four different angles. The differences between the means of the age groups are small and insignificant ($p>0.05$).

Isometric elbow flexion force [N]		
	20-30	60-65
elbow angle	$\bar{x}$ (s)	$\bar{x}$ (s)
140°	135.1 (53.0)	126.7 (46.1)
105°	130.0 (51.1)	122.2 (39.7)
70°	120.6 (43.8)	111.2 (36.0)
35°	97.1 (37.7)	89.1 (29.5)

As mentioned earlier, the isoinertial force measurements were started with a weight of one kilogram. This made it possible to obtain results of submaximal force exertion. The results with the weight of one kilogram were much lower than the results with the larger weight that approximated to one third of the maximal isometric peak force (table 4.3.6).

Table 4.3.6 Isoinertial force exerted in moving one kilogram as percentage of isoinertial force exerted in moving a weight of one third of the maximal isometric peak force. The isoinertial force that is exerted in the measurements with one kilogram is much lower than with the larger weight that approximated to one third of the maximal isometric peak force.

elbow angle	% of isoinertial force with 1/3 peak force weight
140°	54
105°	65
70°	24
35°	38

The means and standard deviations of the larger weight are presented in tables 4.3.7 and 4.3.8, respectively discriminating on sex and age group. Because isoinertial force was exerted in three different movements there are three categories of isoinertial force in each table. Again the results of the males are higher than those of the females, and the differences in means in all angles are significant.

Table 4.3.7 Mean and standard deviation of isoinertial force exerted by males and females in four different angles during three different movements. The differences in both means and variance are significant; males are stronger than females.

Isoinertial elbow flexion force [N]			
	elbow angle	men $\bar{x}$ (s)	women $\bar{x}$ (s)
Single elbow flexion	140°	77.4 (21.6)	42.9 (11.2)
	105°	79.1 (21.4)	46.5 (11.2)
	70°	29.6 (10.3)	20.9 (6.9)
	35°	40.2 (19.3)	24.1 (7.5)
	elbow angle	men $\bar{x}$ (s)	women $\bar{x}$ (s)
Elbow flexion-extension	140°	76.1 (20.4)	43.0 (11.7)
	105°	77.9 (19.9)	47.5 (11.7)
	70°	30.2 (10.8)	21.4 (10.1)
	35°	44.2 (17.9)	27.1 (10.3)
	elbow angle	men $\bar{x}$ (s)	women $\bar{x}$ (s)
Repeated elbow flexion	140°	90.3 (21.9)	53.2 (13.0)
	105°	70.2 (18.7)	45.9 (11.9)
	70°	31.6 (10.3)	20.1 (9.2)
	35°	49.4 (16.5)	25.6 (6.1)

The results of isometric force in the different elbow angles presented per age group show that the subjects under 30 are isometrically stronger than those over 60. A t-test for independent samples indicates that this difference is neither significant ($p>0.05$) for the means nor for the variance.

Table 4.3.8 *Mean and standard deviation per age group of maximal isoinertial elbow flexion force in four different angles during three different movements. The differences between the means of the age groups are small and insignificant (p>0.05).*

	Isoinertial elbow flexion force [N]		
		20-30	60-65
	elbow angle	$\bar{x}$ (s)	$\bar{x}$ (s)
Single elbow flexion	140°	69.9 (26.0)	54.6 (21.7)
	105°	70.2 (29.1)	59.9 (19.5)
	70°	24.5 (10.2)	25.8 (9.6)
	35°	39.4 (19.9)	25.8 (9.9)
	elbow angle	20-30	60-65
		$\bar{x}$ (s)	$\bar{x}$ (s)
Elbow flexion-extension	140°	67.0 (24.9)	54.7 (21.5)
	105°	70.9 (26.6)	59.6 (18.6)
	70°	23.0 (10.8)	27.7 (11.3)
	35°	38.1 (21.8)	33.6 (14.1)
		20-30	60-65
	elbow angle	$\bar{x}$ (s)	$\bar{x}$ (s)
Repeated elbow flexion	140°	80.4 (28.9)	67.7 (22.7)
	105°	64.8 (22.4)	55.4 (18.3)
	70°	24.5 (11.4)	27.1 (9.5)
	35°	37.9 (23.3)	35.6 (14.7)

The correlation coefficients that describe the relation between the isoinertial and isometric measurements are placed in table 4.3.9. It shows that the results ot the isoinertial force during the five times repeated flexion-extension and the isometric results are strongly related. Furthermore, for all isoinertial forces and the isometric force the highest correlations were found between the results in the elbow angle of 140°.

Table 4.3.9 *Correlation coefficients between isoinertial forces and isometric forces per elbow angle. The correlation coefficients are highest between isometric force and isoinertial force during five times repeated flexion-extension. All correlation coefficients are significant (p<0.05).*

	Isoinertial results		
Isometric results	Single flexion	Flexion-extension	Repeated flexion-extension
140°	0.88	0.90	0.94
105°	0.80	0.76	0.79
70°	0.51	0.40	0.64
35°	0.56	0.66	0.60

When for all elbow angles the results of the isometric force measurements and all the results of the isoinertial measurements are presented as boxplots and combined into one figure, figure 4.3.3 arises.

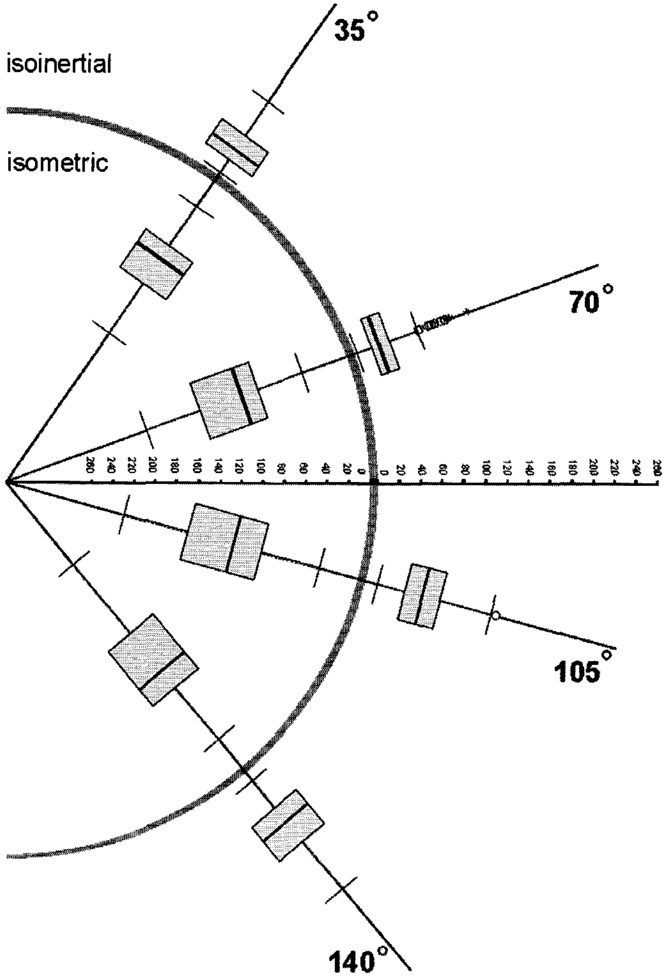

Figure 4.3.3 Boxplots of results of isometric and isoinertial force exertion at all four elbow angles.

Discussion and conclusions

As mentioned in the introduction this was an explorative study. We selected elbow flexion as the movement to study, because the muscle and joint configuration is less complex than in most other joints (Wilkie, 1950). We found insufficient reproducibility in the results of the movements with the one kilogram weight and limited reproducibility in the results in the 35° and 70° elbow angles when moving the weight of one-third peak force. We could have stopped analysing after we established such reproducibility but we chose to do further analysis, because of the explorative nature of the study.

For the isoinertial measurements we selected a weight that approximated to 1/3 of the subjects' maximal peak force in elbow flexion. De Koning (1984) confirmed that the force-velocity curve presented by Binkhorst et al. (1977), in which maximal power was found at 1/3 of maximal force and maximal velocity, applies for elbow flexion. We did not know whether this amount of loading would also result in maximal isoinertial force.

Studies that concentrate on the force-velocity relationship in flexion of the elbow all show that force exertion is maximal at zero velocity (De Koning, 1984; Lagassé, 1979; Stothart, 1973; Slote and Stone, 1963; Young and Bilby, 1993; Sherwood et al., 1988). These studies all concentrated on isokinetic force exertion, which means velocity was kept constant. In isoinertial force exertion the issues are velocity, acceleration force and output force.

The fact that we found the highest correlations between isoinertial and isometric force exertion in the 140° angle was in accordance with the force-velocity literature. At the start of a movement velocity is nil, as in isometric force. At this point in movement acceleration is large and consequently isoinertial so is force exertion. In general, however, this was not the position at which we found the highest isoinertial force. The elbow angle of maximal isometric force exertion was located between 140° and 105°. At this point in movement velocity was not nil, which seems to conflict with the force-velocity relationship described. However, at the highest speed acceleration was nil and consequently was isoinertial force exertion, which is in line with the force-velocity curves. We conclude that isoinertial force exertion does not follow the same force-velocity curve as isokinetic force exertion, but shows some similarity with parts of it.

To reach maximal isoinertial force a sufficient balance between weight and trajectory is required. If the weight is too low the subject will not be able to gain maximal acceleration and if the weight is too large the subject will not be able to move the weight, or will risk being injured. We still do not know if the force we measured was maximal isoinertial force. We do know that the results with the weight that approximated to 1/3 of maximal isometric peak force are much higher than the results with the weight of one kilogram (Table 4.3.6).

This finding differs from Stothart (1973) who concluded in his study that an increase in the loading of the muscle does not increase the correlations between static and dynamic performance.

The results of isometric force exertion in our study were much lower than the results of De Koning (1984), but rather similar to the results of Lagassé (1979).

In contrast to our study, these studies only concerned young men. We could not find studies that included information on the isometric elbow flexion force of women. The result that women are generally weaker than men accorded with our expectation. The insignificance of the differences between the age groups was also expected. Steenbekkers and van Beijsterveldt (1998) found that in grip, twisting, pushing and pulling force differences were not significant when comparing subjects between 20 and 30 and elderly aged under 70.

On the basis of the muscles involved in isometric and isoinertial force exertion a relation between the forces was to be expected, because the muscles that are mainly used are the same. Of course, some of the characteristics of the muscles are influenced by the condition of force exertion. Characteristics such as muscle cross-sectional area and number of myofilaments, however, are the same in both types of force exertion. The latter seems to be more influential in the case of elbow flexion, because we found that isoinertial force exertion is strongly related to isometric force exertion (confer with table 4.3.9).

It is difficult to predict whether such a relation will be found in all isoinertial-isometric comparisons, for instance with other joints. We expect that there will be at least some relation because the muscles involved tend to be the same. We therefore conclude that subjects who are isometrically strong are also isoinertially strong.

We found no significant differences between the results in the three different movements, but we did find that the isoinertial results from the 5 times repeated measurements are most strongly related to the isometric results. At present we do not have a sufficient explanation for this.

Table 4.3.9 shows that the relation between isometric and isoinertial force exertion is weakest at the 70° and 35° elbow angles. Because we measured the isoinertial force three-dimensionally, and the results presented have no notification of direction, it can be assumed that at these angles isoinertial force may be used to brake instead of to increase speed. This would mean extension force rather than flexion force and would explain the lower correlation coefficients.

For product design the consequences of this study may be that the group of intended users based on isometric force may differ from the actual group of able users based on isoinertial force. The weakest of the target population will be even weaker than assumed. The same holds for the strongest. Although information on the strongest users is most often used to prevent damage from abusive force this is not expected to give serious problems in use. The exclusion of a larger group of the weakest users, however, is a serious problem for product designers.

If we look at both our current findings and the general findings of the studies on force-velocity relationships, however, we conclude that the main problem lies in the use of objects that require high-speed motion. Most products do not require very high velocity motions and only small displacements. Although we conclude that isometric force information is not applicable in movement, this problem is most pronounced in high-speed motion. We therefore conclude that this does not lead to insurmountable design problems.

Conclusions:

- In elbow flexion maximal isoinertial force is lower than maximal isometric force.
- In elbow flexion isometrically strong individuals are also isoinertially strong.
- Males are both isometrically and isoinertially stronger in elbow flexion than females.
- Isometric force exertion in elbow flexion does not have the same relationship with velocity as isokinetic force exertion, but there are similarities at some points.

5 General discussion and conclusions

5.1 Hypotheses on the consequences of the results of the Stadyn project for the results of the Gerontechnology project

The forces measured in the Gerontechnology project were all exerted isometrically. In the Stadyn project we argued that isometric force does not adequately represent the activities involved in normal product handling. However, because isometric force measurement is far easier to perform, method and material wise, it is an efficient way to gather useful information for product designers. Ideally we should be able to measure the forces involved in daily activities in natural settings, but at present this kind of research is not possible.

The Stadyn project did contribute to a better understanding of the relevance of isoinertial force for product design. We now realise, for instance, that because isoinertial force is lower than isometric force this may exclude a larger proportion of the weakest members of society from use of a product. This also places the results from the Gerontechnology project, as presented in chapter 2, in another, more explicit, perspective.

We were able to test the hypotheses mentioned in section 3.1.

The hypothesis that there is a positive relationship between isometric force and isoinertial force is accepted. People who are isometrically strong were found to be also isoinertially strong, and the same relation was found for the weak.

The hypothesis that males are stronger than females is also accepted. Both isometrically and isoinertially we found significantly ($p<0.05$) higher means in males than in females.

The hypothesis that the young are stronger than the old could not be accepted. We found no significant differences between the age group of 20-30 year and the age group of 60-65 years. The optimal physique for both isometric and isoinertial elbow flexion force does not seem to be reached between 20-30 years of age because, in our study, the means of the elderly females were somewhat higher than those of the younger females.

Now that we have collected data on isoinertial and isometric force exertion in elbow flexion we are able to define more specific hypotheses on the subject. It would be interesting to test these hypotheses in future research. The hypotheses presented here contain possible consequences they may have for the interpretation of the data from the Gerontechnolgy project.

1. On the basis of inter-individual results, maximal isometric force is greater than maximal isoinertial force.
   Background: Acceleration requires extra force exertion from the muscles, acceleration will always result in a lower output of force.

2. The results of maximal isoinertial force will be higher in slow motions with heavy weights.
   Background: Fast movements require more force exertion from muscles than slow motions, which will result in lower output forces.

3. The position in which maximal isoinertial force is exerted depends largely on the total angle of movement.
   Background: The configuration and characteristics of the active muscles define the acceleration in a movement. The configuration and length of the muscles depends on the angle of movement.

4. Repeating a movement a few times does not influence the isoinertial force exerted. Background: Repetition of movements does not alter the total angle of the movement and therefore causes no difference in isoinertial force.

5. The optimal body position for isoinertial force exertion differs from the optimal position for isometric force exertion.
   Background: Isoinertial force arises from acceleration, which places another demand on the active muscles and alters the effect of muscle configuration compared to isometric force.

5.2 Application of the results in product design

In the aim of the study (section 1.6.2) it is clearly stated that this research aims at providing guidelines for product designers on the use of isometric force information, in situations where isoinertial force information is needed. On the basis of our results in both projects it is possible to propose two general guidelines:

Gerontechnology

The grip strength, pushing force with both hands, pulling force with one hand and twisting force of adults all decline with increasing age. If information on these forces is used in product design, it should be ensured that all age groups are represented in the database. If this is not the case then it is possible to use graphs, such as figure 5.2.1, to establish the forces of users from different age groups who are expected to use the product being designed.

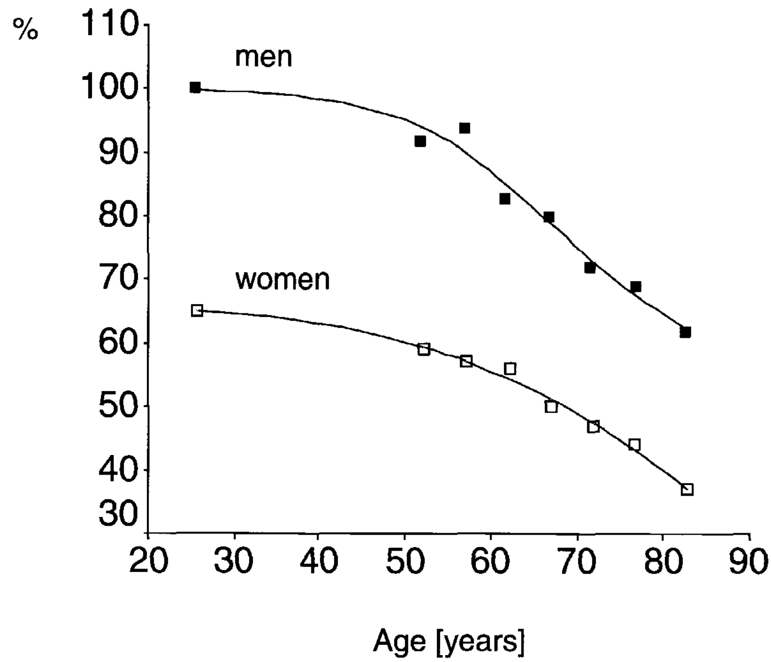

Figure 5.2.1 The average isometric force exertion of older age groups compared to the force exertion of males between 20 and 30 years of age. The women are presented in a separate line. Force exertion decreases with increasing age.

Stadyn

When the handling or operation of a product requires force in motion, it should be noted that the force that can be maximally exerted is lower than the force that could be exerted without the motion. The magnitude of the force that can be exerted depends heavily on the speed required to perform the action. It also depends on the acceleration required, because part of the force is necessary in order to gain acceleration. The following guidelines can be formulated:

- When a substantial force is required, this is only possible during the actual initiation of the movement. As soon as motion is present the degree of maximal force that can be exerted drops.
- If force actually needs to be exerted during motion, the product designer should realise that the highest forces can be exerted in steady, very low speed motions.

These guidelines mainly have implications for the weakest members of the population. The force the product designer has so far assumed they are able to exert is, according to our findings, even lower in terms of movement. This may well exclude them from the use of a product. However, it should be possible to design using the formulated guidelines. Some examples of practical solutions to overcome the problems of lower isoinertial force are:

- A knob or handle which, after strong initial damping, can be pressed further under low force exertion will prevent accidental activation just as well as a knob that is damped all the way.
- A heavy rolling object will, due to its mass inertia, be less heavy to manoeuvre after it has been brought into motion isometrically.

5.3 Comments on the current study and future research

This current study is based on two projects that are very different in type. The intention was to combine the results of the two projects. It was therefore decided to use subjects from the Gerontechnology project in the Stadyn project. At the end of this publication we must conclude that the relation between the two projects has not been studied as thoroughly as planned. Nevertheless, both projects are concerned with human force exertion in connection with product design. We plan to study the relation between the two projects in future projects.

The Gerontechnology project as presented in this study was part of a large project that involved a whole team of researchers, all of whom dealt with all the different variables. This study is only concerned with the forces that were measured. Originally it was intended that the present study would also concern the relation between the forces and all other 75 variables. In section 2.2 the correlation coefficients between grip strength and a number of the other variables are presented, but the relations with the other forces were not studied. This would be an interesting subject for future research. We hypothesise that the relations between variables from different types of human capacities are significantly weaker than relations between variables of the same type of capacity. This was also found by Steenbekkers and van Beijsterveldt (1998).

From the results of a pilot study in the Gerontechnology project we concluded that measuring the isometric force twice leads to reliable data. When measuring forces this greatly reduces both the time needed for measurements and the loading on the subject, compared with the three or more measurements most often advised in the literature. Of course, the possibility of measurement reduction depends on the inter-individual variability. Where subjects show large variability it will not be possible to reduce the number of measurements, in that case even two measurements may not be enough.

Reducing the required number of measurements to only one is not possible, although it would remove the problem of result selection. In the presentation of the results of our research we needed to combine the results of first and second measurements into one figure, or to select one of them. Such choices are arbitrary. In the article on emergency exits (section 2.4) for instance, we used the higher of the two results, but it is a matter for discussion whether it should have been the lowest or the first measurement. An argument for the use of the lowest result would be that it ensures that the subject is able to exert this force on an emergency exit. The suggestion that in an emergency people should need only one attempt argues in favour of the use of the results of the first attempt.

We selected the higher of the two on the basis of the assumption that people are much stronger in an emergency, and that the information in a standard needs to be the best representation of an actual situation. We feel, however, that any of these choices could have been properly defended.

Although we expected age to have an influence on the isometric exertion of force, we were surprised by the clear picture of declining strength with increasing age that emerged from our Gerontechnology study. From the results of our force measurements we were able to make a curve that presents the general decrease of force with age in percentages.

On the other hand we found in the Stadyn study that elbow flexion force in females does not decrease with age. The only explanation we have for this finding is based on training (section 4.2) We are, however, confident that the relations we found in the Gerontechnology study apply to most other human forces. It would be very interesting to confirm this statement in future research.

As mentioned in the introduction to the Stadyn project, this part of the study was of an explorative nature. We made several choices on the methods and materials which were not fully based on prior scientific research.

We left the wrist free because we felt that restraining it with a cuff would make the movement too unnatural. We decided to have the subjects grip the handle or weight firmly to prevent the wrist from flexing. The possible consequences of this decision were not known to us then, and it was satisfying to find that the wrists of the subjects did not deviate too much and that the influence of small flexion angles proved to be insignificant (section 4.1).

We also did not know whether using information on the isometric peak force to determine the weight to be moved in the isoinertial force exertion, would lead to reliable data. We based our choice on results from force-velocity studies. Although we suspected some relationship between the two fields of study, we decided to include isoinertial force measurements with a weight of one kilogram. We are still not fully convinced that we did actually measure maximal isoinertial force with the larger weight, but it was far higher than with the weight of one kilogram. It would be interesting in future research to concentrate on isoinertial force exertion with an even larger weight, to see if the isoinertial force increases even more.

The uncertainty about whether the isoinertial force was maximal when measured with the one-third peak force weight is not so relevant when the relation between the two types of force exertion is considered. We found a strong relation, especially at the beginning of the movement. In our opinion this finding strengthens the expected relationship between isokinetic and isoinertial force exertion.

We incorporated several tests on expected side effects from our choice of method. For example, we measured isoinertial force in three different movements because we expected the choice of movement would have implications for the results. We did not find such an effect. Although the results in the different movements were slightly different the differences were not significant.

We also incorporated two age groups in our sample. Although we were aware, from the Gerontechnology project, that isometric strength is only expected to become significantly less after the age of 70, we expected that isoinertial force would diminish earlier in life. To test this we measured subjects between 60 and 65 years of age and found that at these ages force is generally at the same level as in the young. It would be interesting to concentrate future studies on how isoinertial force exertion develops during a lifetime, and also to measure even older subjects.

Because the finding that elbow flexion force in females does not decrease with age other forces need to be studied to compare the ageing effects of isometric and isoinertial force.

Due to the exploratory nature of the study we did not have high expectations of the reproducibility of the results. Knowing about the fast amount of aspects that play a role in muscle condition added to the low expectations of this reproducibility. With the one kilogram weight the reproducibility was unacceptable in every respect. Because we now argue that this was submaximal force, with hindsight this finding is not surprising. The low reproducibility of the smaller angles in the movement of the one-third peak force weight is harder to explain. It may have been caused by the change in force exertion at the end of the flexion movement. The braking of a movement depends heavily on reflexes and these may not reproduce so well. Of course we realise that with all the influencing muscle characteristics that could not be controlled, acceptable reproducibility is hard to achieve. We feel, however, that to improve on the reproducibility of the forces in all angles our method of measurement should be studied further. Nevertheless, the fact that we found isoinertial force to be reproducible at the beginning of the movement is an achievement for this field of study.

Overall we conclude that the two studies seem to add substantial information on isometric and isoinertial force exertion to the body of knowledge in the fields of force studies and product design.

Summary

In the introduction to this study (chapter 1) we explain the relevance of force measurement for application in product design. For reasons of safety and comfort a product should not collapse under the force of its strongest user. However, the use of a product should not demand too much force from its weakest user. The balance is delicate and to arrive at an ergnomically good design the designer benefits from accurate information about the forces of the intended users.

The information required for product design can be obtained from information about specific forces. Most of the data available to product designers concerns isometric force exertion. In such measurements there is no (perceptible) movement during force exertion. Isoinertial force exertion in a research setting is more relevant to product design because forces exerted in motion are more closely related to real life product use.

Apart from an adequately measured force a product designer will also benefit from force information about a group of subjects who represent the intended users. A group of intended users most often contains subjects of various ages and of both sexes, and a study into human force should therefore also distuingish between those different subject characteristics.

Although the output force of a human body is the result of internal tension in the muscles being used, the designer is not interested in the tension of a specific muscle. Some understanding of the physiology and mechanics of a muscle, however, may help to explain unexpected outcomes of force exertion.

When a study was made of 750 subjects, aged between 20 and 30 years of age and 50-94 of age (the Gerontechnology project), results showed tthat grip force in both right and left hand, torque with both hands, pushing with both hands and pulling with one hand all gradually decrease with age. Because in all forces males are stronger than females this means that, generally speaking, elderly women are the weakest in a subject group and young men are the stongest.

In chapter 2 there are four articles that together give an overview of the clearest findings from the Gerontechnology project concerning the forces mentioned. Below are summaries of the articles:

Differences in grip strength related to various subject characteristics.

This study concerns the design-relevant characteristics of ageing users. 79 variables were measured. The study included a test of maximum grip strength measured on a large sample of subjects, which enabled us to add to the state of the art information on grip force. Amongst other things we studied its relation to other variables.

We modified the standard method of measurement for grip strength in three projects. We introduced arm support and verbal encouragement in a first study which revealed that only two repeated measurements are required to obtain sufficient information on maximum grip force. This finding was implemented in a study of 750 young and old subjects, which showed high reproducibility and mean values of maximum grip strength that are, apart from some small differences, comparable with those found in the literature. We found a gradual decrease in grip strength with age, and higher means in men than in women for all age groups. The correlation coefficients varied considerably. Stature, pushing force and torque were best correlated with grip force. A follow-up study after two-and-a-half years demonstrated a small increase in grip strength that was unexpected, given the results of the earlier transversal study.

The results of this study can, for instance, be used by product designers to adequately gear their product specifications, and the grip strength of their users, to one another. Furthermore, the study enhances the existing information on grip strength.

The twisting force of elderly consumers when opening a jar.

Many people experience difficulty when opening a vacuum-sealed jar. This is common knowledge. Yet solutions to the problem continue to be tool-based rather than exploring the possibility of innovative changes in product packaging.

Improvement depends on gaining knowledge of the capabilities of users, and of using that knowledge as a base for product innovation. To establish such a base we took a sample of 750 subjects and asked them two questions about how they opened jars at home. We then carried out torque measurements using a force transducer shaped like a jam jar. We reached the conclusion that if opening torque was reduced to 2 Nm then 97.6 per cent of users between 50 and 94 years of age and 100 per cent of 20 to 30 year old users would have no difficulty opening a jar.

Clearance of emergency exits for use by the elderly, a proposal for an addition to a Dutch standard.

In this article the maximum pushing and pulling forces of 750 persons between 20 and 30 and over 50 years of age are presented. Measurements were done using a framed strain gauge transducer and recorder. Both forces were measured in a free standing position that was related to opening a heavy door. The latter makes it possible to use the information in a standard on emergency exits. Such a force standard is not available in The Netherlands. We propose an addition to NEN 6082:1997 concerning human capacities in opening unfastened, hinged doors that are on an escape route.

Single and composite relationships between modes of isometric force exertion in young and elderly adults.

This study is part of a large project on design-relevant characteristics of ageing users. A total of 750 young and elderly, male and female subjects were tested. Differences between the sexes were mapped as well as changes in force with age. The relationships between five different isometric forces (left and right gripping, twisting, pushing and pulling) were investigated. The possibilities of extending information on these forces to other forces and other subject groups were also studied. The results indicate that the different types of force are closely related. A strength score was devised. We conclude that calculation of unmeasured forces by means of a general strength score could be possible. Furthermore, we found that the percentage decrease in strength with age is similar for men and women.

Apart from information on specific forces that are relevant for product use in daily living, a designer will also benefit from more general information that marks tendencies or relations. The last article in chapter two is an example of such information, as is also the study presented in chapter 3.

The forces in chapter 2 were measured isometrically, i.e. without movement during force exertion, while most of the activities in daily life concern force exertion during motion. Isoinertial force exertion, i.e. moving a constant mass, best represents force as exerted in average product use. The study, called Stadyn, in chapter 3 concentrates on the isoinertial force exerted in elbow flexion.

Studies on isoinertial force are scarce and we therefore considered this as an explorative study. We decided to measure isometric and isoinertial force in equal settings, but necessarily with different equipment. The isometric forces were measured with a force transducer that was linked to a PC, while the isoinertial forces were measured with an OPTOTRAK 2010 system, which was also linked to a PC. Because of these differences in equipment the forces were measured in two sessions.

We selected the movement of flexion of the elbow because the rotation around the elbow joint can be defined as uni-axial. However, because we did not know if single or repeated flexions would have an effect on the pattern of force exertion, we decided to study three different flexion movements:

- single flexion, fully flexing the elbow and keeping it flexed
- single flexion-extension, fully flexing the elbow, directly followed by extension to the starting position
- flexion/extension repeated five times, a repetition of the second movement with no pause in between

On the basis of a study of the literature and from our own deductions we concluded that isoinertial force can only be exerted optimally if there is a sufficient balance between the moved weight and the trajectory. If the weight is small the maximal acceleration is achieved at another point in the movement than with a larger weight, e.g. the longest possible trajectory is needed to raise the chance of reaching maximal isoinertial force. The maximal trajectory of elbow flexion is from 180° to around 30°. Because a starting angle of 180° is biomechanically less preferable we decided to select a smaller starting angle. We selected 140° between upper and forearm for starting position.

The effect of the magnitude of the weight is not thoroughly described in the literature. We did find literature on maximal power that argued that maximal power is achieved when moving with 1/3 of the maximum force, and that this rule is legitimate for elbow flexion. We used this information and studied two weights: 1 kilogram and 1/3 of the maximal isometric peak force of elbow flexion as exerted by the subject. To establish the maximal isometric peak force the isometric session was extended to include the measurement of this force in the (starting) elbow angle of 140°. In the exertion of a peak force the force is brought to maximum as fast as possible and abruptly released, while in 'normal' isometric force exertion the force is gradually built-up to maximal and held for a few seconds after which it is released.

To compare the results of the two types of force exertion we decided to extract from the isoinertial force curve the force exerted in specific angles, and to measure isometric force in the same angle. We selected four angles to be studied: 140°, 105°, 70° and 35°.

The position of the subject was kept constant in both sessions of measurements. The subject was seated on an adjustable chair with the back and upper arm held against a vertical rest. During force exertion the subject was instructed to look straight ahead. Unlike other studies of elbow flexion the wrist was not held by a cuff during the force exertions.

Because in isometric force males are generally stronger than females we measured both sexes in the study on isoinertial force, and because the Gerontechnology project had shown that isometric force decreases with increasing age we included two age groups in the study: between 20 and 30 years and between 60 and 65 years of age.

Because of the explorative nature of the study we thoroughly investigated the reproducibility of the measurements. From the results presented in chapter 3 we conclude that reproducibility for the movements with the one kilogram weight is not satisfactory and is limited in the 70° and 35° elbow angles for the movements with the one-third peak force weight. With this weight, the reproducibility in the 140° and 105° elbow angle was found to be acceptable. We further conclude that the effect of the moved weight is large; in the movement of the weight of one kilogram the isoinertial force was about half that exerted in the movement of the weight that approximated to one third of the maximal isometric peak force. The effect of the movement performed is not so large and most of the differences found are not significant.

To highlight some of the results from the Stadyn project we presented them in the form of three articles which are collected in chapter 4. The article on wrist angles concerns a sub-study on a separate sample of subjects.

The relationship between elbow flexion strength and wrist angle.

This study concerns the influence of the angle of the wrist on maximal isometric elbow flexion strength. We measured 15 subjects aged between 25 and 63 years. They exerted maximal elbow flexion force while their elbow was flexed to 70° and their wrist was held either in a neutral position, or in flexion or extension of 30 degrees.

We found the highest results when the wrist was in the neutral position, but at 30° flexion the results were not significantly lower. When the wrist was extended 30° the results were significantly lower than in the neutral or the flexed position.

The difference between isometric peak force and build-up force in elbow flexion.

This study concerns design relevant information on elbow flexion. We measured the maximal peak and built-up force in elbow flexion of 52 subjects, aged between 20 and 65 years. Our method deviates from other studies only because we did not immobilise the wrist with a cuff but left it free. We measured elbow flexion force in an angle of 140 degrees. In agreement with the literature, we found that peak force is higher than built-up force. We further established that peak force is more easily reproducible than built-up force. This deviates from findings presented in the literature. We also found that in women the force studied does not decrease with age.

The results of this study can be used by product designers to more accurately adjust the characteristics of their products to cope with the loads exerted by users in peak exertion.

The relationship between maximal isoinertial and isometric force exertion in elbow flexion.

Human isometric force is often measured. Isoinertial force measurements are seldom taken. Product designers would benefit substantially from information about isoinertial force exertion because it represents force exertion in product use much better than isometric force exertion. This, rather explorative, study concentrates on the relation between isometric and isoinertial force exertion in elbow flexion.

In two sessions measurements were performed on 51 male and female subjects, aged between 20 and 30 or between 60 and 65 years. During both types of measurement the subjects were seated. In the isometric force measurements the force was exerted onto a handle, while in the isoinertial force measurements the subjects moved a hand-held weight. The weight moved by the subjects was one-third of their maximal isometric peak force. We compared the two force types at elbow angles of 140°, 105°, 70° and 35°.

We found that maximal isoinertial force exertion is lower than maximal isometric force exertion. The two types of force exertion are, however, strongly related particularly at the start of the movement.

This study provides information for product designers to help them improve the ergonomic fit of their design to the needs and force characteristics of their intended users.

In chapter 5 hypotheses are presented that have, in our opinion, conseqences for the outcomes of the isometric forces measured in the Stadyn project. They concentrate on the general tendencies expected in isoinertial force exertion. The consequences for product design are discussed in this chapter, as well as the consequences of some of the substantial choices made in the two projects.

In conclusion, we feel that this study adds relevant information on isometric and isoinertial force exertion to the existing knowledge in the field of force studies and product design.

Samenvatting

In de introductie van dit boek (hoofdstuk 1) wordt uitgelegd wat the belang is van krachtonderzoek voor toepassing bij het ontwerpen van producten. Een product mag omwille van de veiligheid van de gebruiker niet stuk gaan bij belasting door de sterksten onder de gebruikers. De kracht nodig voor bediening en gebruik mag echter niet de kracht van de zwaksten onder de gebruikers te boven gaan. Het is moeilijk om de krachteigenschappen van beide gebruikersgroepen te implementeren in het ontwerp en een ontwerper heeft daarom nut van accurate informatie over de te verwachten krachten in deze gebruikersgroepen.

De informatie over krachten die een product ontwerper nodig heeft is vrij specifiek. De meeste onderzoeken die in principe bruikbaar zijn voor productontwerpers zijn gebaseerd op isometrische krachtuitoefening. Bij dit soort krachtuitoefening is er geen (waarneembare) beweging tijdens de krachtuitoefening. Isoinertiële krachtuitoefening is qua onderzoeksopzet relevanter voor productontwerpen, omdat de kracht, net als in alledaags productgebruik, gedurende een beweging wordt uitgeoefend.

Een ontwerper kan dus beter ontwerpen als hij kan beschikken over adequate krachtinformatie, maar ook wanneer de onderzochte populatie overeenkomt met de doelgroep van het ontwerp. De meeste gebruiksvoorwerpen zijn bedoeld voor mensen uit verschillende leeftijdscategoriën en van beide geslachten en een onderzoek is dus vooral interessant voor een ontwerper als al deze menselijke kenmerken voorkomen in de beschrijving van de onderzoeksresultaten.

Hoewel de output aan menselijke kracht het resultaat is van interne spanning in de actieve spieren, is een ontwerper over het algemeen niet geïnteresseerd in de spanning in een enkele spier. Enige kennis over de spierfysiologie en de mechanica van de spieren kan echter wel bijdragen aan de verklaring van bepaalde onverwachte uitkomsten.

Een onderzoek onder 750 mensen tussen de 20 en 30 jaar en tussen de 50 en 94 jaar (The Gerontechnology project) liet zien dat de knijpkracht in elk van beide handen, de torsiekracht met twee handen, de duwkracht met twee handen en de trekkracht met één hand allemaal geleidelijk afnemen met het stijgen van de leeftijd. Omdat mannen over het algemeen sterker zijn dan vrouwen, betekent dit dat de oudste vrouwen de zwaksten in een doelgroep vormen en de jonge mannen de sterksten.

In hoofdstuk 2 zijn vier artikelen gegroepeerd. Deze artikelen geven een overzicht van de meest expliciete bevindingen aangaande de krachten uit het "Gerontechnology project". De artikelen laten zich als volgt samenvatten:

Differences in grip strength related to various subject characteristics
(Verschillen in knijpkracht in relatie tot een aantal persoonskenmerken)

Dit onderzoek gaat over ontwerp-relevante eigenschappen van oudere gebruikers. We hebben 79 variabelen gemeten. In het onderzoek werd maximale knijpkracht gemeten bij een grote groep proefpersonen, waardoor het mogelijk was om de hedendaagse kennis over knijpkracht uit te breiden. We hebben onder andere de relatie met andere variabelen bestudeerd.

In de drie projecten die het onderzoek besloeg hebben we de gebruikelijke methode om knijpkracht te meten aangepast. We hebben ondersteuning van de armen en verbale aangemoediging geïntroduceerd in ons eerste onderzoek. Dit onderzoek leidde tot de conclusie dat twee keer meten genoeg informatie biedt bij knijpkracht-metingen. Deze bevinding is toegepast in het tweede onderzoek waarbij 750 jonge en oudere proefpersonen betrokken waren. Dit tweede onderzoeksproject resulteerde in goed reproduceerbare gemiddelde waarden die, op wat kleine verschillen na, vergelijkbaar zijn met waarden gevonden in literatuur. We vonden dat knijpkracht geleidelijk afneemt naarmate men ouder wordt en dat mannen op alle leeftijden meer knijpkracht hebben dan vrouwen.

De correlatiecoëfficiënten tussen de verschillende variabelen varieerden sterk. Lichaamslengte, duwkracht en torsiekracht met de handen hingen het meest samen met knijpkracht.

In een vervolgonderzoek na twee-en-een-half jaar vertoonden de proefpersonen onverwachts een kleine stijging in hun knijpkracht. Dit is in tegenspraak met de resultaten van het transversale onderzoek waarbij de kracht daalde met de leeftijd.

De resultaten van deze drie geschakelde onderzoeksprojecten kunnen bijvoorbeeld gebruikt worden door ontwerpers van producten om hun productspecificaties en de knijpkracht van de beoogde gebruikers goed op elkaar af te stemmen. Bovendien draagt het onderzoek bij aan het vergroten van de kennis op het gebied van knijpkracht.

The twisting force of aged consumers when opening a jar
(De torsiekracht van oudere gebruikers bij het openen van een pot met schroefdeksel)

Het is algemeen bekend dat veel mensen problemen ondervinden bij het openen van een vacuüm-gesloten pot met schroefdeksel. Tot nu toe zijn oplossingen voor het probleem vrijwel altijd gebaseerd op gereedschap of hulpmiddelen in plaats van op aanpassingen van de productverschijningsvorm.

Verbetering door productinnovatie is hier alleen mogelijk na vergroting van de kennis op het gebied van de torsiekracht van de gebruikers en inzet daarvan. Om een goede basis voor een dergelijke innovatie te creëren, stelden wij aan 750 mensen twee vragen omtrent het openen van potten thuis. Daarna onderzochten we de torsiekracht van deze mensen met behulp van een opnemer in de vorm van een jampot. We kwamen tot de conclusie dat, wanneer de benodigde torsiekracht voor het openen van een pot teruggebracht zou worden tot 2Nm, 97,6 procent van de gebruikers tussen de 50 en 94 jaar en 100 procent van de 20 tot 30-jarigen geen problemen zouden hebben met het openen van die pot.

Clearance of emergency exits for use by the elderly, a proposal for an addition to a Dutch standard

(Vrije doorgang van nooduitgangen voor gebruik door ouderen, een voorstel voor een toevoeging aan een Nederlandse norm.)

In dit artikel worden de maximale duw- en trekkracht van 750 mensen tussen de 20 en 30 en boven de 50 jaar gepresenteerd. De metingen zijn verricht met een in een frame vastgezette duw-trekopnemer. Beide krachten werden gemeten in een vrij-staande houding representatief voor het openen van een zware deur. Dit laatste maakt het mogelijk om deze informatie te gebruiken voor een norm over nooduitgangen. Een dergelijke norm bestaat nog niet in Nederland. Wij stellen een aanvulling op NEN 6082:1997 voor bebaseerd op menselijke capaciteiten bij het openen van onvergrendelde, gescharnierde deuren in een vluchtroute.

Single and composite relationships between modes of isometric force exertion in young and elderly adults

(Enkele en samengestelde relaties tussen enkele typen isometrische krachtuitoefening door jongere en oudere volwassenen)

Deze studie maakt onderdeel uit van een groot project op het gebied van ontwerp-relevante eigenschappen van oudere gebruikers. In totaal werden er 750 jongere en oudere, mannelijke en vrouwelijke proefpersonen onderzocht. De verschillen tussen de twee geslachten evenals de veranderingen in kracht met leeftijd werden in kaart gebracht. De relaties tussen vijf verschillende krachten (knijpkracht links en rechts, torsiekracht, trekkracht en duwkracht) zijn onderzocht. Ook de mogelijkheden om de informatie over deze krachten te gebruiken voor het berekenen van andere krachten of het berekenen van krachten op andere leeftijden dan gemeten, zijn bestudeerd. De resultaten duiden erop dat de verschillende krachten sterk samenhangen. Een score voor kracht werd ontworpen. We concluderen dat de berekening van ongemeten krachten met behulp van een algemene score voor kracht in principe mogelijk lijkt te zijn. Daarnaast vonden we dat de procentuele afname van kracht met het stijgen van de leeftijd voor mannen en vrouwen gelijk is.

Een productontwerper profiteert niet alleen van informatie over specifieke krachten maar ook van informaties over bepaalde relaties, verhoudingen en tendensen. Het laatste artikel in hoofdstuk 2 is hier een voorbeeld van, maar ook de studie die staat beschreven in hoofdstuk 3.

De krachten uit hoofdstuk 2 zijn isometrisch gemeten, i.e. geen beweging gedurende de krachtuitoefening, terwijl krachtuitoefening in de meeste dagelijkse activiteiten gepaard gaat met beweging. Isoinertiële krachtuitoefening, i.e. beweging van een constante massa, komt over het algemeen het meest overeen met de kracht zoals uitgeoefend in het hanteren van producten. De studie, genaamd 'Stadyn', die beschreven is in hoofdstuk 3 gaat over isoinertiële krachtuitoefening in elleboogflexie.

Onderzoeken op het gebied van isoinertiële krachtuitoefening zijn schaars en we beschouwen deze studie dan ook als een exploratief onderzoek. De isometrische en isoinertiële kracht werd gemeten in gelijke opstellingen, maar noodzakelijkerwijs met verschillende apparatuur. De isometrische krachten werden gemeten met een krachtopnemer die was aangesloten op een PC, terwijl de isoinertiële krachten werden gemeten met een OPTOTRAK 2010-systeem die op een andere PC was aangesloten. Vanwege de verschillen in apparatuur werd er in twee sessies gemeten.

We hebben gekozen voor het buigen van de elleboog als beweging, omdat deze beweging kan worden beschouwd als een draaiïng om een enkele as. Omdat we echter niet wisten of een herhaling van de beweging invloed zou hebben op het krachtverloop hebben we besloten om drie verschillende flexie-bewegingen te meten:

- Alleen buiging, de elleboog volledig buigen en gebogen houden.
- Eenmaal flexie-extensie, de elleboog volledig buigen en onmiddellijk weer strekken tot in de starthouding.
- Vijf keer flexie-extensie, herhaling van de flexie-extensie zonder tussenstops.

Op basis van een literatuurstudie, gecombineerd met eigen deductie, concludeerden wij dat isoinertiële kracht alleen optimaal kan worden uitgeoefend als er voldoende balans is tussen het bewogen gewicht en het af te leggen traject. Als het gewicht te klein is zal de maximale versnelling op een ander punt in de beweging bereikt worden dan met een groter gewicht, dus zal een zo lang mogelijke weg nodig zijn om het bereiken van de maximale kracht te bewerkstelligen. Het langst mogelijke traject voor elleboogbuiging loopt van 180° tot ongeveer 30°. Omdat 180° biomechanisch beschouwd niet zo gunstig is, hebben we gekozen voor een kleinere starthoek. We selecteerden 140° tussen onder- en bovenarm als beginpositie.

Het effect van de grootte van het gewicht was onvoldoende beschreven in de literatuur. We vonden wel literatuur over maximaal vermogen waarin beargumenteerd werd dat maximaal vermogen bij spieren wordt bereikt als 1/3 van de maximale kracht werd uitgeoefend, bovendien zou deze verhouding ook specifiek voor buiging van de elleboog gelden. We hebben deze informatie gebruikt en onderzochten twee gewichten: een van 1 kilogram en een die ongeveer overeenkwam met 1/3 van de maximale isometrische piekkracht van de proefpersoon. Om de maximale piekkracht vast te stellen werd de sessie voor het meten van de isometrische krachten uitgebreid met een meting van de maximal piekkracht bij een elleboogshoek van 140° (de starthouding). Bij de uitoefening van een piekkracht, wordt de kracht zo snel mogelijk naar maximaal gebracht en abrupt weer losgelaten, terwijl bij een -meer gebruikelijke- opbouwkracht de kracht geleidelijk naar maximaal wordt opgebouwd, dat maximum een paar seconden moet worden volgehouden alvorens weer los te laten.

Om de isoinertiële en isometrische krachten te kunnen vergelijken werd besloten om uit de isoinertiële krachtgrafiek de krachten te selecteren die werden uitgeoefend in specifieke elleboogshoeken en isometrische kracht in diezelfde hoeken te meten. We selecteerden vier hoeken om te onderzoeken: 140°, 105°, 70° en 35°.

De houding van de proefpersoon werd gelijk gehouden in beide meetsessies. De proefpersoon zat op een instelbare stoel met de rug en bovenarm verticaal afgesteund. De proefpersoon werd geïnstrueerd om tijdens het krachtzetten recht vooruit te kijken. Afwijkend van andere onderzoeken naar elleboogflexie was het feit dat de pols van de proefpersoon niet vastgezet werd tijdens de krachtuitoefening.

Omdat mannen over het algemeen isometrisch meer kracht hebben dan vrouwen, hebben we beide geslachten meegenomen in het onderzoek naar isoinertiële kracht. En omdat uit het 'Gerontechnolgy project' naar voren was gekomen dat kracht afneemt met het oplopen van de leeftijd hebben we twee leeftijdsgroepen meegenomen in het onderzoek: tussen de 20 en 30 jaar en tussen de 60 en 65 jaar.

Vanwege het exploratieve kenmerk van het onderzoek hebben we de reproduceerbaarheid van de metingen grondig bestudeerd. Op grond van de resultaten in hoofdstuk 3 concludeerden we dat de reproduceerbaarheid bij beweging van het 1 kilogram gewicht onvoldoende is en dat deze in de elleboogshoeken van 70° en 35° bij beweging van het 1/3-piekkracht-gewicht niet optimaal is. Voor dit laatste gewicht, kon wel een goede reproduceerbaarheid worden vastgesteld in de elleboogshoeken van 105° en 140°.

We concluderen ook dat de invloed van het gewicht dat bewogen wordt groot is; bij beweging van het kleine 1 kilogram-gewicht werden maar half zo grote krachten gemeten als bij het zwaardere 1/3-piekkracht-gewicht. De invloed van de gemaakte beweging is niet zo groot en de meeste verschillen die gevonden werden waren niet significant.

Om een paar van de resultaten uit het Stadyn project wat meer naar voren te halen hebben we deze in de vorm van artikelen opgenomen in hoofdstuk 4. Het artikel over polshoeken is gebaseerd op een sub-studie en een aparte steekproef.

The relationship between elbow flexion strength and wrist angle.
(De relatie tussen elleboog-flexiekracht en de hoek van de pols.)

Deze studie gaat over de invloed van de hoek van de pols op de maximale isometrische elleboog-flexiekracht. We hebben 15 proefpersonen gemeten variërend in leeftijd van 25 tot 63 jaar. Deze personen oefenden maximale elleboog-flexiekracht uit terwijl hun elleboog tot een hoek van 70° gebogen was en hun pols respectievelijk neutraal, onder 30° flexie en onder 30° extensie gehouden werd.

We vonden de hoogste krachten als de pols neutraal gehouden werd, maar het verschil met de kracht in de 30°-flexiestand was niet significant. Wanneer de pols gebogen werd tot 30° extensie, resulteerde dit in significant lagere elleboog-flexiekrachten dan in de twee andere houdingen.

The relation between isometric peak force and built-up force in elbow flexion.

(De relatie tussen isometrische piekkracht en opbouwkracht in elleboogflexie.)

Dit onderzoek heeft tot doel om ontwerprelevante informatie te verzamelen over elleboog-flexiekracht. We hebben bij 52 proefpersonen tussen de 20 en 65 jaar de maximale elleboog-flexiekracht gemeten in een piek en opgebouwd. Onze methode wijkt af van die van anderen omdat we bij deze metingen de pols vrij gelaten hebben. We hebben de elleboog-flexiekracht gemeten bij een ellebooghoek van 140°. We vonden dat piekkracht hoger is dan opgebouwde kracht, wat overeenkomt met bevindingen in literatuur. Bovendien vonden we dat de resultaten van de piekkrachtmetingen beter reproduceerbaar zijn dan de opgebouw-krachtmetingen, wat afwijkt van bevindingen zoals beschreven in literatuur. We vonden ook dat elleboog-flexiekracht bij vrouwen niet lager wordt bij een hogere leeftijd.

De resultaten uit dit onderzoek kunnen door productontwerpers benut worden om hun producten beter af te stemmen op de piekbelastingen van de 'extreme' gebruikers.

The relationship between isometric and isoinertial force exertion in elbow flexion

(De relatie tussen isometrische en isoinertiele krachtuitoefening bij buiging van de elleboog)

Informatie over isometrische menselijke kracht is eenvoudig te vinden, omdat het vaak gemeten is. Isoinertiële metingen worden zelden uitgevoerd. Productontwerpers hebben veel belang bij informatie over isoinertiële krachten, omdat uitoefening van deze kracht het dagelijks productgebruik beter benadert dan isometrische krachtuitoefening. Deze, enigszins exploratieve, studie concentreert zich op de relatie tussen isometrische en isoinertiële krachtuitoefening bij elleboog-flexie.

De metingen zijn in twee sessies uitgevoerd op 51 mannelijke en vrouwelijke proefpersonen tussen de 20 en 30 of tussen de 60 en 65 jaar. De proefpersonen zaten bij beide soorten metingen op dezelfde stoel, maar bij de isometrische metingen werd kracht gezet tegen een handvat, terwijl de proefpersoon in de isoinertiële metingen een gewicht in zijn hand bewoog. De proefpersonen bewogen een gewicht van 1 kilogram en een dat overeenkwam met ongeveer 1/3 van zijn piekkracht. We vergeleken de twee soorten krachten in elleboogshoeken van 140°, 105°, 70° en 35°.

We constateerden dat maximale isoinertiële kracht lager is dan maximale isometrische kracht. De twee soorten krachten zijn echter wel sterk aan elkaar gerelateerd. De sterkste samenhang werd gevonden aan het begin van de beweging.

Dit onderzoek voorziet in een stukje informatie voor productontwerpers, waarmee ze hun product ergonomisch gezien beter kunnen afstemmen op de eigenschappen en wensen van de bedoelde gebruikers.

In hoofdstuk 5 worden hypothesen gepresenteerd die naar onze mening consequenties hebben voor de interpretatie van de isometrische resultaten uit het 'Gerontechnology project'. Ze bevatten de verwachtingen over algemene tendensen in isoinertiële krachtuitoefening. Verder komen de consequenties van al onze bevindingen en bepaalde gemaakte keuzes binnen de twee projecten voor het productontwerpen in dit hoofdstuk aan de orde. De uiteindelijke conclusie van de gehele studie is dat het er naar uit ziet dat we erin geslaagd zijn om relevante informatie over isometrische en isoinertiële krachtuitoefening toe te voegen aan de kennis op het gebied van krachtonderzoek en productontwerpen.

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