# Fit for Washing

Human Factors and Ergonomic Evaluations of Washing Machines

Nicole Busch

# Fit for Washing –
## Human Factors and Ergonomic Evaluations of Washing Machines

**Cover and Layout:** Jens Keunecke, Munich, Germany
based on the image of Jana Tröger, Stuttgart, Germany

**Printing:** Absolut-Digital, Hamburg, Germany

**ISBN:** 9090213651



# Fit for Washing

## Human Factors and Ergonomic Evaluations of Washing Machines

**Proefschrift**

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. dr. ir. J.T. Fokkema,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op woensdag 22 november 2006 om 10.00 uur.

door

**Nicole BUSCH**

Diplom Biologin,
geboren te Hamburg, Duitsland

**Dit proefschrift is goedgekeurd door de promotoren:**
Prof. dr. ir. P. Vink
Prof. ir. D.J. van Eijk

Toegevoegd promotor:
Dr.ir. J.F.M. Molenbroek

**Samenstelling promotiecommissie:**
Rector Magnificus, vorzitter
Prof. dr. ir. P. Vink, Technische Universiteit Delft, promotor
Prof. ir. D.J. van Eijk, Technische Universiteit Delft, promotor
Dr. ir. J.F.M. Molenbroek, Technische Universiteit Delft, toegevoegd promotor
Prof. Dr.-Ing. R. Bruder, Zollverein School of Management and Design, Essen, Duitsland
Prof. Dr. rer.habil. H. Greil, Universität Potsdam, Duitsland
Prof. dr. M. de Looze, Vrije Universiteit Amsterdam
Prof. dr. J.P.L. Schoormans, Technische Universiteit Delft

# Table of Contents

# 1 Prologue

In every household people have to wash clothes. Worldwide people use approximately 500 million washing machines*. If we take the time to think about it, many of us will presume that the ergonomic and comfortable design of the opening height and position of the drum of all these washing machines has certainly room from improvement. It is not understandable that an ideal working position is not applied in washing machines. However, the design of washing machines looks almost the same as some 50 years ago. Also, there is no research available to provide manufacturers with information about a better height and position and additionally showing whether this is applicable in different washing situations. That is remarkable as millions of households could take advantage of it.

This is the first time a scientific study is pursued regarding the opening height and position of the drum of a washing machine. The main reason for starting this study was the interest of Siemens Household Appliances. They wanted to find out whether their consumers would appreciate an innovative washing concept and whether it was worthwhile to develop a new washing machine.

*In 2007 the world will have 6,600,115,810 citizens (Source: U.S. Census Bureau, Population Division, 2006). In China 97 million washing machines existed in 1994 (Danish Board of technology, 1996) If this number is calculated for the world population of today the number of washing machines is estimated as 500 million in the world. So at least one out of 13 people could have a washing machine in 2007.

After a first exploration in literature, it became clear that there is hardly any scientific research regarding the ideal loading and unloading process of a washing machine. Of course there are guidelines for ideal working heights and lifting heights (e.g. Voskamp et al., 2006), but these guidelines do not take the specific washing situation into account. Washing includes for instance lifting without handles combined with looking into the basket and drum leading to postures, which cannot be found in the traditional tables and calculations. Besides, these guidelines are focused on prevention of complaints and only some are focused on comfort.

**The research question of this thesis is:** Which location is preferable for the opening of the drum and does this fit into a household situation?

To answer this question an overview of the washing cycle and methods to study the ergonomics of washing is given in chapter 1.
In chapter 2 it is studied how the laundry is done in different areas of the world. This overview is needed to find out if innovations are compatible with existing cultural habits. In some cultures the washing machine is placed on wheels to be transportable within the house, sometimes it is positioned on the balcony or in narrow spaces. This has consequences for the redesign. As a side effect of this global orientation, different ways of washing could inspire us for new design ideas.
In chapter 3 a laboratory experiment was carried out to research, how differences in drum height and drum angle effect comfort, body posture and speed. Based on this study an indication for an ideal position could be made.
A disadvantage of laboratory studies is that in reality people behave differently. A disadvantage of studies in the field is that the conditions can't be standardised totally. Therefore, in this thesis a laboratory as well as a field study was carried out. The field study is described in chapter 4.
A growing part of the world population will be older and especially for this group loading and unloading of washing will be a heavy task.
Chapter 5 pays specific attention to this group and it is observed what solutions are applicable in senior residences.
In all of the above-mentioned experiments the objective methods concern the static posture analysis. An additional measurement is done (chapter 6) to check whether dynamic measurements indicate the same ideal height.

Fig. 1: Mauritian women washing laundry in the river, using a stone for mechanical treatment (photographer: C. Busch, 2003).

Of course this study also has advantages and drawbacks. These are discussed in chapter 7.
Based on the previous chapters new design directions are described to point out that it is possible to implement the results of this study in future design concepts (chapter 8). Heightened washing machines could be found also tilted drums are newly available. However, the ideal combination is not implemented yet, probably because there was no research available on the optimal position. However, with the data of this thesis it is possible to design a washing machine with a drum position favourable for users not only in Europe but also in several other countries.

In the following paragraph of this chapter washing and the washing cycle are described in a phenomenological way (chapter 1.1 - What is washing?) to give the reader an over-view of the total washing process. In chapter 1.2 selected variations of washing machines with their consequences for the user are described. The ergonomic aspects, which have to be considered when developing everyday products, are specified in chapter 1.3. It is assumed that the toughest part of using the washing machine is the loading and unloading. Methods to study this part and studying effects of improvements are discussed in chapter 1.4. As comfort is important during loading and unloading methods are described to study comfort subjectively (chapter 1.5). Finally, in chapter 1.6 the methods for evaluation of the washing task are chosen.

**1.1 What is washing?**

The need to wash clothes is as old as mankind, since man had the necessity to clean garments from dirt or sometimes parasites for hygienic, aesthetic or cultural-religious reasons (Geuther, 1998).

### 1.1.1 Definition

Geuther defines 'washing' as the treatment or process of cleaning clothes with water and additional mechanical treatment (also called agitation). Geuther (1998) describes that also in early days people often used some kind of soap or soda (detergent). Washing is therefore defined in this thesis as cleaning clothes using water, agitation and detergent. The term 'washing' and the phrase 'doing the laundry' are used as synonyms.

### 1.1.2 Activities of washing

Based on seven years of washing process observations of people doing their laundry and interviews with users in different cultures (see chapter 2,) an overview of the laundry process is outlined in this chapter.

Washing is a task which is done almost everywhere around the world. In earlier days and even today the laundry was and still is done manually (see figure 1). It is seen as heavy and time-consuming work (Carter, 2005). Occasionally, the whole family is involved in managing the laundry. Depending on people's income, washing was and still is sometimes handed over to launderers or laundresses. Many stories as well as paintings underline the intensity of this work (see figure 2).
Manual washing is a physically demanding task in terms of awkward body postures, repetitive movements and high energetic workload, because of the physical agitation and wringing to get the laundry clean. Moreover, the detergents in combination with high water temperatures can be hazardous. At the end of the 19th century, washing machines were developed to reduce this enormous physical and time-consuming effort (Fiell and Fiell, 2000). Today doing the laundry in the washing machine is a task which is done in general between once a week and a few times daily, depending on family size (P&G, 2005).

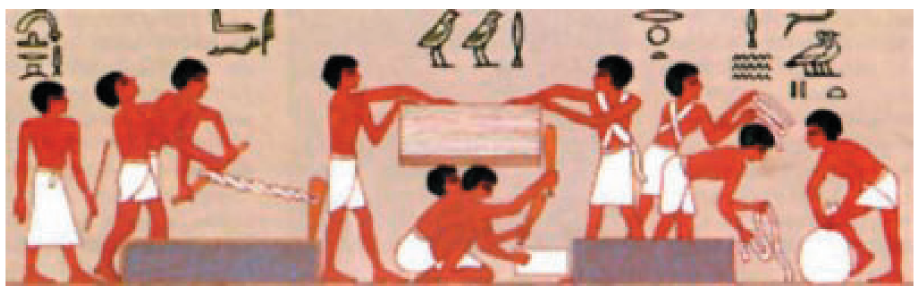


Fig. 2: Egyptian wall painting showing slaves treating the laundry with beaters and wringing the wet clothes (from Geuther, 1998).

Freudenthal (1999) describes washing as problematic for senior citizens and rates washing machines among the top ten items of everyday products, which are relevant to senior citizens living in their own home.
There are many Internet sites warning back patients of laundry activities (North Eastern Rehabilitation Network, 2005, DIA, 2005, and HGTV, 2005) with suggestions for handling, and laundry task safety tips in the Safety Gram (2002). These warnings indicate that doing the laundry is a hazardous task for back pain patients. Additionally, there are many texts on the Internet about washing as a heavy and demanding task for service personnel (NIOSH, 1997; CCOHS, 1998).
However, there is no clear evidence for these warnings in scientific literature.

### 1.1.3 Washing cycle

Washing is a never-ending story, a cycle with several steps including a drying sub-cycle as illustrated in figure 3. The washing process is described phenomenologically as a cycle showing the daily to weekly routine of the person responsible for the washing. It shows the steps connected to the use of the washing machine as well as the additional tasks related to washing. The cycle structured by activities such as wearing, sorting, loading, unloading or ironing, only to mention some of the tasks. The specific problems of these tasks will be described in more detail and are mapped out across the complete user journey.

As washing is a returning task (see images on front page), it starts with wearing the clothes, which get dirty, wrinkled or smelly. Dirty laundry is collected, sometimes in dedicated baskets or laundry sacks.
At special times or when reaching a certain amount of laundry, the washing gets sorted into user-defined piles, which can be according to colour, temperature or texture, and then filled into a washing basket, which is carried to the washing machine. The steps 'sorting the laundry', 'filling the transport basket' and 'transporting it to the machine' can be exchanged as they have the same problem like choosing the right washing program: which pieces can be washed together and how do they have to be treated.
The user may pre-treat the laundry, e.g. to remove stains, and then loads the laundry into the washing machine. People use different patterns when loading the washing machine: Some press the laundry into the drum all at once, some do it piece by piece. As will be described in detail (chapter 3, 4 and 5), body postures vary obviously. The

hand wash of, for example, delicates is not taken into account in this cycle. Users then choose the washing programme depending on the kind, amount, and dirt of the laundry. Depending on this choice they fill in an amount of dedicated detergent. These two steps, choosing the programme and filling in a detergent, are exchangeable in people’s habits.

After a waiting time depending on the chosen program, the user has to unload the washing. A variety of methods can be seen in unloading. The observations of this study pointed out that people try to unload the machine as quickly as possible after washing, because wet laundry becomes wrinkled and smelly if it stays in the drum for too long. Some people try to get everything out at once and throw it in the basket, though some small pieces remain in the drum. Others pick things out one by one, which can become difficult as clothes get entangled. Some people even fold the washing into the basket. A variation in body postures is also seen in unloading (see chapter 3, 4 and 5). The possible next step could be wringing pieces of laundry, e.g. when using a low spinning program for wool.

The drying sub-cycle contains two possibilities: drying with a tumble-dryer (in figure 3 dark blue) or hanging up the clothes on a clothesline (in figure 3 pale blue). When hanging up the laundry, more physical effort is involved in the process, in terms of carrying the basket with the wet laundry to the clothesline, hanging up the pieces, taking them down and carrying back the basket.

When using a dryer, the basket gets moved from the drum opening of the washing machine to the opening of the dryer. The loading is similar to the washing machine, except for the important difference that the pieces are wet and heavier when loading the dryer. For space reasons, the dryer is sometimes placed on top of the washing machine, which leads to a larger lifting distance for the laundry.

The cleaned and dried laundry is folded and sometimes ironed. Ironing is one of the least favourite tasks in the washing process. It is time-consuming and delicate. Finally, the clothes are stored in the wardrobe or drawers and the cycle starts again.

The washing cycle shows the complexity of the whole washing task. The washing machine is only partly involved in this cycle. It is used for the very direct washing steps indicated in green in the cycle: loading the machine, filling in detergent, choosing the


Fig. 3: General washing cycle with a drying sub-cycle, developed by the author after seven years of washing process user observations and interviews. The green steps mark the tasks, which involve the washing machine; the darker blue steps indicate steps, which might involve the washing machine. The pale blue sub-cycle illustrates the drying cycle, which comprises two possibilities: using a dryer or hanging up the laundry on a clothesline.

washing program, waiting for the machine to be finished and unloading. This part used to be the exhausting part of the washing procedure. But even today, parts of these tasks could entail discomfort.

Washing machine manufacturers are looking for innovation possibilities and there certainly are such possibilities. Improvements of tasks, like sorting the laundry or ironing, may have potential for the more distant future. The handling of the washing task itself can be improved as loading and unloading a frontloader are tasks, which could be more comfortable and, especially for the elderly (see chapter 5) and back pain patients (see above), less painful. Loading and unloading of the washing machine, especially of frontloaders, forces the users into uncomfortable body postures, which will be studied in detail later on.

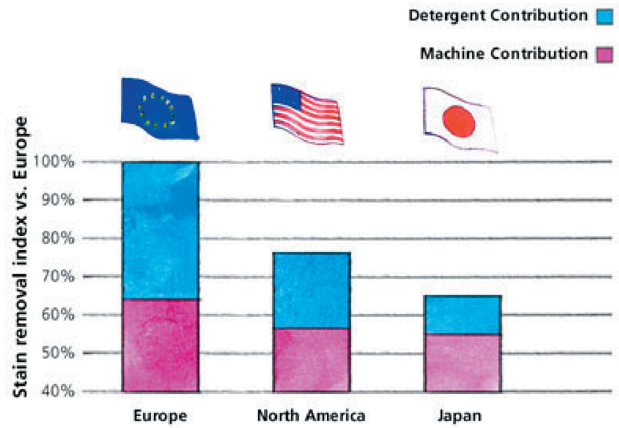
### 1.2 Variation in washing machines

Fiell and Fiell (2000) remark that at the time washing machines were invented, most of them were based on the principle of a washtub. That is a container, which had to be filled with heated water, detergent and the washing from the top. The washing was agitated, either with a beater or a rotating drum around a vertical axis. Most of the machines had to be operated manually, including the heating of the water, pouring it in, getting it out, adding fresh water and wringing. One problem was that the clothes got entangled, either around each other or around the beater. Another issue according to Fiell and Fiell (2000) was the automated heating of the water, which was solved with a more constant electricity supply around 1940.

Building on the old principles of a washtub, toploaders rotating around a vertical axis became popular in North America, and, due to the influence of the USA, also in Middle America, Asia and Oceania (see also chapter 2). The advantage of today's North-American-style toploaders is the opening on the top with direct access to the drum (Fiell and Fiell, 2000). It is easy to load and easy to unload, although sometimes flexing of the upper body is seen. It is on a quite comfortable working height with an opening at around 90 cm and offers good visibility. The disadvantage of the American-style toploaders is the rotation around the vertical axis, which acts more like a centrifuge. The pieces get compressed at the periphery and get stuck there without interfering with each other, even though agitation between the pieces is important for the cleaning process. Beaters are supposed to help agitate the washing, with the result that clothes get entangled around the beater, get torn and hence wear faster. It takes longer to get the washing clean, is less energy efficient and needs more detergent including bleach (Procter & Gamble, 2005), which is less environmentally friendly.

Fig. 4: Left: Wooden domestic washing machine from 1920 with a dolly-style agitator. Right: Automated washing machine from 1961 (Fiell and Fiell, 2000).

Tab. 1: Efficiency of washing machines compared by Procter & Gamble (2005).




Fiell and Fiell (2000) report that in Europe, washing machines were built as frontloaders, rotating around a horizontal axis from as early as 1960. They were space saving and therefore suitable as built-in appliances in the kitchen, bathroom or in small, pantry-like rooms dedicated to doing the laundry (so-called 'wash kitchens'). As the washing machines became more visible, design became more important (Fiell and Fiell, 2000). The advantage of European-style frontloaders is that they use less time for a good washing result, as pieces interfere with each other, and therefore less energy and detergent (Procter & Gamble, 2005). Clothes do not wear out so fast by washing and keep their colour longer. The disadvantage of frontloaders is the usability. People have to bend or

Tab. 2: Consumer washing habits analysed by Procter & Gamble (2005).

| Global Variation in Automatic Washing | | North America | Europe ▸5 Biggest Countries | Japan |
|---|---|---|---|---|
| Population | People | 280 000 000 | 388 000 000 | 127 000 000 |
| | Households | 103 000 000 | 155 000 000 | 42 000 000 |
| Performance Factors | Average wash temperature | 29° | 42° | 23° |
| | Detergent dosage index | 50 | 100 | 25 |
| | Cycle length (Main wash) | 35 (12) minutes | 90 (40) minutes | 60 (11) minutes |
| | Main wash water volume | 60 litres | 15 litres | 45 litres |
| | Average load size | 2.8 kg | 2.8 kg | 2.5 kg |
| Wash Habits | Consumers Pretreating | 49% | 28% | 69% |
| | Bleach usage | 53% | 25% | 62% |
| | Washes per week | 7 | 5 | 10 |

squat when loading and unloading. Additionally, the visibility into the drum is limited, which results in a checking movement of users. They give the drum a twist to really feel if everything was taken out.

In Europe toploaders are also used, but with the same rotation of the drum around a horizontal axis like frontloaders. The benefits of this toploader is a more comfortable loading and unloading process, as people use it in a more upright and comfortable standing body posture. A disadvantage of the European-style toploader is that at least two lids have to be opened: the lid of the machine and the lid of the drum itself, which is a slightly complicated mechanism. Another point is the long distance that has to be covered when loading the laundry from the washing basket on the ground into the drum. Moreover, a negative side effect is that people cannot use the top of the machine for storage or build it in.

A disadvantage of the machines rotating around a horizontal axis is the suspension system, which is more complicated to produce and therefore results in a high price of the machines on the market (Lichtenberg, 1994).

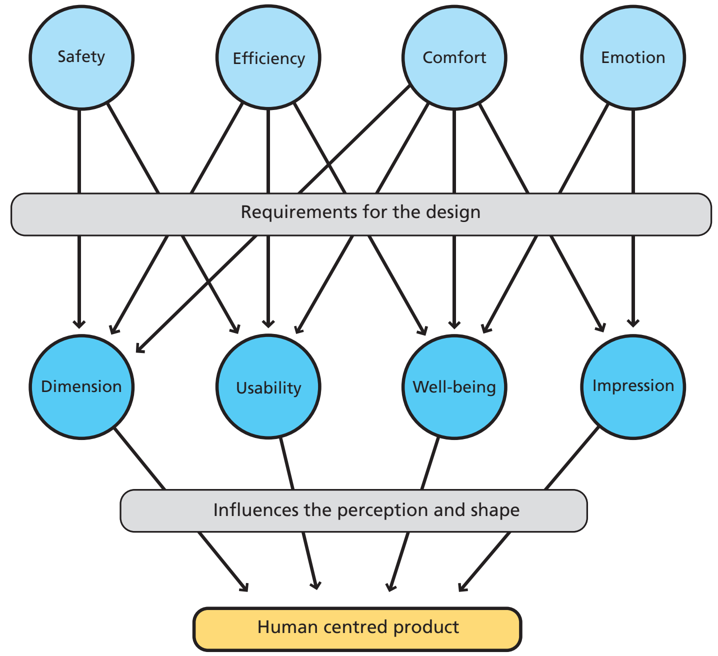
As already pointed out, the state-of-the-art washing machine has room for improvement. The current washing machine in Europe has an opening at a standard level of about 60 cm above the floor. The height of this opening has not been changed in years. This can be an opportunity for manufacturers to improve the height of the opening of a washing machine and the drum angle to gain a larger market share by fulfilling the needs of their customers.

### 1.3 Ergonomic aspects to be considered when developing everyday products

Poorly designed seats can cause discomfort and an uneasy feeling resulting in a negative effect on concentration (Schoeffel, 1985), and in the worst case lead to body disorders and pain (Hettinger, 1991, Hettinger und Hahn, 1991, Vink and Kompier, 1997, Marras, 2003). Consequently, this leads to economic damage (Ayoub and Mital, 1989).

For consumer goods and everyday products the economic damage is less. Especially, for washing machines no research has been conducted. However, these should also be designed in a way that people can use them safely, and support people's well-being and comfort (Kuijt-Evers et al., 2004). A product should be safe, efficient, comfortable and pleasurable (IDSA, 2004). In figure 5, a model is made to summarise how the product design influences the safety, efficiency, comfort and emotion. In this study safety, efficiency and comfort are in focus as they are assumed as mostly influenced by changing the drum opening. The task should be safe and not leading to musculoskeletal injuries. It should be efficient as most people do not like the task and it should be subjectively comfortable. In this case the dimensions are changed and have a direct relationship according to the model in figure 5. The model is helpful as usability, well-being and impression of the product should be taken into account as well in designing, but emotions are not the main focus of this thesis.

Fig. 5: Influencing aspects and their interrelation for a human-centred product modified after the model of Kuijt-Evers et al. (2004) and the requirements of IDSA, (2004).




Dimensions of the product and of the user influence safety, efficiency and comfort. Therefore, influences of the product and the environment as well as the individual differences between people are considered in this thesis. Body height, age or gender can lead to differences in movement patterns or postures (Molenbroek, 1994).

The variability of the human body dimensions can be characterised and differentiated by anthropometric tools and data (e.g. Dreyfuss, 1960, Flügel et al., 1986, Molenbroek, 1994, Jürgens, 1999). Methods were developed to ascertain coherences between human measurements and their interrelation (e.g. Seidl, 1994, Looze et al., 2003). Not only body postures and movements are measured, but also human movement behaviour and motion patterns are often observed to study safety (musculoskeletal loading) and efficiency. One of the first systems to observe and analyse human movement was invented by Borelli (1680-81). The main focus of his study was the evolution of movements and the meaning of the centre of gravity for the human and animal motion sequences (see figure 6).

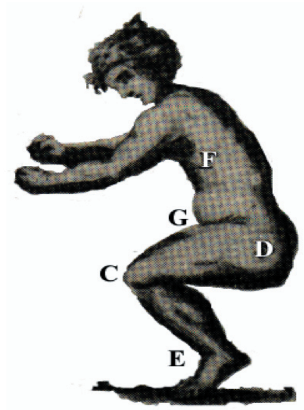
### 1.4 Studying the toughest part of washing

#### 1.4.1 Discomfort in the washing cycle

Around the world people follow the washing cycle, but depending on the country the whole process could be done manually (see chapter 2), or only partly by the machine. But even when using a washing machine, washing can be a demanding job, depending on the amount of laundry. A calculation according to the NIOSH (1991) formula shows that the maximal acceptable lifting load is 2.3 kg for healthy persons between 18 and 45 years of age while unloading a frontloader. This is acceptable as the weight is mostly lower. For elderly and persons having back complaints this load could still be too high. Of course for hand-arm-shoulder loading, it might be too heavy to. Pushing or pulling, bending and lifting the washing basket, also maintaining balance and reaching, can be movements when loading and unloading a washing machine which can cause discomfort. Not only the work at the machine, but also the lifting and carrying of the basket, especially when filled with wet laundry, to the clothesline could cause discomfort as well. Snook and Ciriello (1991) analysed the psychophysical aspects of manual handling tasks. According to their tables, 90% of the females "in relatively good health" (who can manipulate significantly lower weights and forces than men) can lift 4 kg every 5 sec from shoulder height to reach height or 5 kg every 5 sec from floor level to knuckle height. These data show that lifting 3 to a maximum of 7 kg of laundry in either one or two steps should not be a problem for the healthy young population.

This is probably a reason why not much research was done. However, with a growing number of elderly and a growing population with musculoskeletal problems, an improvement in the washing machine serves a growing demand. Snook and Ciriello (1991) did their research under specific conditions. They expected a task to be performed "without strain or becoming tired, weakened, overheated or out of breath." Moore (1978) describes that the ergonomic design of machines determines the level of discomfort. He also described that opening and closing the door or loading and unloading the washing machine strongly affects the subjective experience of subjects. In 1978 (Moore), the following features of an ideal machine were rated as important:

Fig. 6: Illustration of a movement pattern from the opus of G.A. Borelli (1680/81): „De motu animalum". The letters mark different joint angles of this specific body posture.




1. Door release operated by a button and protected by interlocks.
2. The door itself, the aperture size and the size of the drum.
3. The aperture height should be as high as possible and then followed by the user interface.
4. On-off switch, which must have a light to indicate the "on" position.
5. Programme selector with clear "wash numbers" and colour coding.
6. Programme stage indicator with clear indication of stages: washing, rinsing and spinning.
7. Detergent dispenser, depending on the ease of access.
8. Filter, if necessary, with easy access.
9. Mobility, with castors for ease of push and pull and handles recommended.

As washing machines did not change drastically, with respect the opening, the points are largely valid nowadays. While points 4 to 8 are interface problems, which have much attention of washing machine manufacturers, points 1 to 3 will be part of this current research.

#### 1.4.2 Methods to study the washing process

The washing process itself (see chapter 1.1.3) is automated. However, it is presumed in this thesis that problems with loading and unloading the washing machine still exist. To study whether the loading and unloading task is really problematic and to find out whether improvements are better for the musculoskeletal loading, available methods were reviewed to check the suitability for this study.

Developers and designers of everyday products have a diversity of ergonomic databases at hand, which help to fit a product to the human variability. The databases are described in this chapter, analysed and checked for suitability for the task of loading and unloading a washing machine. The evaluation criteria, critical aspects, and suitability are summarised in table 3.

Many data are available, but as can be seen in the suitability row, they are neither completely satisfactory for the loading and unloading of a washing machine nor specific enough to design a washing machine (see table 3).

| Database | Description | Suitability | Source |
|---|---|---|---|
| Anthropo-metric Data | Body dimensions, static and range of motions | Useful for first analysis, but based on standard measurements, mostly not applicable to real life situations, range of motion data insufficient for body posture analysis. | Dreyfuss (1960), Burandt (1978), Diffrient et al. (1981), Lange (1981), Flügel et al. (1986), Jürgens et al. (1989), Kirchner and Baum (1990), Molenbroek (1994), Steenbekkers and an Beijsterveldt (1998), www.dined.nl |
| Reach envelopes | Reach envelopes when squatting | Subjects 20 to 24 years of age | Flügel, Greil, Sommer (1986), Dirken and Steenbekkers (1998) |
| Handling of objects | Handling of objects with 3 kg or more at walking speed on horizontal plain | No concrete advice, not committing | ISO/DIS 11228-1.2 (1999) |
| Muscular and body force | Definition of static/dynamic muscular and body force | Hard to differentiate between work situations | DIN 33 411, Part 1 (1982), Grandjean (1991), Kroemer and Grandjean (1997) |
| Lifting force of packages | Lifting force in front of the body with a rectangular package | Only for industrial settings, not for everyday tasks | Schmidtke, Rühmann (1989) |
| Pushing against vertical plain | Pressure force against a vertical plain | Theoretical force, hard to use in reality | Schmidtke, Rühmann (1989) |
| Pushing, pulling, carrying and holding | Data base with maximal limits for forces and weight for different percentiles and body postures | Mainly for industrial settings (worker, task, environment), not for non-repetetive everyday tasks | Ayub and Mital (1989), Mital et al. (1997) |
| Action force of the arms | Limiting values for action force of the arms | Values only for men. Data hard to use in reality. | DIN 33 411, Part 2 (1982), Rohmert (1993), Rohmert et al. (1989), Rohmert and Rutenfranz (1983) |
| Static work postures | Recommendations for different work tasks | Recommendations for work/job task, not for everyday tasks | ISO 11226:2000 (1995) |
| Individual movement pattern | Analysing individual movement strategies for building archetypes | Does not present 3D data or comfort evaluation | Gransitzki (1994), Busch (1998, 2000), Schröder (1997), Bronkhorst and Krause (2005) |
| Visual field | Aspects of the visual field taken into account | Requirements for the environment, product or workspace | Klaasen, A. (1979), Jenner, Berger (1986), Jürgens (1993) |
| Construction vacuities | Spacial clearance at workspaces | Requirements for the environment and not for product or workspace itself | Jürgens et al. (1989) |

Tab. 3: Overview of recordings that can be used to estimate, whether the loading and unloading of a washing machine is acceptable.

Tab. 4: Overview of relevant measurement methods, simulation and ergonomic tools to analyse work tasks and their usefulness the washing task.

| Measurement method and simulation tools | Description | Suitability | Source |
|---|---|---|---|
| Standardised Nordic Questionnaires | Questionnaires about diseases, particularly of musculoskeletal problems of spine, neck and shoulder | Not useful to qualify body postures and movements | Kuorinka (1987) |
| NIOSH lifting equation | Method to analyse load manipulation to determine loading limits | Special basic conditions limit the usability of application | NIOSH (1981), Jäger et al. (1999), Jäger and Luttmann (1997), Hettinger and Hahn (1991), Heuchert et al. (1993) |
| Revised NIOSH lifting equation | Method to analyse load manipulation to determine loading limits considering asymmetric movements | Artificial conditions limit the usability of application | Waters et al. (1993) |
| OWAS System | Analysis, classification and evaluation system for body postures | Systematic description of body postures and hazard evaluation in the working field | Karhu et al. (1977, 1981), Matthila et al. (1993), Stoffert (1985) |
| ‚The Dortmunder' biomechanical model calculation for load manipulation | System to analyse pressure forces of the lower intervertebral disc | Physical calculation of spine strains | Jäger and Luttmann (1998), Hartung et al. (1999) |
| Reach envelopes research using 'Flock of Birds' | 3D method to realise body movements | Data depend on additional measurement methods | Malyusz (1998) |
| 2D stencil: Kieler Puppe | 2D stencil for static and dynamic determination of comfort criteria for joint angles | Not usable for joint angle chains; stencil made for sitting postures | Helbig, Jürgens (1977), DIN 33408 (1981) |
| 3D Dummies: e.g RAMSIS, PCMAN; JACK, SAFEWORK | Analysing system of movement spaces for comfort evaluation in three dimensional spaces | Not usable for joint angle chains; adjustment of data base to task situation, expensive software packages | Seidl (1994), Geuß (1994), Bubb (1998), Seitz (1998), see Chaffin (2001) for overview on human modeling |

Additionally, there are various ways described in literature to measure human movements. Frequently used methods for movement analysis are presented in table 4. They are analysed for usability in loading and unloading a washing machine. The evaluation criteria and critical aspects are summarised in table 4. The Nordic questionnaire will not lead to specific ideal heights of the drum and is therefore not suitable. Both, NIOSH equations can only be applied in special conditions, which are not found in doing the laundry. Besides, NIOSH does not take the position of the head into account. The Dortmunder is only focused on the spine. The Kieler Puppe is not suitable for other than sitting postures and not for 3D movements and the 3D simulation systems do not measure the realistic way of moving. Therefore, in this thesis the OWAS and Flock of Birds system are used to evaluate the unloading and loading the washing machine. A disadvantage of these systems is that they do not take the subjective feeling of the user into account. Therefore, additional methods are studied that record comfort or discomfort.

### 1.5 How important is comfort?

Ergonomic knowledge supports the human performance by adapting the product to the human capabilities (IEA, 2006). One of the outcomes of an applied ergonomic design is comfort or the reduction of discomfort (Vink et al., 2005).

**But what is comfort?** There are many definitions of comfort. According to Vink et al. (2005), most comfort descriptions from scientific research are concerned about thermal comfort, physical comfort (dealing with seating, posture or physical loading), vibration, shock or acoustic comfort. For discomfort, however, research mostly deals with musculo-skeletal aspects of physical discomfort or pain research in terms of fatigue, restlessness, pain/biomechanics, strain and circulation (Zhang et al., 1996).

Comfort is influenced by many factors in the human environment. Research on comfort is more than a material commodity, which is integrated between standard and luxury. Instead, Barbirat (1998) defines it as the physically reasonable load in a body posture or a movement sequence. Christiansen (1997) describes comfort as the state of physical well-being, which reflects a sensation. Richards (1980) underlines this and describes comfort as a state of a person that involves a sense of subjective well-being, in reaction to an environment or situation. Vink et al. (2005) add to this aspect that every individual has its own opinion on comfort. So, comfort is a subjective phenomenon. That means a product in itself can never be comfortable, only if it is evaluated by the user. Slater (1985) defines comfort as a pleasant state of physiological, psychological and physical harmony between a human being and its environment.

In this thesis, the definition of Vink et al. (2005) is applied, "The convenience experienced by the end user during or just after working with the product."

From this experience, comfort can only be questioned or interviewed, not directly measured. The following approaches could be the result:

- The fit of a product to the anatomy of the user,
- the effort of a user and/or his or her behaviour while using a product
- or the subjective rating and verbalisation of a user's personal comfort sensation.

Comfort is a very abstract term for a very personal sensation. Therefore standardised tests have to be used to compare different conditions, In that case the individual comfort feeling can be rated (Christiansen, 1997). While the first two approaches for the evaluation of product comfort are termed as objective evaluation methods, the third approach is based on an individual subjective rating of the comfort feeling of the user (Christiansen, 1997).

Sometimes the objective assessment of a neutral researcher and the subjective rating can be contradictory. So, a discrepancy between anatomical and ergonomic analysis and a subjective rating of comfort can appear. For example, when lifting a heavy load subjects rate the lifting with a flexed upper body as more comfortable, while in some orthopaedic and ergonomic studies' perspective, lifting from a squatting position is defined as more comfortable (Deutscher Verband für Physiotherapie, 2001). In this thesis, comfort is measured subjectively. To explain the reason behind the subjective rating objective measurements were taken and correlated.

#### 1.5.1 Measuring comfort subjectively

In the literature a large variation of methods can be found to measure comfort subjectively. Some use a question: "Is it comfortable?" with the possibility to answer just yes or no (Bronkhorst and Krause, 2005) or on a three point scale adding an intermediate (Brauer et al, 2003). Others use a 10-point scale and ask subjects to rate their local perceived discomfort (LPD) for different body regions several times during the task (Delleman, 1999). This LPD method is also used with a 6-point scale (Groenesteijn et al., 2004). Delleman (1999) uses in other experiments 5 points scales to find optimal working heights. Kuijt-Evers et al. (2004) described a completely different method. They selected 58 descriptors of comfort from 25 papers and asked subjects if these descriptors are related to comfort. By this method more about the background of comfort could be found. Only little is known about the validity of these methods. The LPD method is probably best validated as it is used often and checks whether it measures what it should measure (Delleman, 1999) and the test-result reliability appeared to be good (Grinten & Smitt, 1991).

There is some debate in the literature regarding the fact whether or not to use discomfort or comfort. Helander & Zhang (1997) discuss that there is a difference between discomfort and comfort during sitting. Discomfort is more related to physical aspects like feeling pressure and muscle pain. Comfort is more related to emotional aspects like feeling safe and luxury. However, Kuijt-Evers (2004) didn't find these differences in using hand tools.

In this thesis it was decided to ask questions regarding comfort as the interest was not only on the physical side. It is easier for a subject to rate in terms of comfort than in discomfort. In this thesis it was also decided to use a scale instead of a yes/no question as it distinguishes better between different postures according to Delleman (1999).

### 1.5.2 Measuring objective and subjective data

As is shown in table 3 and 4 all methods have their drawbacks. Subjective methods lack accuracy and are influenced by the state of the subjects and objective methods do not measure the feelings. Many authors (e.g. Delleman, 1999; Christiansen1997) agree that using the combination of objective and subjective methods is favourable. This is especially true for comfort. In fact the only way to measure this subjective phenomenon is by asking. However, to explain the reason behind this subjective rating additional objective measurements are useful.

In this thesis it was chosen to measure anthropometric factors like body height, body mass index, age, gender, etc. as they can restrict movements and therefore influence the comfort experience. Speed of the task was measured to see if some drum heights are more effective than others. Body posture were analysed to find correlations between subjective comfort rating and specific postures. Body movements were also measured with 3D methods to analyse the dynamic activity and control comfort angles.

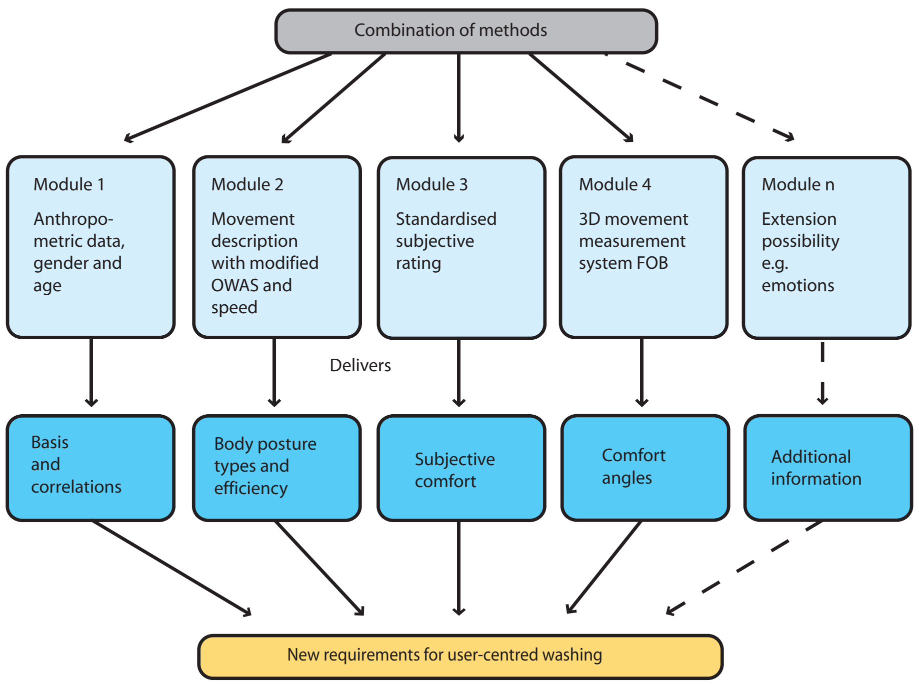



Fig. 7: Overview of the linked research modules. An extension module n is possible for later research e.g. for measuring emotions (Busch, 2006).

## 1.6 What is useful for the evaluation of washing?

As is shown above, there are many ways to study the product use to improve a product. Safety, efficiency, comfort and emotions play a role. In case of unloading and loading a washing machine, safety, efficiency and comfort are especially relevant. Conventional washing machines are built according to safety standards. But efficiency and comfort have not been studied yet. If users can load and unload their washing machine quickly and comfortably, it would make their daily tasks easier. Additionally, they might even learn to love this task, if the machine could provoke positive feelings. This could be a requirement for future design (see chapter 8). In this thesis comfort and efficiency are measured with the four following combinations of methods:

- Module 1: The anthropometric data, gender and age of the subjects.
- Module 2: The movement description with the modified OWAS-system including speed.
- Module 3: A standardised, subjective rating of the movement sequences and posture comfort of subjects.
- Module 4: The 3D movement measurement system 'Flock of Birds'.

Module 1: Anthropometric data, gender and age of subjects were measured to obtain objective data about the individual differences of the subject. These data were used to examine whether coherences between movements and body postures exist.

Module 2: The OWAS system was used to analyse and classify the observed movements and frequencies of body postures. For this thesis, OWAS was modified: context dependent additional information like the degree of the flexion of the upper body or special positioning to the washing machine was added. Originally OWAS was developed to evaluate heavy working tasks, like steel milling, lifting heavy loads or shovelling steel. In this thesis a degree of flexion was added and speed was measured, because these aspects could be important for the end-user.

Module 3: Subjects rated the comfort after loading and unloading the washing machine. The subjective rating was used for the evaluation of comfort. Moreover, it was used to correlate the rating with the body posture analysis. Then the rating was compared with the anthropometric data, gender and age to analyse possible relations between rating and physical features.

Module 4: The 'Flock of Birds' system was used to test whether dynamically the same ideal height was found as statically. It was used to identify comfort angles and strains within a movement sequence. It was used to record the dynamic movements and to analyse the frequency of angles. This gives the opportunity to analyse the comfort angles of measured body postures. With these comfort angles, comfortable and hazardous postures can be categorised.
With the use of the above-mentioned modules, the following research questions about doing the laundry will be answered in this thesis:

- Does a change of the opening height influences the movement and body postures for loading and unloading a washing?
- Are body postures and anthropometric data correlated?
- Do body postures and age or gender correlate?
- Do comfort problems occur at different opening heights?
- Is there a relationship between comfort and body postures when loading or unloading a washing machine?
- Are there relationships between subjective comfort and anthropometric data, age or gender?
- Based on these results, can a washing machine be innovated?
- How would an innovative design fit in people's homes?
- Could this innovation be successful in other cultures as well?

**References**


Ayoub, M., Mital, A., 1989, Manual Materials Handling, Taylor & Francis, London

Babirat, D. et al., 1998, Körpermaße des Menschen - Komfortbereich der Gelenkwinkel der Körpergelenke, in: Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (ed.), -Forschung- Fb 818, Wirtschaftssverlag NW, Dortmund/ Berlin.

Borelli, G.A., 1680/81, De motu animalum, quoted in Glaser R., Grundriß der Biomechanik, Bernabo, Rom.

Brauer, W. et al., 2003, Office 21 – Push for the future better performance in innovative working environments, Fraunhofer Institute, Cologne/Stuttgart

Bronkhorst, R., Krause, F., 2005, Designing Comfortable Passenger Seats, in: Vink, P., Comfort and Design, pp. 155-168, CRC Press, Boca Raton.

Bubb, H., 1998, in: Strassmann, B., Mensch trifft Maschine - Virtuelle Arbeitnehmer helfen, Montagebänder und Fahrzeuge zu verbessern, Die Zeit, 44/1998.

Burandt, U., 1978, Ergonomie für Design und Entwicklung, Verlag Dr. Otto Schmidt, Köln.

Busch, N., 1998, How to exit a car, in: Proceedings of the 4. International Congress on Physiological Anthropology, Zagreb.

Busch, N., 2000, Thermography as a Method for Describing Different Processes of Thermoregulation, in: Proceedings of the 5th International Congress on Physiological Anthropology, Seoul, Korea.

CCOHS, 1998, Canadian Centre for Occupational Health & Safety, OHS Answers - Occupations & Workplaces - Hotel Laundry in: http://www.ccohs.ca/oshanswers/occup_workplace/laundry.html.

Carter, C., 2005, The History of Household Technology, in: http://www.loc.gov/rr/program/journey/household-transcript.html.

Chaffin, D., 2001, Digital Human Modelling for Vehicle and Workplace Design, SAE Society of Automotive Engineers, Warrendale.

Christiansen, K., 1997, Subjective Assessment of Sitting Comfort, Coll. Anthropol. 21, pp. 387-395.

De Greene, K., 1980, Major conceptual problems in the systems management of human factors/ergonomics research, Ergonomics, no. 23, pp. 3-11.

Delleman, N., 1999, Working postures: prediction and evaluation, VU, thesis, Amsterdam

Deutscher Verband für Physiotherapie, 2001, quoted in: Scheffler, C., Bewegungsmuster in Alltagssituationen, ed. Greil, H., Scheffler, C., Mensch – Technik – Umwelt, Forschungsforum Anthropologie, Schriftenreihe des Zentrums für Umweltwissenschaften der Universität Potsdam, Potsdam.

Deutsches Institut für Normung (ed.), 1981, DIN 33 408, Körperumriß-schablonen für Sitzplätze, Beuth Verlag, Berlin.

Deutsches Institut für Normung (ed.), 1982, DIN 33 411, Part 1 and 2, Körperkräfte des Menschen, Beuth Verlag, Berlin.

Deaconess Healthcare, December 2005 taken from http://www.deaconess-healthcare.com/btb.html.

Diffrient et al., 1981, Humanscale 1-9, The MIT Press, London.

Dirken, J., Steenbekkers, L., 1998, Project data and design applicability, in: Steenbekkers, L. and Beijsterveldt, C. van (eds.), Design relevant characteristics of aging users, Delft University Press, Delft.

Dreyfuss, H., 1960, The Measure of Man, Whitney, New York.

Fiell, C., Fiell P., 2000, Industrial Design A-Z, Taschen Verlag, Köln.

Flügel, B., Greil, H., Sommer, K., 1986, Anthropologischer Atlas, Verlag Tribüne, Berlin.

Freudenthal, A., 1999, The design of home appliances for young and old consumers, Series ageing and ergonomics 2, Delft University Press.

Geuß, H., 1994, Entwicklung eines anthropometrischen Meßverfahrens für das CAD-Menschmodell RAMSIS, Dissertation, Technische Universität München.

Geuther, A., 1998, Wie man eine weiße Weste bekommt – Zusammensetzung, Wirkungsweise und Tips im Umgang mit Waschmitteln, in: http://www.uni-giessen.de/~ge1016/publikation/geuther/waschen/waschmittel.html, Gastvortrag am Institut für Didaktik der Chemie der Otto-Friedrich-Universität Bamberg, Bamberg.

Grandjean, E., 1991, Physiologische Arbeitsgestaltung, Leitfaden der Ergonomie, 4. Auflage, Ecomed Verlagsgesellschaft mbH, Landsberg.

Gransitzki, K., 1994, Biomechanics of Entering a Car, in: Proceedings of the 2. International Congress on Physiological Anthropology, Kiel.

Grinten, M. van der, Smitt, P., 1991, Test-retest reliability of a practical method for measureing body part discomfort, in: Quinnec, Y. and Danielliou, F. (eds) Designing for everyone, pp. 54-56, Taylor & Francis, London

Groenesteijn, L., Eikhout, S., Vink, P., One set of pliers for more tasks in installation work: the effects on (dis)comfort and productivity, Applied Ergonomics 2004, 35(5), pp. 485-492

Hartung M. et al., 1999, Vorschlag zur Beurteilung der arbeitstechnischen Voraussetzungen im Berufskrankheiten-Feststellungsverfahren, Teil II, in Arbeitsmedizin Sozialmedizin Umweltmedizin, 34. Jahrg., pp. 112-122, Heft 3, Gentner Verlag, Stuttgart.

Helander, M., Zhang, L., 1997. Field studies of comfort and discomfort in sitting, Ergonomics, 40 (9), pp. 895–915

Helbig, K., Jürgens, H., 1977, Entwicklung einer praxisgerechten Körperumrißschablone des sitzenden Menschen, ed.: Bundesanstalt für Arbeitsschutz und Unfallforschung, Forschungsbericht Nr. 187, Wirtschaftsverlag NW, Dortmund.

Hettinger, T., 1991, Occupational hazards associated with diseases of the skeletal system, Ergonomics 28, Nr 1., pp. 69-75.

Hettinger, T., Hahn, B., 1991, Schwere Lasten - leicht gehoben, ed. Bayerisches Staatsministerium für Arbeit, Familie und Sozialordnung, München.

Heuchert, H. et al., 1993, Erkrankungen der Wirbelsäule bei körperlicher Schwerarbeit und Ganzkörperschwingungen: Erläuterungen zu den neuen BK-Nummern 2108, 2109, 2110 und zur EG-Richtlinie 90/269/EWG (Heben und Tragen von Lasten). Schriftenreihe der Bundesanstalt für Arbeitsmedizin: Sonderschrift 3, Wirtschaftsverlag NW, Bremerhaven.

HGTV, 2005, in: http://www.hgtv.com/hgtv/ah_personal_care_other/article/0,1801,HGTV_3148_1391008,00.html.

IDSA, Industrial Designers Society of America (IDSA), 2004, What is ID?, www.idsa.org, Dulles.

IEA, International Ergonomics Association, 2006, in: http://www.iea.cc/ergonomics/.



International Institute for Standardisation, 2000, ISO 11226, Ergonomics – Evaluation of static working postures, International Standard, ISO 11226:2000E, International Organisation for Standardisation.

International Institute for Standardisation, 1999, ISO/DIS 11228-1.2, Ergonomics - Manual handling- Part 1: Lifting and Carrying, Draft International Standard, ISO/TC 159/SC 3, International Organisation for Standardisation.

Jäger, M. et al., 1999, Retrospektive Belastungsermittlung für risikobehaftete Tätigkeitsfelder, Teil I, in Arbeitsmedizin Sozialmedizin Umweltmedizin, 34. Jahrg., pp. 101-111, Heft 3, Gentner Verlag, Stuttgart.

Jäger, M., Luttmann A., 1997, Critical survey on the biomechanical criterion in the NIOSH method for the design and evaluation of manual lifting tasks, International Journal of Industrial Ergonomics, 23, S. 331-337, Elsevier Science.

Jäger, M., Luttmann, A., 1998, Möglichkeiten der biomechanischen Modellrechnung und Beurteilung von Wirbelsäulenbelastungen bei der Lastenmanipulation, in R. Pangert (red.): Heben und Tragen von Lasten, Landesamt für Soziales und Familie, Suhl und Thüringer Ministerium für Soziales und Gesundheit (ed.), Erfurt.

Jenner, R., Berger G., 1986, Arbeitsplatzgestaltung und Körpermaße, W. Lange, W. Doerken (eds.), Verlag TÜV Rheinland.

Jürgens, H., 1999, Körpermaße, in: Handbuch der Ergonomie, ed. Bundesamt für Wehrtechnik und Beschaffung, Koblenz, 2. Auflage, Band 3, Carl Hanser Verlag, München.

Jürgens, H., 1993, Arbeitsgestaltung; Anthropometrische Grundlagen der Arbeitsgestaltung, Teil 6 in Ergonomie, in: Schmidtke, H. (ed.), Carl Hanser Verlag, München.

Jürgens, H. et al., 1989, Internationaler anthropometrischer Datenatlas, Schriftenreihe der Bundesanstalt für Arbeitsschutz, Forschung Fb 587, Dortmund.

Karhu, O. et al., 1977, Correcting working postures in industry, A practical method for analysis, Applied Ergonomics 8, no. 4, pp. 199-201.

Karhu, O. et al., 1981, Observing working postures in industry: Examples of OWAS application, Applied Ergonomics 12, no. 1, pp. 13-17.

Kirchner, J., Baum, E., 1990, Ergonomie für Konstrukteure und Arbeitsgestalter, ed. REFA Verband für Arbeitsstudien und Betriebsorganisation e.V., Carl Hanser Verlag, München.

Klaasen, A., 1979, De elektronificatie van de wasmachine, Afstudeerverslag, September 1979, Industriele Vormgeving, Technische Hogeschool Delft.

Kuijt-Evers, L. et al., 2004, Identifying factors of comfort in using hand tools, Applied Ergonomics, 35(3), pp. 453-458.

Krömer, K., Grandjean E., 1997, Fitting the task to the human, 5th ed., Taylor and Francis, London.

Kuorinka, I. et al., 1987, Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms, Applied Ergonomics, 18.3, pp. 233-237.

Lange, W. et al., 1981, Kleine Ergonomische Datensammlung, ed.: Bundesanstalt für Arbeitsschutz und Unfallforschung, Verlag TÜV Rheinland.

Lichtenberg, W., 1994, Technik im Haushalt, ed. B. Busse, Verlag Handwerk und Technik.

Looze, M. et al., 2003, Sitting comfort and discomfort and the relationships with objective measurements, Ergonomics, 46, pp. 985-998.

Marras, W., 2003, The future of research in understanding and controlling work-related low back disorders, on Ergonomics in the Digital Age, IEA CD-rom, Proceedings of the XVth Triennial Congress of the International Ergonomics Association, Seoul.

Mattila M. et al., 1993, Analysis of working postures in hammering tasks on building construction sites using the computerized OWAS method, Applied Ergonomics 24, no. 6, pp. 405-412.

Malyusz, V., 1998, Untersuchungen zur Systematik von Greifräumen, Diplomarbeit, Universität Kiel.

Mital, A. et al., 1997, A Guide to Manual Material Handling, Taylor & Francis, London.

Molenbroek, J., 1994, Op maat gemaakt – Menselijke maten voor het ontwerpen en beoordelen van gebruiksgoederen, Delft University Press, Delft.

Moore, T., 1978, CA Report No.1, Results of an experiment to compare design features of automatic washing machines, ed. Institute for Consumer Electronics, for Consumers' Association Project No. A2998 Ergonomics, University of Technology, Loughborough.

National Institute for Occupational Safety and Health (NIOSH), 1981, Work practices guide for manual lifting, Dept. Health and Human Services, Publ. No. 81-122, Cincinnati.

National Institute for Occupational Safety and Health (NIOSH), 1997, Control of Health and Safety Hazards in Commercial Drycleaners - Chemical Exposures, Fire Hazards, and Ergonomic Risk Factors, U.S. Department of Health and Human Services, Public Health Service Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, December 1997, DHHS (NIOSH) Publication No. 97-150 in: http://www.cdc.gov/niosh/97-150.html#ergo.

North Eastern Rehabilitation Network, 2005, in: http://www.northeastrehab.com/Guides/goodtoback.htm.

Procter & Gamble (P&G), 2005, in: http://www.scienceinthebox.com/en_UK/research/washabits_en.html.

Richards, L., 1980, On the psychology of passenger comfort, in: Oborne and Levis (eds.), Human Factors in Transport Research, vol. 2, pp. 15-23, Academic Press, London.

Rohmert, W., 1993, Biomechanische Grundlagen, in Ergonomie, ed. Schmidtke, H.,

3. Auflage, Carl Hanser Verlag. München.
Rohmert, W. et al., 1989, in Handbuch der Ergonomie, Bundesamt für Wehrtechnik und Beschaffung, Koblenz, 2. Auflage, Band 1, Carl Hanser Verlag, München.
Rohmert, W., Rutenfranz, J., 1983, Praktische Arbeitsphysiologie, 3. Auflage, Georg Thieme Verlag, Stuttgart.
Safety Gram for Laundry & Housekeeping Staff, 2002, Volume 1, No. 1, January.
Schmidtke, H., Rühmann, H., 1989, Körperkräfte, in: Handbuch der Ergonomie, ed..: Bundesamt für Wehrtechnik und Beschaffung, Koblenz, 2. Auflage, Band 3, Carl Hanser Verlag, München.
Schoeffel, R., 1985, Zur anthropometrischen Bewertung von Arbeitsplätzen an Bildschirmen und Konsolen, in: Wehrpsychologische Untersuchungen, ed.: Bundesministerium der Verteidigung, Heft 1/85, 20. Jahrgang, Kiel.
Schröder, I., 1997, Variations of sitting posture and physical activity in different types of school furniture, Coll. Antropol. 21, pp. 397-403.
Seidl, A., 1994, Das Menschmodell RAMSIS – Analyse, Synthese und Simulation dreidimensionaler Körperhaltungen des Menschen, Dissertation, Technische Universität München.
Seitz, T., 1998, The optical measurement system PCMAN, in: Proceedings of the Workshop on 3D Anthropometry and Product Design, ed. A. Coblentz, Paris.
Slater, K., 1985, Human comfort, Charles C. Thomas, Springfield, Illinois.
Snook, S.H., Ciriello, V.M., 1991, The design of manual handling tasks: revised tables of maximum acceptable weights and forces, Ergonomics, Vol. 34, No. 9, pp. 1197-1213.
Steenbekkers, L. and Beijsterveldt, C. van (eds.), 1998, Design relevant characteristics of aging users, Delft University Press, Delft.
Stoffert, G., 1985, Analyse und Einstufung von Körperhaltungen bei der Arbeit nach der OWAS-Methode, Zeitschr. d. Arbeitswissenschaft 39 (11NF), no. 1, pp. 31-38.
Vink, P., Kompier, M., 1997, Improving office work: A participatory ergonomic experiment in a naturalistic setting, Ergonomics, 40(4), pp. 435-449.
Vink, P. et al., 2005, Theory of Comfort, in: Comfort and design: principles and good practices, CRC Press, Boca Raton.
Vink, P. et al., 2005, Comfort experience, in: Comfort and design: principles and good practices, CRC Press, Boca Raton.
Voskamp, P., Scheijndel PAM van, Peereboom, KJ, Handbook ergonomics (in Dutch), Kluwer, Alphend aan de Rijn, 2006
Waters, T. et al., 1993, Revised NIOSH equation for the design and evaluation of manual lifting tasks, Ergonomics, 36, pp. 749-776.
Zhang, L. et al., 1996, Identifying factors of comfort and discomfort in sitting, Human Factors, 38(3), pp. 377-389.

# 2 Doing the laundry

Different strokes for different folks

Paper shall be submitted to journal: Design Research

**Authors: Nicole Busch and Henri Christiaans**
nicole.busch@hamburg.de and henri.christiaans@io.tudelft.nl
Delft University of Technology, Faculty Industrial Design Engineering, Landbergstraat 15, 2628 CE Delft, The Netherlands

**Abstract:** Globalisation and profit maximisation force companies to introduce their products in many different regions of the world. Only an awareness of the local circumstances, the needs and desires of the local consumers, their habits and rituals, as well as the local restrictions and limitations will make their efforts a success. This chapter gives an overview of the different washing cultures worldwide to find out if innovations are compatible with existing cultural habits. It appeared that washing machines are used in Europe, Australia and parts of Asia, Africa and America. In some cultures the washing machine is placed on wheels to be transportable within the house, sometimes it is positioned on the balcony or in narrow spaces.

**Keywords:** culture, everyday product, household appliances, product design.

**2.1 Introduction**

Today, companies are interested in selling their products worldwide. Products are used by different user groups, for example different age groups, with different interests. Products have to fit to different abilities and multiple body dimensions as well. Research was done (Busch and Vink, 2006, Busch et al. 2006) and standards were set, to make products as useful and as desirable as possible. For the global market, products have to meet even more requirements, as users in different countries and cultures behave in different ways, depending on their circumstances.

However, many products are designed by European design agencies or produced by European manufacturers. This means that many people have to use products, which were not originally designed for them, their countries or their culture. A company's failure to acknowledge cultural differences often limits its product's marketability (Rutter and Donelson, 2000). Cultural differences were studied by comparing markets and products internationally (Kenntner, 1973, Hariandja and Daams, 2005, Ono, 2005, Kim, 2005, Rompay et al., 2005). The conclusion from these studies is that products should either be produced and designed locally to satisfy local consumers, or should be equally usable and fit across different countries and cultures. But what does culture mean?

### 2.1.1 Aspects of culture

Max Frisch (2005) claims: "We live in a time, in which man are not able to define the meaning of culture anymore." Indeed, the definitions of culture are numerous. As a starting point, most common definitions of culture are described. Kroeber and Kluckhohn (1952) collected more than 200 theories, which mirror studies about the evaluation of culture and the understanding of human behaviour. They define culture as consisting of patterns of or for behaviour, which are transmitted by symbols, constituting the distinctive achievements of human groups, including the design of products. The essential core of culture is made up of traditional ideas and above all of people's values in the present and the future. Microbiologists understand by culture organisms, cells and bacteria grown in special media. Anthropologists define culture as a divider between Homo sapiens and animality, i.e. the beginning of hominisation and the development of culture (Grupe et al., 2005). Dahl (2004) states that the word 'culture' is used in "everyday language to describe an abstract entity, which involves a number of usually man-made, collective and shared artefacts, behavioural patterns and values". Hofstede (1994) defines culture as "mental software" – "the collective programming of the mind, which distinguishes the members of one group or category of people from another".
In their models, Hofstede (1994) and Trompenaar (1993) provide guidelines to examine differences in culture and how to understand people's own cultural biases. Hall (1977) defines culture as the lifestyle of a group of people, as the sum of their behavioural patterns, attitudes and material things. All definitions state that culture is learned and not inherited. That is a reason why Hoecklin (1995) points out that culture can only be considered in relation to other cultures. She describes the effect that culture dictates what groups of people pay attention to. The learnability aspect was also demonstrated in studies in which people were observed when moving from one cultural area to another, taking over habits and behaviour of the new culture (see e.g. De Leur et al., 2005). However, it is not always clear at what level this 'new' behaviour was internalised: on the level of outward appearance or on deeper levels of beliefs and values?

### 2.1.2 Cross-cultural research

The main global success factor of products is their international usability (Christiaans, 2005). ISO 9241-11 defines usability as the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use. Leonard and Rayport (1997) emphasize the value of ethnographic research to understand how people interact with products, environments, and services. To help companies in foreign markets with various cultural factors and their implications, observational studies on the use of products in different cultures have to be conducted (IDEO, 2003). Foreign correspondences can give input about various cultural and environmental contexts in which the product might be used. Cultural probes can be collected to evaluate perceptions and behaviours to underline similarities or differences of cultures.
Intuitive cross-cultural products should reflect the cultural orientation of the users and fit to the users' cultural differences. They have to be able to fulfil people's demands, needs and desires in their environment.

### 2.1.3 Doing the laundry

As white goods companies aim to sell their products, like washing machines, worldwide, it would be smart to know the local rituals, needs, wishes or even limitations. This cultural overview focuses on one household task, which is doing the laundry, an activity that is by its nature a basic need. It could be used prototypical for other basic household tasks. Washing is an activity, which is done globally, though local circumstances, patterns, automation or washing machine constructions vary.
People do the laundry everywhere around the world. In some areas people still wash manually (it can be done by foot as well); in the industrial world the washing process is generally automated. Depending on the fabric, though, people still wash delicate pieces by hand. Washing machines were developed at the beginning of the 20th century to reduce the enormous amount of physical effort and time that went into washing. Depending on local circumstances, washing machines work in totally different ways, resulting in very different designs and patterns of usage.
Not all washing machines are produced locally. Many companies produce and design washing machines for an international market with diverse cultural differences, which have to be carefully considered (Cushman and Rosenberg, 1991). Companies that are strong in marketing their offerings to their local markets find it difficult to successfully enter new, culturally unfamiliar markets (Kumar, 2004). Kumar describes how companies underestimate the differences of patterns in daily life in different cultures and therefore fail to meet people's culture-specific needs. For example Whirlpool's "World Washer", which was designed to be a one-size-fits-all machine and was introduced as an important part of the company's global strategy into the Indian market in the late

eighties. It failed because designers did not study what most women wore in India (Honhold, 2000). Women wear saris, a 30-foot long cloth wrapped around the body, which became entangled in the machine paddles and caused abrupt water and electrical stoppages in mid-cycle. This shows that if companies want to expand globally, they need to recognize the differences in people's lifestyles and tailor their offerings accordingly. This example demonstrates that markets can be very diverse in terms of users' demands and needs.

The aim of this study is to give a cultural overview of several countries.
In closer detail, this research answers the following question:

- Do people wash differently when influenced by a different culture?
- Where do washing machines fit in the washing process with improved loading height and angle?

It is assumed that some of the washing diversity

- may be due to the diversity of environments,
- comes from different types of clothes to wash,
- depends on different histories and backgrounds,
- is driven by economical aspects, or
- could relate to different levels in a social structure.

It is hypothesised that these influences could result in

- different washing strategies with
- different needs and limitations when washing clothes.

**2.2 Method**

In order to answer these research questions about the cultural differences in washing between countries, qualitative research methods were used. It was impossible from a budget and time perspective to study all countries in the world. Therefore, countries from the main continents were selected. In the selection it is important to have the leading countries (Europe, USA, Japan and Australia) and the upcoming countries (India and China). Countries with additional washing methods were added (Latin America, Gambia, South Africa, Maldives, Russia). Observations were done by the author. To reduce travel budget, additional information was gathered by asking local researchers to observe and make pictures of the situation. Information was gathered in America (USA, Venezuela, Argentina, Uruguay, Paraguay, Chile, Brazil), Europe (Germany, the Netherlands, Scandinavia, Spain, Russia), Asia (China, India, Korea, Japan, the Maldives) and Africa (South Africa, the Gambia). Photographs were taken of people doing their laundry and open questions about habits and circumstances were asked.

Data were collected through so-called 'cross-cultural observations' (IDEO, 2003). For this method, 11 socio-cultural reports, were studied to compare related data about washing in different countries. The relevant comparisons about washing in general, differences in machine systems, loading and unloading, and other environmental, social and economic circumstances were filtered as interface usability was not the focus of this research. To reveal cultural differences in the context of washing reports from Brazil, the Netherlands, Germany, India, China, South Korea, and Australia, general overviews on everyday objects used as well as the habits of carrying loads were researched.

To collect information about latent consciousness, so-called cultural probes (IDEO, 2003) were chosen. Camera journals were assembled and distributed to participants across Asian cultures. Participants were asked to take pictures of their daily routine. The cultural probe could not focus on the laundry process only, as it was part of a company project study, but some information, images and descriptions of this photos (so called photo surveys) could still be used. From 20 photo surveys, ten were returned and only three contained details about washing. Two photo surveys were from China and one was from Japan.

To acquire information about local circumstances for this cultural summary, so-called 'foreign correspondents' (IDEO, 2003), i.e. colleagues, friends and their contacts were contacted in other countries via e-mail to learn about local needs, problems and limitations. These contacts sent images and/or descriptions about the washing process from the USA, Mexico, Brazil, Norway, Spain, Egypt, Russia, China, Taiwan, Japan and Australia.

**2.3 Results**

The results are sorted according to the continents eastbound starting in America. American style washing machines influenced the South American and Asian markets. When presenting cultural habits, first the average user with average income is described and

then, if collected data is available, it is pointed out in which way habits differ for people over and under the average income.
Differences in washing machines or washing methods, as well as differences in related washing habits are presented.
For a first overview, Proctor & Gamble (2005) compared washing habits for automated washing in the USA, Europe and Japan (table 1 and 2 in chapter 1 - Prologue).

### 2.3.1 America

#### North America

In North America practically every household or apartment building has a washing machine. In apartment buildings there is a communal washing machine room. People mainly use toploaders for washing. They describe them as very comfortable to load and unload. The downside is that the drum rotates on a vertical axis, with the result that the laundry inside the drum gets pressed to the periphery. As a consequence, the pieces of laundry do not interfere with each other. This physical rubbing effect, though, is important for the washing result, as it makes clothes cleaner. One remedy is to use stronger washing liquid as well as bleach for a better result (see table 1 and 2). The effect is that the colour of clothes fades quicker, besides stronger environmental issues. Another solution is a mechanical tool to agitate the pieces, with the effect of physical stress of


Fig. 1: USA washing machines; left: toploader spinning on a vertical axis (photographer: Yellow dog production - Image Bank), right: frontloader with stacked dryer - space matters (photographer: Ted Barber).


Fig. 2: Mexican washing machines: left: interface of recent semi-automatic machine (photo-grapher: Jonathan Clark), right: old machine (image from equally_ different).

the fabrics and clothes that are worn out sooner. In general, European-style washing machines are becoming more interesting for consumers because they are renowned for their better washing results.
The population structure of the USA with its large proportion of immigrants and people with a Latin American background, its many people with an under-average income who cannot afford a washing machine, and those who live in small city apartments without the space for a washing machine, are factors that lead to the popularity of launderettes and launderers, North American Laundromats, or shared community washing machines.

#### Latin America

In many countries of Latin America, people do not have high-tech washing machines, if at all. Old models and basic models are more common. Some of them are only half-automatic, so users have more manual, hard and time-consuming work to do (Clark, 2004). In some washing machines, water has to be filled in by hand and a centrifuge is not included, so that people, mostly women, have to wring out the wash. Especially in underdeveloped Latin American countries, the whole process of laundry is often done manually. Washing powder is sold, like all other consumer goods, in small packaged sizes instead of in bulk-size packages. The reason is mostly that people cannot afford to buy bigger sizes.



#### South America

In Venezuela, Colombia and Brazil, the difference between people with high and low income is tremendous. People with higher income have modern, mostly American-style washing machines, which are sometimes used by housemaids. Housemaids usually have a lower level of education, which includes illiteracy. People with low income still wash with less automation, which is comparable to people from Latin America using old, less automated washing machines. In Brazil, many people have toploader washing machines,

Fig. 3: Left: Washing in Venezuela without electricity in a very humid climate (photographer: Jane Sweeney for Lonely Planet). Right: image of a Brazilian housemaid washing in Curitiba in the region Paraná in Brasil (photographer: Jose Tadeu Smolka).

which are placed in special cabinets close to the kitchen with the tap (Russo, 2005). For the technical perspective, Ono (2005) describes that home appliances are less robust and durable than European and North American ones. Brazilian washing machines do not have a water filter to reduce water pollution. All Brazilian washing machines have a safety system to stop the process when users open the lid, though people like to fool the system, open the lid and see the machine working. As a result, Electrolux integrated a glass lid (in: Ono, 2005). Concerning the colours, Ono (2005) describes that Brazilians prefer white household appliances in contrast to more colourful household appliances in Asia (which will be described in the chapter on Asia). According to Ono, home appliances do not need a "recherché" finish (e.g. chromed finish). Unlike North America, laundromats are very uncommon and are not used by Brazilians, which is different to many other nations worldwide.

In countries like Uruguay, Paraguay, Argentina and Chile, European-style washing machines are used more often. Many of the people have a middle-sized income. In cities like Buenos Aires or Montevideo, washing machines are even placed on balconies. In the countryside, machines stand in garages and the garden as well. As weather conditions show strong variations in temperature and humidity, rust and oxidation are limiting the durability of washing machines.

### 2.3.2 Europe

In Western Europe most households have their own washing machines. Frontloaders are most popular. As a result, people use uncomfortable loading and unloading strategies as analysed from Busch and Vink (2006). People start to build workarounds, such as understructures to place their machine on.

In general, only a few differences can be seen between countries, mainly in the circum-

Fig. 4: Top left: Typical set-up in Germany with frontloader and dryer next to it. Top right: old semiautomatic Dutch toploader, where drum needs to be opened for loading and unloading as it spins on a horizontal axis. Bottom left: Spanish washing machine on an understructure produced by Whirlpool (image taken from equally_different). Bottom right: in rural Greece (Corfu, Kavos) some people still wash manually (photographer:
Darren Robb for Stone)

stances in which a washing machine is used. In Spain, for example, there is no standard for water pressure. Low water pressure is a problem in multi-level apartment buildings. That is why washing machines suffer from a lack of water, causing frustration because predicted washing times cannot be maintained. Missing water filters cause problems with sand in the machine, which is even worse for the drainage than for the washing result itself.

German washing machines (e.g Bosch, Siemens, Miele) are perceived as very robust, solid and conservative (Ono, 2005), compared to Italian (e.g. Zanussi) or British models.

In Russia the difference between people with high and low income is tremendous. People with higher income have modern, mostly European-style washing machines. In general, though, if at all, people have old, low-tech washing machines of mainly Russian brands. The biggest problem, however, is drying the clothes after the washing procedure, as a colleague reported. The climate can be very cold in winter or very humid in summer, so clothes stay dank and start to mildew. According to Martin Lindstrom (2006) Russians associate with washing the smell of clothes dried at -20°C.

Fig. 5: Top: In most parts of Russia, people still wash by hand (photographer unknown).
Bottom left: In Georgia, drying is a problem, especially in very cold winters. Clothes never really dry (quote by Mecayla Beaver; photographer: Randy Olson for National Geographic).
Bottom right: Western mashing machine in a parliament building (photographer unknown).

Fig. 6: Top: Woman in Dakar, Senegal doing the laundry out in the street, surrounded by her neighbours (image taken from equally_different).
Middle: Woman doing her laundry outside her shack in Khayelitsha, a township outside Cape Town, South Africa. People usually come from the rural areas in Eastern Cape pro-vince to find work as maids and labourers (photographer: Per Anders Pettersson).
Bottom: Mauritian women washing in the river, using a stone for scrubbing (photographer: Christel Busch).

As Northern Europe has the same problems, dryers are very popular. Where space does not matter, dryers are placed next to the machine. Many people complain that the doors open against each other, to the wrong side and are generally in the way. Where space does matter, dryers are placed on top of the washer and lifting wet clothes becomes an issue.

### 2.3.3 Africa

In most parts of Africa, the laundry is still done manually, mainly because water in the house and electricity are not or only seldom available. For manual washing less water is used than for a washing machine. Even middle class families in Banjul, Gambia, have tap water for only one hour in the evening. So most of the washing is done by hand. As firewood is rare and expensive, the laundry is done with cold water, lots of washing powder and scrubbing. The soil is red and dry, dust is ubiquitous and stains clothes immediately. Washing is done either in plastic washtubs close to the well, pump or directly in the river. Another method is sharing the hard work. Two women put the laundry, together with water and soap, into a wooden bucket and use beaters to alternately beat the washing in the bucket, singing a song to the beating rhythm. After washing white linen is still spread out for bleaching. Afterwards all pieces have to be ironed, as this kills nested bugs. Right after the washing is finished, the red dust stains the clothes already.
In South Africa big differences can be seen between high and low income. People who own a washing machine (often frontloader) normally have maids to work with it, but most people still wash by hand.
In general, Africa is the continent where clothes are generally washed using pre-industrial resources (Gestora, 2004).

### 2.3.4 Asia

China

In China differences between the newest design of washing machines and manual washing are very large, which is highly related to people's income but also to export technology. The phrase 'white goods' only works in the Western culture. In China and India, 'white' is perceived as the colour of mourning, instead of as the colour for cleanliness and innocence. Siemens (2001) reports that it is tradition in China to receive a washing machine as a wedding present. So washing machines are painted pink and have hearts stuck on them to remind the couple of their wedding day, and of the gift-

Fig. 7: Washing in China varies between the newest and most modern models, semiautomatic machines and washing by hand. (Photographer upper left and middle image: Ying Ying Lau, and right: Chinese correspondent for 'Whose life'.)

giver, every time they use it. Space matters a lot as well, because people live very closely packed in the big cities of China. While Chinese people in general enjoy noisy conversations, games and music, the noise level of the washing machine, especially when centrifuging, seems to bother people (Siemens, 2001). So the washing machine 'Super Silent', which was produced by BSW, a joint venture between Bosch Siemens Home Appliances and Wuxi Little Swan, received an award from the Chinese patent office for washing, rinsing and spinning without producing noise. Moreover, it is a colourful appliance. Not all people in China have washing machines, though, and manual washing in washtubs is still very common.

In Taiwan many people use a washing machine today instead of washing by hand. However, most of the poor people still do the laundry by hand. Taiwanese women, very often the daughter-in-law, will use the time to do the laundry to communicate gossip or social information. The rich prefer to send the clothing to a laundry house.

### India

In India, as already pointed out in the introduction, the consumer needs vary dramatically compared to Europe. The variations also apply to other Southeast-Asian countries. As garments are very thin, long and colourful, washing by hand or even taking a shower with the clothes still on is very common in Southeast Asia. Honold (1999) reports that Indians wash almost once every day, and depending on whether they separate white and colours even twice. They do not collect soiled clothes for hygiene reasons. In general, Indians use four different methods of washing: manual washing, a washer, semiautomatic and automatic toploaders. In a washer, clothes are rotated in cold water, spinning around a vertical axis without a centrifuge function. Semiautomatic toploaders use two drums, a bigger one for washing, and a small one to centrifuge. After 5 to 15 min washing time, cloths have to be portioned into the small drum for centrifuging. The automatic machine combines washing and centrifuging, always around a vertical axis with cold water (Honold, 1999).

In cramped living conditions in the cities, washing machines are placed on the balcony, in the hallway or even in the bedroom. Honold reports about a marketing specialist who observed washing machines placed on mobile carts in Mumbai. They draw the conclusion that mobility must be important as place matters in crowded circumstances. But difficulties in cleaning are the main reason for this habit as the climate is hot and humid.

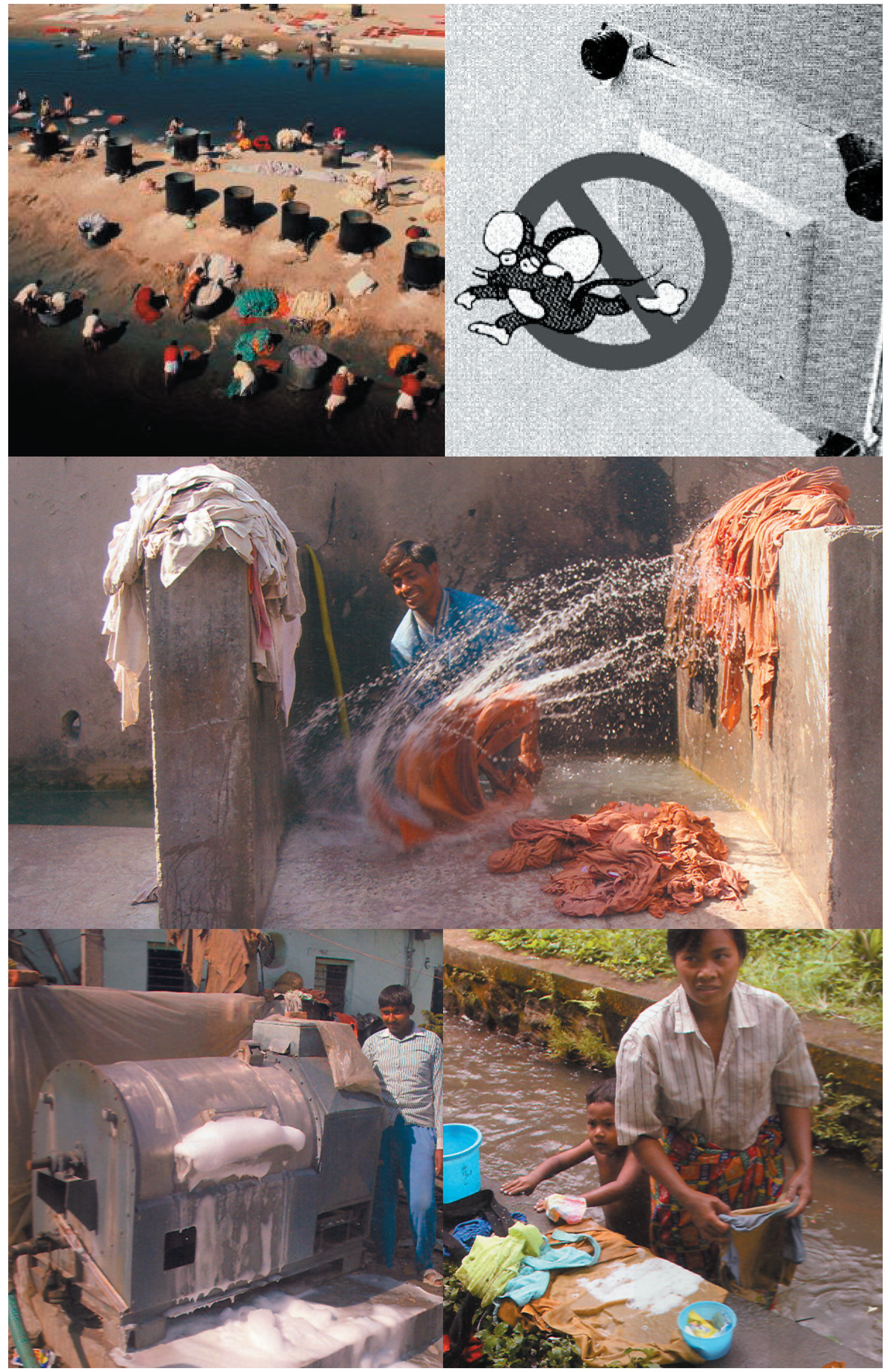


Fig. 8: Top left: laundry done by professional washers at the Yamuna River, India (photo-grapher: Paul Harris for Stone). Top right: Cover for rat protection from Indian advertising (image taken from Honhold, 1999). Middle: professional Indian washer. Bottom left: Indian pre-industrial washing machine on the street. Bottom right: Indonesian woman washing in a river in Bali (middle and bottom images taken from equally_different).

It is very dusty, which makes wiping the floor daily necessary, also underneath the machine. If it was not done daily, dirt would collect, mould and fungi would grow and vermin (e.g. rats) would nest. So it is not the mobility but the cleaning aspects that make the cart useful. (See also Honold, 1999 and Honold, 2000.)

### Korea and Japan

In Korea and Japan nearly every household has a washing machine. As America introduced their design of washing machines, most of the machines are toploaders with a vertical axis. Washing is mainly a female task in Japan and Korea. People in Japan wash depending on the family size between one and four times a week. They separate colours, whites and delicate fabrics (e.g. silk).

In very cramped cities like Tokyo, people have very small flats, so it is very common to have the washing machine on the balcony. Most balconies have taps installed for this case. The washing is hung on the balcony as well.
In suburban or rural Japan, people have a separate laundry and the washing hangs outside as well. Very hot summers, warm springs and autumns may be the reason that dryers are not that popular in Japan. A new washing machine with angled drum was just recently introduced into the market. The advertising campaign points out that the angle makes the washing machine more usable for the elderly, wheelchair users and even children (see fig. 9).

### 2.3.5 Australia

Van Santen reports that Australian machines are almost identical with American machines: huge toploaders spinning around a vertical axis. But people avoid hanging their laundry out for drying as the sun bleaches the pieces immediately. One report from Cottrell and Anderson-Berry (2002) talks about washing in difficult climate conditions during the wet season in Queensland, Northern Australia. Washing and drying the laundry in very wet conditions is described as extremely problematic. People run short of dry clothing and it is hard to get on top of washing everything to avoid mildew. Queenslander style homes are built on stilts to keep dry, but the laundry is done underneath the home. When flooding is announced, people have the particular need to raise the washing machine onto a higher level. A group of people helps raise the washing machines of elderly people who cannot manage on their own.

Fig. 9: Top: Australia: People normally avoid hanging the laundry out for drying as it bleaches immediately (photographer: Tobias Titz for fstop).
Japan: Middle left: advertising for new washing machine with angled drum. Middle right: Washing cabinet in Kyoto. Bottom left: drum spinning on a vertical axis. Bottom right: washing machine placed on the balcony (photographer of bottom images: Mina Oshima).

### 2.4 Discussion

Regarding the aim of this study to overview different needs and limitations when washing clothes and to show different strategies of washing in different cultures, the results of this paper are summarised as follows:

**Where** do people (**who**) wash (**how**) **what**? These attributes phrase the multiple dimensions of washing clothes. Below each attribute is explained:

- **Where** people wash is influenced by various factors. Different climates and environments need to be taken into account. Resources like water or energy are limiting factors. The climate heavily influences the process of washing, e.g. can clothes be collected, then washing happens once a week, but in adverse weather conditions they have to be washed every day. How often people have to wash also depends on how dirty, dusty, sweaty or mouldy clothes get because of their specific environment, not only on how soiled they become through the work people do. Furthermore, the climate dictates whether a washing machine has to be combined with a dryer or whether the laundry is allowed to dry outside.

- **What** people wear is also defined by their environment. They adapt their clothes to their climate and that defines what people have to wash. Depending on their culture people wash different fabrics with different densities, textures and sizes, like the great lengths of cloth for saris in India. The differences in colourfulness of clothes, how they are dyed and how careful they need to be washed are a result of the cultural background. These differences become very important when it comes to defining an interface or the duration of washing cycles.

- **Who** does the laundry is probably the one criterion that most cultures have in common. The laundry, especially at home, is mainly a female task. In some nations, where females do not work outside the house like Arabia or the Maldives, men can work as professional washers, too. In cities with a high percentage of singles or in countries with less gender differences like Northern Europe, men do wash as well. Stancel (2005) describes this phenomenon humorously by using the cleanliness index of men and women, "For women there are two states of cleanliness – clean and dirty. For men there are at least three states – clean, dirty and something in between." As washing has always been and in some parts of the world still is heavy work, women draw upon their family or other women of the community to help them.

- **How** do people do their washing? All washing methods from manual to automatic washing are used around the world. The automation of this task can be related to how much people can afford to spend for a washing machine and also to whether a machine makes sense, depending on the availability of water and electricity conditions. Still it is unclear why there are two main systems of washing machines on the market: washing machines spinning on a horizontal or on a vertical axis. It is proven that washing machines spinning on the vertical axis show poorer results, use more water and detergent and wear the fabrics faster than machines spinning on the horizontal axis (Stiftung Warentest, 1996). Maybe the main reason lies in the production costs, which are less for a vertical axis machine. This results in a lower consumer price, with more people being able to afford to buy such a machine. In the end, this machine reduces the labour of washing enormously compared to manual washing. To a great extent, the design of a washing machine depends on the choice of the axis. However, the design impression varies in different countries. Colour and finishes are adjusted to local taste or rituals. Depending on the markets interfaces are designed according to local conditions, e.g. certain symbols for regions with a high percentage of illiteracy. The available washing programs are based on local washing habits, e.g. short washing cycles with cold water for saris in India.

- Rompay et al. (2005) found that an adequate understanding of what objects express requires taking into account the role of ordinary experiences arising in recurring, everyday interactions between people and their environment.

- Leur et al. (2005) describe an emerging interest in the impact of cultural dimensions on the experience and interaction between people and products. If companies want to design and produce washing machines which will be used in different cultures and environments, they have to study the needs and requirements of their export market, especially when something is designed or produced for a totally different culture. People wash everywhere in this world, but as this paper shows, no global washing culture exist. Local needs vary, even for countries close to each other.

## 2.5 Conclusion

The new idea of the washing machine with optimal loading height and angle is applicable in every continent of the world (see table 3). The applicability varies as in some countries consumers have to change from the toploader system to a tilted drum and heightened washing machine. In the main parts of Africa the applicability is low, but in Asia and Europe there are large opportunities.

As consequence, this thesis will focus on European designed washing machines, for two reason: European washing machines are valued for the best washing results (see table 1) and for their sustainability with good durability and water, detergent and energy saving. Building on this a better ergonomic handling would even enhance this good image. The machine then has large opportunities to be sold in various parts of the world.

| | Applicability | Comments |
|---|---|---|
| North America | yes | adaptation could be difficult as toploaders are used |
| Latin America | partly | adaptation could be difficult as toploaders are used |
| Western Europe | yes | |
| Russia | partly | |
| Africa | no | |
| South-Africa | partly | |
| China | partly | limited space + colour and noise need attention |
| Taiwan | partly | |
| India | partly | different washing process |
| Japan/Korea | yes | limited space |
| Australia | partly | adaptation could be difficult as toploaders are used |

Tab. 3: Application possibilities of the washing machine in different parts of the world.

## References


Busch, N. et al., 2006, Comfort of washing machines when loading and unloading in a field study, (Paper submitted), Applied Ergonomics.

Busch, N., Vink, P., 2006, Comfort, body posture and speed in washing machine loading and unloading, (Paper submitted), Applied Ergonomics.

Christiaans, H., 2005, Cultural Differences, Presentation on internationalisation, TU Delft

Clark, J., taken from http://www.geocities.com/jonclark500/weblog/2004/08/happy-time-cleaning-time.html.

Cottrell, A. and Anderson-Berry, L., 2002, Women and the Wet season in Northern Australia, EMA Project 13/2002, Center for Disaster Studies, James Cook University, Emergency Management Australia, Commonwealth of Australia.

Cushman, W. and Rosenberg, D., 1991, Human Factors in Product Design, Elsevier Science Publishers, Amsterdam.

Dahl, S., 2004, An Overview of Intercultural Research, Middlesex University Business School, Middlesex.

Frisch, M., 2005, quote taken from http://de.wikiquote.org/wiki/Kultur.

Gestora, J., 2004, ed., Equally_Different - Everyday objects from around the world, FAD, Forum Barcelona 2004.

Grupe, G. et al., 2005, Anthropologie – Ein einführendes Lehrbuch, Springer Verlag, Berlin.

Hall, E., 1989, Beyond Culture, Anchor Books Editions, New York.

Hariandja, J. and Daams, B., 2005, Cultural Differences in Product Use and User Needs: Cross-cultural Usability Testing of a Food Processor in Indonesia and The Netherlands, IWIPS Conference 2005, Amsterdam.

Hoecklin, L., 1995, Managing Cultural Differences. Strategies for Competitive Advantage, EIU S, Financial Times Prent. Int, New York.

Hofstede, G., 1994, Culture and Organizations - Software of the mind, HarperCollins-Business, London.

Honhold, P., 1999, Interkulturelles Usability Engineering - Eine Untersuchung zu kulturellen Einflüssen auf die Gestaltung und Nutzung technischer Produkte, Inaugural-Dissertation, Regensburg.

Honhold, P., 2000, Culture and Context: An Empirical Study for the Development of a Framework for the Elicitation of Cultural Influence in Product Usage, Journal of Human-Computer Interaction, 12 (3&4), pp. 327-345.

IDEO, 2003, IDEO Method Cards: 51 Ways to Inspire Design, Palo Alto.
International Institute for Standardisation, 1994, International ISO DIS 9241-11, Draft, Ergonomic requirements for office work with visual display terminals (VDTs) - Guidance on Usability, International Organisation for Standardisation.
Kenntner, G., 1973, Biogeographica, Gebräuche und Leistungsfähigkeit des Menschen im Tragen von Lasten, Vol. 3, Dr. W. Junk Publishers, The Hague.
Kim, C., 2005, Exploring the influence of culture in consumer electronic products, Graduation research, Faculty of Industrial Design Engineering, Delft University of Technology, Delft.
Kroeber, A., Kluckhohn, C., 1952, Culture: A Critical Review of Concepts and Definitions, in: Adler, N., 1986, International Dimensions of organisational behaviour, PWS-Kent Publishing Company, Belmont.
Kumar, V., 2004, User Insights Tool - A Sharable Database for Global Research, IWips Conference.
Leonard, D., Rayport, J., 1997, Sparking Innovation Through Empathic Design, Harvard Business Review, Nov-Dec 1997, 102113.
Leur, K. de et al., 2005, Cross-Cultural Product Design: Understanding people from different cultural backgrounds, IWIPS Conference 2005, Amsterdam.
Lindstrom, M., 2006, It Simply Makes Sense! Summary of speeches from the 11th German Trend-day, 11. May, 2006, www.trendbuero.de
Ono, M., 2005, Design and culture: essentially interlinked, plural, variable, and beyond the predictable, (Paper submitted), Journal of Design Research, Delft University Press, Delft.
Rompay et al., 2005, The bodily basis of product experience, Design studies, No. 26(4), pp. 359-377
Russo, B., 2005, personal quote.
Rutter B., Donelson, T., 2000, Measuring the Impact of Cultural Variances on Product Design, Medical Device & Diagnostic Industry Magazine, October 2000.
Santen, L. van, 2005, personal quote.
Siemens, 2001, taken from: http://w4.siemens.de/FuI/en/archiv/zeitschrift/heft2_99/artikel02/.
Stancel, Roby, 2005, personal quote in the presentation of IDEO, Munich.
Stiftung Warentest, 1996, Testheft 3/96, Waschmaschinen, p. 25, Berlin.
Trompenaars, F., 1997, Riding the Waves of Culture, Nicolas Brealey Publishing, London.

# 3 Comfort, body posture and speed in washing machine loading and unloading

Paper conditionally accepted by Applied Ergonomics

**Authors: Nicole Busch[a], * and Peter Vink[a,b]**

[a] Delft University of Technology, Faculty Industrial Design Engineering, Landbergstraat 15, 2628 CE Delft, The Netherlands

[b] TNO Work and Employment, P.O. Box 718, 2130 AS Hoofddorp, The Netherlands

**Abstract**

In performing everyday tasks, comfort often comes into play. One of those daily tasks, washing, can be very hard work, especially for elderly people. Washing machines are often used as an example for everyday things people have problems with. Recommendations are given for elderly people, people with back pain and also service personal. This paper studies whether changes applied to the opening of the washing machine improve the comfort of end users and if so, what the best height and angle of the opening of a washing machine are.

54 subjects participated in loading and unloading a washing machine mock-up. Body posture, speed and comfort were recorded. The most comfortable body postures were observed with the middle of the opening at 105 cm and at 123 cm above the floor. The height for loading the washing machines was quickest between 69 and 105 cm with a tilted opening of the washing machine. Unloading was done fastest at the heights of 89 and 69 cm. The height subjects preferred was 105 cm with a tilted drum opening. The study shows that there is room for innovations in the design of washing machines to increase comfort for everybody and especially to improve the situation for elderly.

**Keywords:** Everyday product, user comfort, product design

### 3.1 Introduction

Worldwide people use approximately 500 million washing machines (Busch, 2006). Washing machines are often used as an example for everyday things people have problems with (Norman, 1988). Steve Jobs (2005) refers to it as well, "We spent some time in our family talking about what's the trade-off we want to make. [...] We'd get around to that old washer-dryer discussion. And the talk was about design." In the end, the family opted for European washing machines. This quote points out that the design of washing machines actually shows room for improvement. Remarkably though, there are only a very limited number of studies about innovations in doing the laundry (Philips, 2003; Whirlpool, 2004).

The desire for more comfort is important for everyone, especially for the elderly, who want to remain independent and look after themselves as long as possible. Household appliances should address these needs. One of the heavier household tasks is doing the laundry, even when using a washing machine. Freudenthal (1999) describes washing as problematic for senior citizens and the washing machine as being among the top ten of problematic everyday products for senior citizens at home.

Problems in doing the laundry are not only described for the elderly. There are many Internet sites warning back pain patients for laundry activities (North Eastern Rehabilitation Network, 2005, DIA, 2005 and HGTV, 2005) and giving suggestions for handling; e.g. the laundry task safety tips in the Safety Gram (2002): "When sorting the laundry limit the amount of laundry in a bag - they should never be more than two thirds full. Use carts or a sling. Carts should have a spring-loaded bottom to reduce bending. For unloading the washing machine use washing machines with a 'shaker' option that loosen the laundry after the spin cycle. If the washer or drier does not tip to empty, use a clothes rake instead of bending and stretching to remove laundry." These warnings indicate that doing the laundry is a heavy task for back pain patients. However, there is no clear evidence for these warnings in scientific literature.

Many articles can be found on the Internet (NIOSH, 1997; CCOHS, 1998) with recommendations for service personnel for whom washing is a heavy and demanding task.

Snook and Ciriello (1991) analysed the psychophysical aspects of manual handling tasks to determine the percentage of the industrial population that can be expected to perform a task "without strain or becoming tired, weakened, overheated or out of breath". According to the tables of Snook and Ciriello (1991), 90 % of females "in relatively good health" (who can manipulate significantly lower weights and forces than men) can lift 4 kg every 5 sec from shoulder height to reach height, or 5 kg every 5 sec from floor level to knuckle height. These data show that lifting 3 to a maximum of 7 kg of laundry in either one or two steps should not be a problem. Furthermore, the NIOSH-equation (Waters et al., 1993) supports the assumption that these weights are often acceptable. The Recommended Weight Limit (RWL) is exceeded only in the case of a person doing the laundry for a large family. However, the NIOSH equation does not take into account the arm forces needed and the position of the neck/shoulder as people have to look into the drum.

There are indications that for the 18-45 year old, washing is not a hazardous task regarding back loading. However, there are suggestions on the internet (see above) of possible risks for back patients, the elderly and service personnel, and improvements are welcome also for the healthy young population, perhaps not for preventing back problems but certainly for improving comfort. From these studies (NIOSH, 1993; Snook and Ciriello, 1991) it becomes clear that reaching distance, weight, height and frequency could be risk factors. The design of a washing machine could influence reaching distance and height in particular.
The question is whether improvements in height and angle of the opening of the washing machine will be noticed by the user and lead to better postures. The washing machines currently in use in Europe have openings at about 50 cm above the floor. The height of this opening has not been changed in years. If a different opening height leads to better postures or improved comfort during use, it may offer manufacturers a unique opportunity to better fulfil the needs of their customers, thereby increasing their market share.

Not only psychophysical improvements of tasks are important, but another aspect to take into account is that people also buy a product for the subjective experience (Norman, 2004) and for comfort. A lot has been said about these aspects in literature. Comfort is influenced by many factors in the environment. Christiansen (1997) describes comfort as the state of physical well-being which reflects a sensation. Richards (1980) underlines this and describes comfort as the state of a person, which involves a sense of subjective well-being in reaction to an environment or situation. Vink et al. (2005) add to this aspect that every individual has its own opinion of comfort. The conclusion is that comfort is a subjective phenomenon, which means that a product can never be comfortable in itself. The comfort a product offers can only be studied in the evaluation of the product by the user. In this study, Vink's (et al., 2005) definition is applied: "The convenience experienced by the end user during or just after working with the product."

There is some agreement in literature with respect to the construct of comfort (Looze et al., 2003):
- Comfort is a construct of a subjectively defined personal well-being
- Comfort is affected by various factors (ergonomical, physiological, psychological) and
- Comfort is a reaction and reflection of the environment.

Discomfort has received much more attention in literature (Looze et al., 2003; Marras, 2003). It is seen as a precursor of musculoskeletal problems and should be prevented for that reason, among others (Webster and Snook, 1994; Proper et al., 1999; Vink et al., 2004).
In this paper, factors related to comfort were studied during loading and unloading a washing machine at different heights. The aim is to find out the ideal opening height and angle of the drum.

In this study, two research questions are answered:
1. Do people experience differences in comfort if the opening height and angle of a washing machine are changed?
2. If so, which opening height is experienced as comfortable by individual ratings, results in postures that are biomechanically seen as favourable, and in the fastest operation time as two indicators of comfort?

### 3.2 Method

In this research, objective and subjective analysing methods (Christiansen, 1997) were combined to study comfort. Objective methods were used to analyse body postures during loading and unloading of a washing machine and the duration of these tasks at different heights. The individual feeling of comfort during the execution of these tasks was studied by using the subjective method of rating on a standardised scale.

### 3.2.1 Subjects

54 healthy subjects (34 female and 20 male) with experience in washing were asked to load and unload the washing machine. The subjects were workers, employees, professors and students recruited from the companies designafairs and Wildner AG in Southern Germany, and from the Faculty of Biology of the University Kiel in Northern Germany. The data of body height, upper body height, reaching distance and Body Mass Index (BMI) did not show significant differences when compared with extrapolated data from literature according to Flügel et al. (1989). Other characteristics of the subjects are shown in table 1. In terms of habituation to doing the laundry, the older men in this group had relatively less experience, as is the case in real life.

### 3.2.2 Task description

The subjects were asked to load and unload the washing machine as they thought it is best. They were only told to 'do the laundry' and did not receive any explanation of the body posture analysis, to avoid that the subjects become conscious about their body postures at different heights. The 3 kg of laundry consisted of 4 large bed and blanket cases, 2 pillow-cases and 6 smaller pieces like washcloths and towels.

The laundry was handed over to the subjects without using a washing basket, so that the positioning of the basket could not influence a body posture. The subjects were free to load the washing machine according to their individual preference, for example by using one hand to pile the laundry on and the other to take off the laundry and fill the washing machine piece by piece. Or they could use both hands and put the laundry into the machine in one go.

Unloading was done with 5 kg of wet laundry (3 kg laundry plus 2 kg water in the laundry). The wet laundry had to be placed (one subject just let it drop) into the basket, which was standing on the ground in front of the mock-up. The long side of the basket (width 55 x height 45 x depth 25 cm) was facing the subject. Still, the subjects were free to move the basket to their own preferred place.

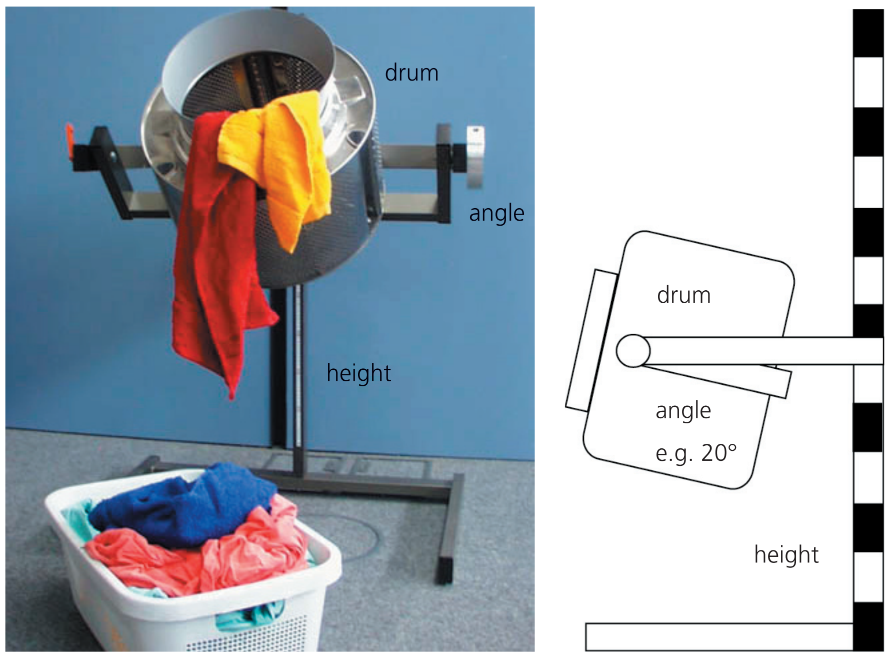



Fig. 1: Washing machine mock-up with adjustability of height and angle.

Tab. 1: Anthropometric data ± Standard Deviation of all 54 studied subjects clustered by age, generation and gender. Body height, upper body height, and reach distance measured according to Flügel et al., 1986, BMI measured according to Greil, 1998.

| Generation | N | Gender | Av. body height | Av. upper body height | Av. reach distance | Av. BMI |
|---|---|---|---|---|---|---|
| 18-29 years | 4 | Male | 180.3 ± 6.04 | 94.2 ± 1.67 | 86 ± 3.12 | 22.3 ± 0.08 |
| | 13 | Female | 166.9 ± 6.68 | 88.3 ± 3.29 | 80.6 ± 4.95 | 23.3 ± 0.33 |
| 30-39 | 6 | Male | 182.2 ± 7.24 | 93.9 ± 2.86 | 88.1 ± 2.22 | 23.9 ± 0.35 |
| | 11 | Female | 166.2 ± 6.89 | 87.8 ± 3.24 | 79.5 ± 5.12 | 22.3 ± 0.33 |
| 40-49 | 3 | Male | 178.2 ± 4.53 | 96.6 ± 4.10 | 89.6 ± 2.05 | 26.8 ± 0.09 |
| | 4 | Female | 169.4 ± 7.12 | 88.6 ± 4.58 | 82 ± 4.88 | 22.9 ± 0.20 |
| 50-62 | 7 | Male | 172.7 ± 5.56 | 88.5 ± 3.62 | 88.3 ± 4.21 | 27.1 ± 0.31 |
| | 6 | Female | 161.2 ± 4.24 | 86.2 ± 2.29 | 79.5 ± 3.21 | 23.9 ± 0.23 |



### 3.2.3 Mock-up description

Even though washing machine manufacturers did not research doing the laundry extensively yet, they are interested in whether aspects of use and comfort are not only technically feasible but also desirable. Especially the two parameters of ideal height and angle of the opening of the washing machine play an important role.

That is why a mock-up with a height-adjustable and tiltable frame was built for the simulations in this study. A washing machine drum was mounted in the height-adjustable frame (from 10 cm to 120 cm). The frame could also be tilted in 5° steps from 0° (horizontal) to 90° (vertical) (see figure 1).

In a pre-study to this research, 20 female subjects were asked to define angles to reduce the large number of possibilities of designing new heights in combination with angles. For the angle definition half of the subjects started at the height of 120 cm and went downwards. The other half started at 60 cm and went upwards. The subject had to rate the subjective comfort on the scale described in chapter 3.2.6. The rating was compared with the frequency of distribution of chosen angles. In the end, these 20 subjects clearly defined the angle based on five heights. For the opening height of 60 cm a bimodal distribution appeared without clear preference, and both angles were selected in this pre-study: a slightly tilted angle of 15° (almost that of a conventional washing machine) and a strongly tilted angle of 60°.

Based on this study, 6 different height-and-angle combinations were set up, see table 2. In the main study, half of the subjects started loading and unloading at the height of 120 cm and then worked their way downward. The other half started at 60 cm and went upwards. Each subject had to once load und unload for each drum height. Subjects did one operation, loading and unloading, per day to avoid tiredness or dependent results. Although all subjects did wash before, the sequence of heights was varied between the subjects to reduce the effect of learning.

### 3.2.4 Posture recording and classification

Video recordings were made of all subjects loading and unloading the washing machine. All 54 subjects were continuously observed and categorised by the researcher of this study. If there were two or three distinguishable postures, these were also used for OWAS categorisation. Afterwards, the full body posture was first classified from the video recording into 7 modified OWAS categories (Karhu et al., 1977), see figure 2.

| Height (in cm) | Angle (in °) | Middle of the opening height of the drum |
|---|---|---|
| 120 | 20 | 123 |
| 110 | 25 | 114 |
| 100 | 30 | 105 |
| 80 | 35 | 86 |
| 60 (a) | 60 | 69 |
| 60 (b) | 15 | 63 |

Tab. 2: Drum height with angles that were defined in a pre-study and used in this study

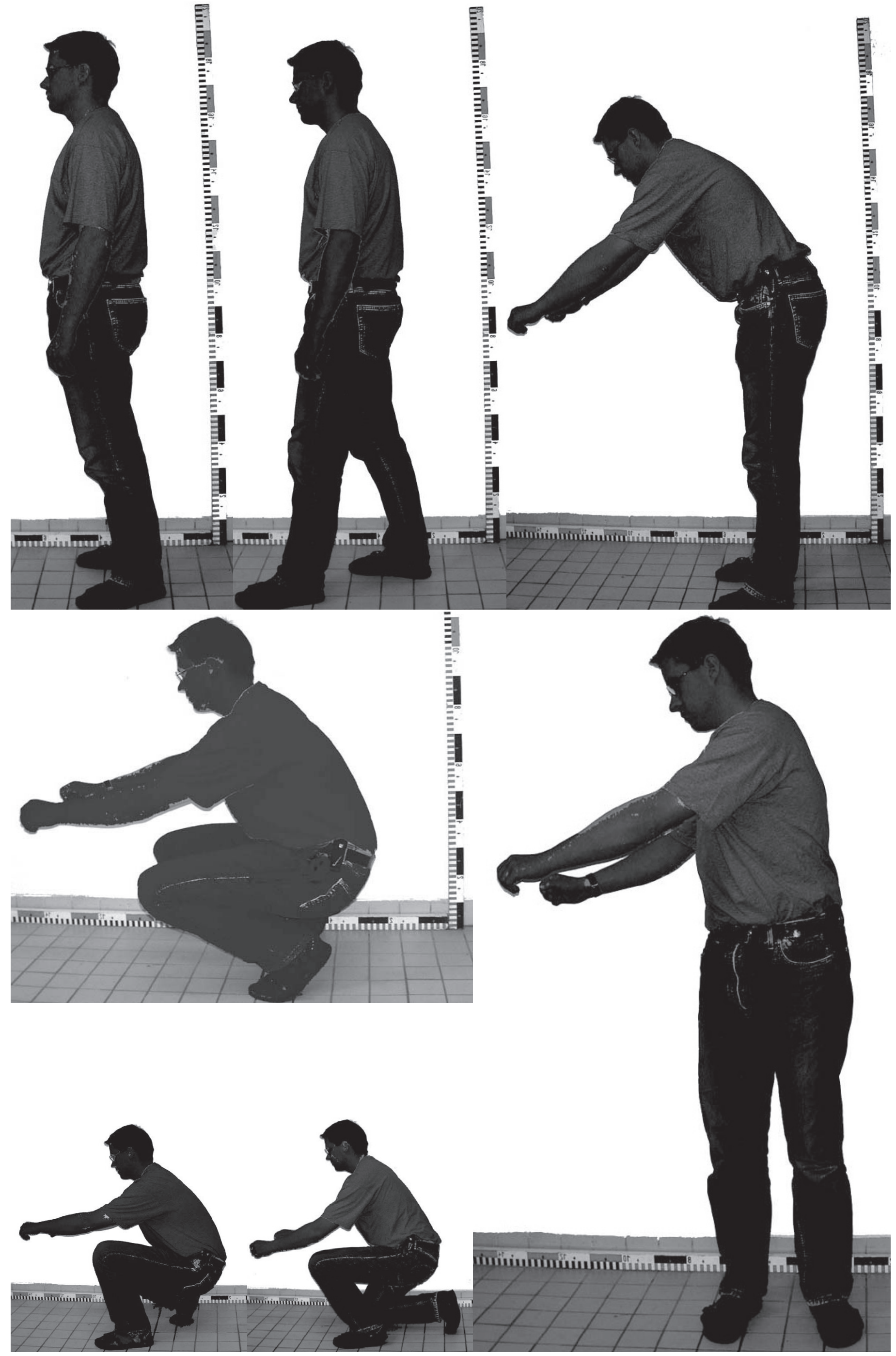


Fig. 2: OWAS positions according to Karhu et al. (1977): 1st position: standing upright (code 21); 2nd pos: upright with one foot forward (code 31); 3rd pos: flexed upper body (code x2), 4th pos: squatting (code 41), 5th pos: squatting with one foot forward (code 51), 6th pos: kneeling with one balancing and one loading leg (code 61), and 7th pos: twisted upper body (code x3). Posture 21 standing upright appeared at high loading heights; posture 32: upright with one foot forward and flexed upper body occurred with increased loading height; posture 42: squatting with flexed body at lowest heights.

Secondly, the way in which the subjects flexed their back was scored from the videos. In this research, subjects flex their upper body in a range of -20° to 110° (definition: 0° is standing upright, 90° is flexed forward with a horizontal trunk).

### 3.2.5 Speed recording

Speed was measured as an objective indicator. It was compared with the comfort rating of the various loading and unloading heights. The durations of the postures were measured with a stopwatch and the video timer. All durations of postures were recalculated at a later stage as a percentage of the total time observed. The total duration of the task was recorded from the video. Loading started the moment the subject received the laundry and ended when everything was in the drum. Unloading started when subjects started to take one piece out and ended when subjects checked the drum after the last piece was out. The differences in speed between loading and unloading were tested with the Wilcoxon Test to compare averages ($p<0.05$). The speed of each height for loading and unloading was tested with the Wilcoxon Test as well, to find differences for each height for loading and unloading. The Wilcoxon Test was used as it was expected that the tested data are not normal distributed. Knußmann assesses the test with almost the same test strength like the T-Test (1992).

### 3.2.6 Comfort recording

In chapter 1 the large variation of methods to measure comfort subjectively have been discussed. Based on these findings subjects had to rate the comfort of their body posture for loading and unloading the washing machine in this thesis. Based on the described variation of methods to measure comfort (chapter 1.5) it was decided to use a forced-choice 6-point scale (see figure 3) as subjects had to decide if they rate the task as comfortable or unpleasant and did not have the neutral undecided position (Christiansen, 1992; Trochim, 2005). Subjects were asked to rate their experience of comfort directly after loading and directly after unloading.

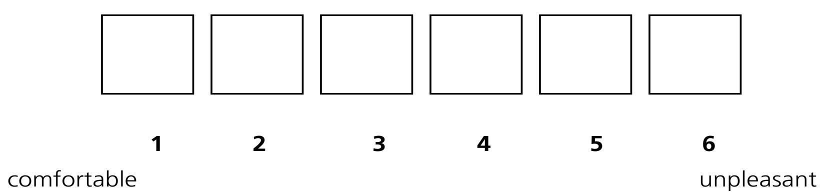



Fig. 3: 6-point scale for individual comfort rating.

This scale was preferred over a 7-point scale with more detailed description after a prestudy. It became apparent then that subjects did not take the time to read the description properly. Instead, they gave a score they were used to from school in Germany. To make this exercise easier for them, the scale was adjusted to the German school marking system (from 1 = very good/excellent to 6 = insufficient/unsatisfactory). The data were analysed with the Wilcoxon Test ($p<0.05$) to find out whether differences in rating comfort were significant for loading and unloading at different heights.

### 3.2.7 Additional information

During the experiment notes were taken on typical comments subjects made or on extreme postures that required special attention during the analysis of the video.

### 3.2.8 Interrelations

A correlation between age and height was tested, an interrelation between different drum heights and body postures was expected, as well as a relationship between age of subjects and different body postures. It was assumed that with increasing age, more unpleasant and avoiding body postures would occur. The body postures at all drum heights were analysed and described in percentage of appearance. Correlations between anthropometric data, age and subjective comfort rating were calculated by using the Spearman rank correlation coefficient. Correlations between body postures and anthropometric data were calculated by using the Chi-square Test ($p<0.05$).



## 3.3 Results

### 3.3.1 Do people experience differences?

Changes of only 10 cm in opening height sometimes showed significant differences in comfort experience (see table 8 and 9). This means that, although the body postures are not hazardous for the 18 to 45 years old and healthy population, the musculoskeletal loading of the subjects is high enough to experience differences.

### 3.3.2 Posture recording and classification

All 54 subjects were able to fulfil the task. One subject had to do the handling again, because the videotape had finished. All body postures, which are described in figure 2, could be measured in this study. Body postures were aligned with the comments made by the subjects. When body postures with a flexed upper body were recorded, their angle was estimated from the video for comparison with data about comfort angles from literature. This paper will focus on those body postures, which appeared most frequently at each height. The results are summarised in figure 2 and 6.

### 3.3.3 Body postures and loading or unloading height

Firstly, the body postures were analysed for each loading height (see table 3 and figure 4). When loading the drum at the heights of 120, 110 and 100 cm, the most frequent position was the comfortable position no. 21, standing upright with feet next to each other. This was followed by the position no. 31, standing upright with one foot forward (for body postures, see figure 2). Both body postures were observed 83 % of the time at a drum height of 120 cm. At 110 cm, this was 83.8 %, and at 100 cm, they take up even 91.5 % of all body postures. The lower the drum heights, the lower the percentages of these two body postures: at 80 cm 34.3 %, at 60 cm with strongly tilted opening (a) 15.7 %, and at 60 cm with slightly tilted opening (b) only 3.4 % (for relative frequency see table 3 and figure 4). Other, more uncomfortable body postures increased. At the loading height of 80 cm, the forward flexed body postures nos. 22 and 32 amount to 47.8 % of the observations, at 60 cm (a) 68.7 %, and at 60 cm (b) 31.7 %. At the loading height of 60 cm (b), the squatting and kneeling body postures were found 63.4 % of the time, at 60 cm (a) 12.9 %, and at 80 cm 13.5 %. Overall, only a low percentage of body postures with twisted upper body occurred when loading: at the height of 120 cm 5.6 %, at 110 cm 4.3 %, and at 100 cm 1.5 %. At the lower heights of 80 cm, 60 cm (a) und 60 cm (b), twisted body postures were observed 4.5 %, 1.6 % and 1.7 % of the time, respectively.

Secondly, the body postures were analysed for each unloading height (see table 4 and figure 5).

When unloading the drum at the heights of 120, 110 and 100 cm, the comfortable position no. 21, standing upright with feet next to each other, and the position no. 31, standing upright with one foot forward, were often seen (see table 4 and figure 5, for

| OWAS Position | Loading height 120 cm | Loading height 110 cm | Loading height 100 cm | Loading height 80 cm | Loading height 60 cm (a) | Loading height 60 cm (b) |
|---|---|---|---|---|---|---|
| 21xx | 57.7 | 57.8 | 49.2 | 20.9 | 9.4 | |
| 22xx | | 4.3 | 1.5 | 19.4 | 23.4 | 11.7 |
| 23xx | 1.4 | | | 1.5 | 1.6 | |
| 24xx | | | 1.5 | | 1.6 | 1.7 |
| 31xx | 25.3 | 26.0 | 32.3 | 13.4 | 6.3 | 3.4 |
| 32xx | 1.4 | | 7.7 | 28.4 | 45.3 | 20.0 |
| 33xx | 2.8 | 4.3 | 1.5 | 3.0 | | |
| 34xx | | | 1.5 | | | |
| 41xx | 1.4 | | 1.5 | 3.0 | 4.7 | 5.0 |
| 42xx | 4.2 | 1.4 | 1.5 | 6.0 | 3.1 | 21.7 |
| 43xx | | | | | | |
| 44xx | 4.2 | 4.3 | | | | 1.7 |
| 51xx | | | | 1.5 | 1.6 | 10.0 |
| 52xx | | | | 3.0 | 3.1 | 10.0 |
| 53xx | 1.4 | | | | | |
| 54xx | | 1.4 | 1.5 | | | 1.7 |
| 61xx | | | | | | 10.0 |
| 62xx | | | | | | 3.3 |

Tab. 3: Descriptive statistic: Relative frequency (in %) of the analysed body postures depending on the loading height.
The most frequent body posture is marked in grey.
a = machine with strongly tilted and b = slightly tilted angle.

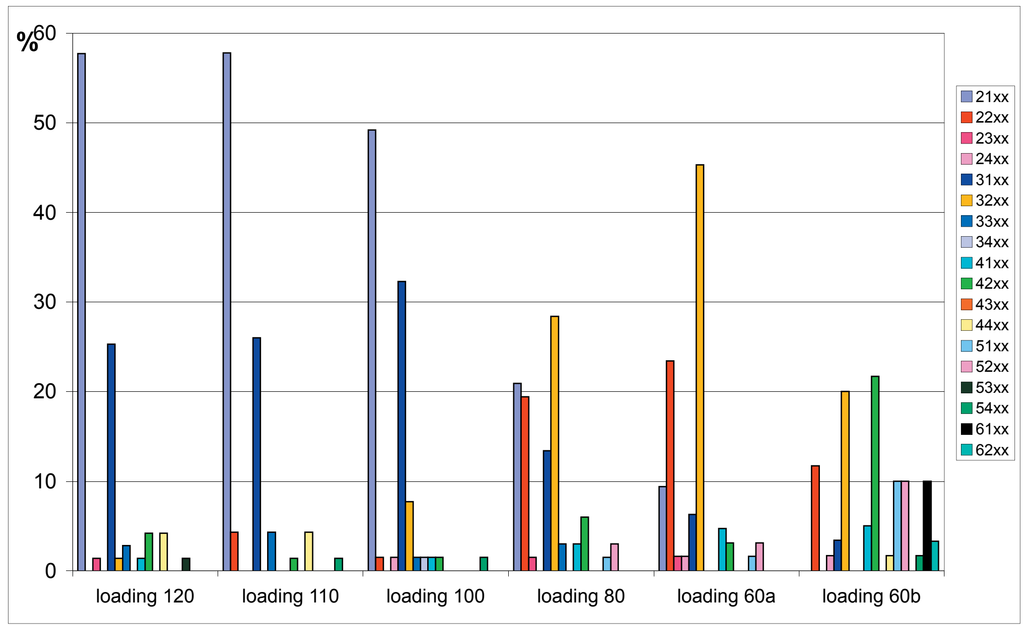



Fig. 4: Descriptive statistic: Relative frequency (in %) of the analysed body postures depending on the loading height. Overview about the changes of frequency for each body posture.

body postures, see figure 2). Both body postures accounted for 53.4 % of all body postures at a drum height of 120 cm, and for 65.5 % at the height of 110 cm. By contrast, they amounted to only 38.2 % of all body postures at the height of 100 cm.
The lower the drum, the more the percentages of these body postures decreased: at 80 cm to 17.6 %, at 60 cm (a) to 9.9 %, and at 60 cm (b) to 4.5 % (for relative frequency, see table 4 and figure 5). The forward flexed body postures increased with lower drum heights. At the unloading heights of 120, 110 and 100 cm, the flexed body postures nos. 22 and 32 occur in the following relative frequency: 18.9 %, 27.5 %, 36.5 %. At the unloading height of 80 cm, these postures amounted to 65.8 %, at 60 cm (a) 75 % and at 60 cm (b) 39.3 %. The opening height of 60 cm (b) demonstrated clearly that low heights force people into strange, seldom used body postures: squatting with and without one foot forward or kneeling. At this height of 60 cm (b), the squatting and kneeling postures amounted to a high percentage of 53.1 %. The other opening heights in the lower range showed lower percentages: at 60 cm (a) 12 %, and at 80 cm 7.2 %.
The same was observed during unloading, where only a low percentage of body postures with twisted upper body occurred: at the height of 120 cm 2.8 %, at 110 cm 5.6 % and at 100 cm 7.4 %. At the lower heights of 80 cm, 60 cm (a) und 60 cm (b) twisted body postures reached 6.2 %, 1.1 % and 3 %, respectively. It is interesting that most of the twisted body postures occurred at the middle heights of 110 cm, 100 cm and 80 cm.

It is noticeable that the percentage of upright postures (no. 21) is higher when the loading height of the washing machine increases. The percentage of flexed postures with one foot forward (no. 32) is highest at a conventional washing machine height with an angle of 60° (type 60 cm (a)). The percentage of squatting postures (no. 42) was highest for the conventional washing machine height with a slightly tilted opening (type 60 cm (b)).

Figure 6 shows that the percentage of upright postures (no. 21) reduces when the loading height of the washing machine decreases. The occurrence of a flexed upper body combined with one foot forward increases steadily, the lower the loading height becomes. Only in the case of the conventional washing machine height with a slightly tilted opening, subjects used the squatting position more than any other body posture.

| OWAS Position | Unloading height 120 cm | Unloading height 110 cm | Unloading height 100 cm | Unloading height 80 cm | Unloading height 60 cm (a) | Unloading height 60 cm (b) |
|---|---|---|---|---|---|---|
| **21xx** | 42.3 | 50.8 | 28.9 | 12.4 | 5.5 | 1.5 |
| **22xx** | 13.2 | 20.2 | 26.2 | 38.0 | 33.7 | 25.7 |
| **23xx** | 1.9 | 2.8 | 3.7 | 2.1 | | |
| **24xx** | 7.5 | 2.8 | 1.9 | | 1.1 | 1.5 |
| **31xx** | 13.1 | 14.7 | 9.3 | 5.2 | 4.4 | 3.0 |
| **32xx** | 5.7 | 7.3 | 10.3 | 27.8 | 41.3 | 13.6 |
| **33xx** | 0.9 | 2.8 | 2.8 | 4.1 | 1.1 | 1.5 |
| **34xx** | | | 0.9 | 3.1 | 1.1 | |
| **41xx** | 0.9 | | 1.9 | 1.0 | | 6.1 |
| **42xx** | 8.5 | 6.4 | 9.3 | 5.2 | 5.4 | 16.7 |
| **43xx** | | | 0.9 | | 1.1 | |
| **44xx** | 0.9 | 0.9 | | | | 1.5 |
| **51xx** | | | | | 2.2 | 6.1 |
| **52xx** | 2.8 | 2.8 | 1.9 | 1.0 | 2.2 | 10.6 |
| **53xx** | | | | | | |
| **54xx** | 0.9 | 1.8 | 1.9 | | | 1.5 |
| **61xx** | | | | | 1.1 | 7.6 |
| **62xx** | | | | | | 3.0 |

Tab. 4: Descriptive statistic: Relative frequency (in %) of the analysed body postures depending on the unloading height. The most frequent body posture is marked in grey.
a = machine with strongly tilted and b = slightly tilted angle.

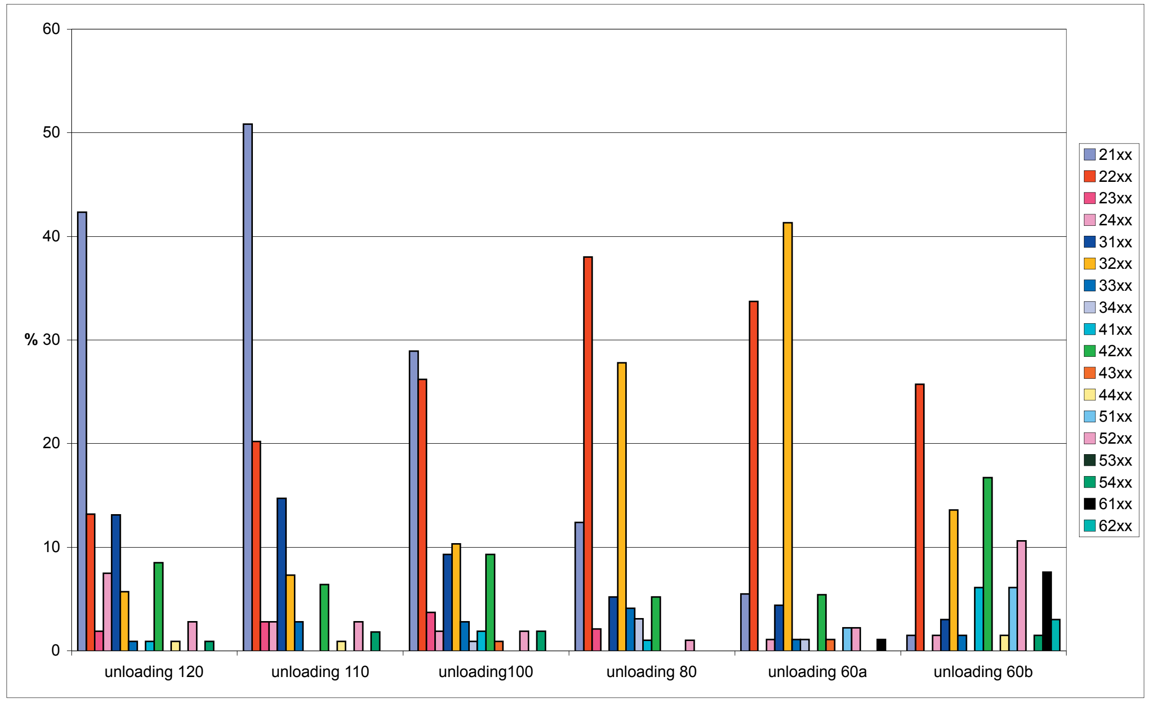



Fig. 5: Descriptive statistic: Relative frequency (in %) of the analysed body postures depending on the unloading height. Overview of the changes of frequency of each body posture.

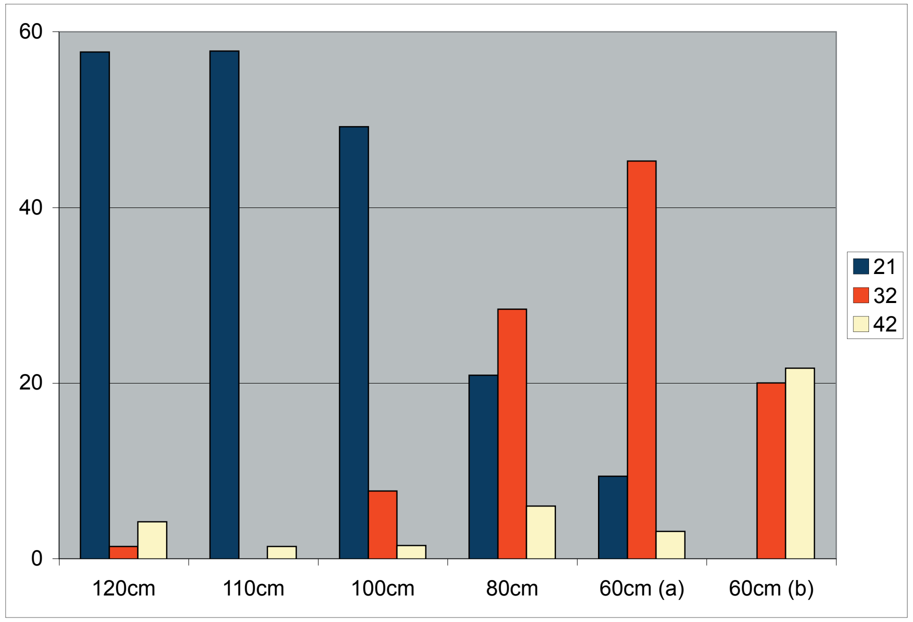



Fig. 6: The percentage of relative frequency postures was scored by observing 54 subjects loading a washing machine. Posture 21 was scored most frequently loading at 100, 110 and 120 cm. Posture 32 was scored most frequently at 60 (a) and 80 cm, and posture 42 at 60 cm (b).

### 3.3.4 Speed recording

In table 5, the average, minimum and maximum speed of all subjects for the 5 heights are summarised.

The Wilcoxon Test shows that the averages of the loading and unloading times for each height are highly significantly different (Z = -3.17; P = 0.002). The subjects loaded the washing machine significantly faster than they unloaded it. The differences in the heights had a special effect on the unloading time. Unloading was fastest at lower heights. As shown in table 6 and 7, significant differences of speed for loading and unloading between the different heights were analysed with the Wilcoxon Test.

| Heights in cm | Minimum t in sec | Maximum t in sec | Average t in sec | Standard deviation |
|---|---|---|---|---|
| **L 123** | 2.59 | 25.60 | 7.15 | 4.95 |
| **L 114** | 2.82 | 21.47 | 6.04 | 3.69 |
| **L 105** | 1.94 | 18.62 | 5.42 | 3.46 |
| **L 86** | 2.04 | 16.18 | 5.11 | 2.83 |
| **L 69** | 1.49 | 19.90 | 5.01 | 3.59 |
| **L 63** | 1.67 | 21.54 | 6.74 | 4.82 |
| **U 123** | 4.04 | 42.78 | 9.48 | 5.70 |
| **U 114** | 3.68 | 37.58 | 8.48 | 5.09 |
| **U 105** | 2.77 | 35.19 | 9.21 | 5.87 |
| **U 86** | 2.62 | 30.15 | 7.96 | 4.62 |
| **U 69** | 3.09 | 36.12 | 7.82 | 5.40 |
| **U 63** | 3.06 | 40.75 | 7.41 | 6.24 |

Tab. 5: Analysed minimum, maximum, and average speed and standard deviation separated for loading (L) and unloading (U) at different heights.

Tab. 6: Loading: Significances between speeds at different heights (Wilcoxon Test for comparing averages; *p<0.05, **p<0.01).

| **Loading** | **123** | **114** | **105** | **86** | **69** | **63** |
|---|---|---|---|---|---|---|
| 123 | | | | | | |
| 114 | - | | | | | |
| 105 | - | * | | | | |
| 86 | * | - | - | | | |
| 69 | ** | ** | - | - | | |
| 63 | - | - | ** | ** | ** | |

Tab. 7: Unloading: Significances between speeds at different heights (Wilcoxon Test for comparing averages; *p<0.05, **p<0.01).

| **Unloading** | **123** | **114** | **105** | **86** | **69** | **63** |
|---|---|---|---|---|---|---|
| 123 | | | | | | |
| 114 | ** | | | | | |
| 105 | - | - | | | | |
| 86 | ** | - | * | | | |
| 69 | ** | ** | ** | - | | |
| 63 | ** | ** | ** | ** | * | |

### 3.3.5 Comfort experience and loading height

Figure 7 shows that subjects rated comfort as highest both for loading and unloading at the 100 cm position. The lowest comfort rating was for the conventional washing machine height with the slightly tilted opening.

As shown in table 8 and 9, significant differences were found for the different heights.


Fig. 7: Subjective experienced comfort for different heights of the opening averaged over 54 subjects rated on a scale from 1 to 6; 1= comfortable, 6=unpleasant.

| Loading | 123 | 114 | 105 | 86 | 69 | 63 |
|---|---|---|---|---|---|---|
| 123 | | | | | | |
| 114 | ** | | | | | |
| 105 | ** | - | | | | |
| 86 | - | - | ** | | | |
| 69 | - | ** | ** | - | | |
| 63 | ** | ** | ** | ** | ** | |

Tab. 8: Loading: Significances between rating of comfort at different heights (Wilcoxon Test for comparing averages; *p<0.05, **p<0.01).

| Unloading | 123 | 114 | 105 | 86 | 69 | 63 |
|---|---|---|---|---|---|---|
| 123 | | | | | | |
| 114 | * | | | | | |
| 105 | ** | - | | | | |
| 86 | - | * | ** | | | |
| 69 | ** | ** | ** | ** | | |
| 63 | ** | ** | ** | ** | * | |

Tab. 9: Unloading: Significances between rating of comfort at different heights (Wilcoxon Test for comparing averages; *p<0.05, **p<0.01).

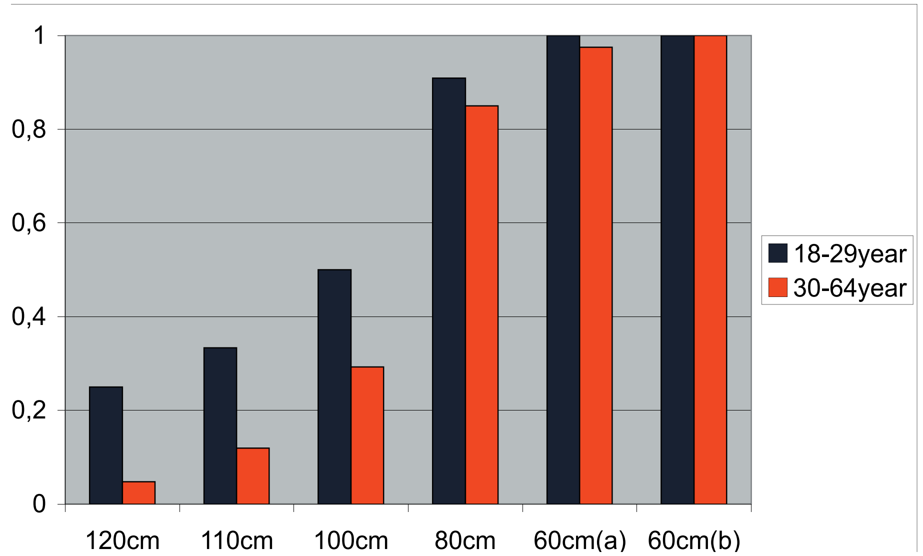
### 3.3.6 Correlations

Correlations were calculated to answer the research question if anthropometrics, gender or age influence the subjective comfort rating. For unloading the drum, significant positive correlations were found for subjective comfort rating and body height (2-sided; rho = 0.349; P=0.023*) and upper body height (2-sided; rho = 0.377; P=0.014*) at a height of 100 cm. That means that the smaller the body and upper body height, the higher the comfort levels. A significant negative correlation was found for subjective comfort rating and age (2-sided; rho = -0.348; P=0.024*). That means that the older the subjects, the higher the comfort level.

For unloading the washing machine, significant negative correlations were found for subjective comfort rating and age (2-sided;
rho = -0.436; P=0.004**) at a height of 100 cm. No further significant correlations were found.

With regard to possible correlations between loading and anthropo-metry, no significant values were found. Moreover, no correlation could be calculated between anthropometric data and body postures.

Fig. 8: Number of observed postures that are qualified (postures 32 and 42) as more hazardous for older and younger subjects.




### 3.3.7 Body postures and age

As shown in figure 8, the more hazardous body postures occurred less often at the 3 higher loading levels than at the 3 lower loading levels. It was noticeable that younger subjects used these postures more frequently than older subjects at the 3 higher loading levels. By contrast, older subjects were able to use the comfortable body posture (no. 21) at the 3 higher drum levels more often. In the lower range of loading heights, though, the older and younger subjects used very much the same body postures.

## 3.4 Discussion

With respect to the research question whether changes in opening height are experienced by end users, the answer should be yes. Concerning the second question, which opening height of the washing machine is experienced as comfortable, it turns out to be 100 cm, having the middle of the opening height at 105 cm above the floor.

### 3.4.1 Ideal opening height

The most comfortable opening height does not correspond directly to the best postures. The less hazardous postures are found at 110 and 120 cm. It also does not correspond to the fastest height, which is 60 cm (a) with a strongly tilted opening for loading and 60 cm (b) with a slightly tilted opening for unloading. Probably the users look for an optimum between fast work and less hazardous postures. Based on Snook and Ciriello (1991) and NIOSH (1981), these postures may not be not hazardous at all for such a short time. On the other hand, though, Snook and Ciriello (1991) also expect the performance of the task to be “without strain or becoming tired, weakened, overheated or out of breath". For the elderly, for persons who do the laundry for large families, or for those working in the service industry and persons with back pain, these postures could be hazardous and their avoidance is not only a matter of comfort.

The results of this paper are summarised as follows:

- Less hazardous body postures appeared at the heights between 100 and 120 cm (which is the middle of the opening (MO) situated at 105-123 cm from the floor). From 80 to 60 cm, people use avoidance postures (MO at 86 to 63 cm).
- Loading the washing machine was fastest at the heights between 100 cm (MO at 105cm) and 60 cm with a strongly tilted opening (MO at 69 cm). By contrast, the fastest unloading happened at 80 cm and 60 cm with the strongly and the slightly tilted opening (MO at 86, 69 and 63 cm).
- Subjects rated their favourite height as 100 cm, followed by 110 cm and 80 cm (MO at 105, 114 and 86 cm).

It was surprising to see that all subjects with different anthropometrics rated the same height of 100 cm as comfortable - even the male subject of the 90th percentile and the female subject of the 10th percentile. This seems to support the conclusion that a height-adjustable washing machine is not needed here, even though many other studies on ergonomics promote height adjustability (Pekkarinen and Anttonen, 1988).

### 3.4.2 Reflection on the results

This study is a correlative study and interprets the results. It refers to the used sample and is not representative for the total population.
It can be argued that a drawback of this study is that all heights are new. Perhaps the 60 cm (b) with the 15° angle comes closest to the traditional washing machine and therefore results in the fastest loading and unloading times. Habituation could play a role here, however, even the inexperienced male preferred the 100 cm.

Another disadvantage is that the heights are not studied in a continuum. The optimum height could be somewhere else between 95 and 110 cm above the floor. The question is whether differences in these small ranges can be experienced in real life.

Normally workspaces are analysed in terms of comfort or discomfort - most of the time because they can either cause health problems (Kuorinka et al., 1987) or even injuries (Hettinger, 1991). An example is working on a heavy earth moving machine like an excavator where new improvements lead to less vibrations and more seating comfort, and therefore result in less economically relevant damage (Vormer, 2004). But comfort is also critical in making a product more desirable, e.g. improved comfort in a car or airplane seat. For a washing machine, both types of comfort are relevant. Washing is an everyday task for many, sometimes two machine loads a day. Washing is a demanding task for the elderly (Freundenthal, 1999). A pre-study showed that washing is not seen as comfortable by many people.
The analysis of body postures as comfortable body postures was done using a combination of Kuorinka's OWAS methods and video to analyse hazardous angles in the distribution of the movements over the joints. Not all problems in body postures could be covered using OWAS, e.g. how people bend their upper body and how people squat is not recorded. A comparison of analysed angles between body parts with findings in literature is difficult, as most of the data on comfort angles is only on sitting postures, mainly from car and furniture manufacturers. The data analysis relied on one paper only which deals with standing positions (Barbirat et al., 1998). More research is necessary for all other body postures except sitting.

Speed measurement was done on the subjects' natural use of movement. They were not asked to load or unload as quickly as possible. The higher the drum height, the more time-consuming it became if subjects lost some pieces during loading or unloading. Instead of keeping the laundry in their hand, people use a basket. For heights between 80 and 120 cm, a support for the basket makes sense and would speed up the process of loading and unloading. It was not expected that people rated the new heights as more comfortable than the lower heights as people can get used to circumstances, as they do in various areas of life.



A disadvantage of this study is the laboratory setting. In this setting, there were no restrictions caused by the surrounding of the mock-up. In this study the washing basket was not relevant for loading, because the aim was to measure the ideal body posture. In real life people use a basket for loading which is generally placed on the floor. The distance between picking up the laundry (the lifting load) out of the basket and the drum height could make a difference, as shown in various experiments (Waters et al., 1981, Snook and Ciriello, 1991, Mital, 1993). The influence of various basket heights were taken into account in the follow-up real life study described by Busch et al. (2006).

In real life, the space around washing machines is limited. Often the machine is positioned next to a door opening or a dryer, or there are construction restrictions like a small space in front of the washing machine. The lab setting was without any restrictions of this kind. In fact, studying a real life setting at home was considered as a post-study to prove the laboratory results.

### 3.5 Conclusion

This study shows that designers, ergonomists and engineers should reconsider and innovate the construction of a washing machine. As the mock-up simulation demonstrated, the best height for the opening of the door of a washing machine is 105 cm (the middle of the door above the floor) with an angle of 30°. A renewed design is necessary as today's conventional 60 cm machines cause restrictions in comfort and result in hazardous postures for the elderly. Innovation is necessary because this new machine may not fit under a normal height counter top. Lower heights are faster to load and to unload according to this study, which means that innovators should also look for possibilities to speed up the process. A possible solution is elevating the basket.

### Acknowledgements

The authors would like to thank two anonymous reviewers for their helpful suggestions on an earlier version of the manuscript. We would like to thank Siemens Household Appliances who partially funded this research. We extend our thanks to designafairs GmbH (formerly Siemens Design & Messe GmbH), the Wildner AG, the Christian-Albrechts University of Kiel for supporting the laboratory tests and Julia Körner for her help with the speed recording. Finally, we gratefully acknowledge the support and discussions with Gitta Rüscher in the process of analysing the data of this study.

### References

Babirat, D., Küchmeister, G., Nagel, K., 1998. Körpermaße des Menschen - Komfortbereich der Gelenkwinkel der Körpergelenke, in: Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (ed.), Schriftenreihe -Forschung- Fb 818, Wirtschaftsverlag NW, Dortmund/Berlin.

Busch, N. 2006, Prologue in Fit for Washing - Human factors and ergonomic evaluation of washing machines, Doctoral Thesis, Technical University, Delft

CCOHS, 1998, Canadian Centre for Occupational Health & Safety, OHS Answers - Occupations & Workplaces - Hotel Laundry in: http://www.ccohs.ca/oshanswers/occup_workplace/laundry.html

Christiansen, K., 1992, Psychologische Tests und Explorationsmethoden, in: R. Knußmann (ed.), Anthropologie, Handbuch der vergleichenden Biologie des Menschen, vol. I/2, Fischer Verlag, Stuttgart, pp. 205-278.

Christiansen, K., 1997, Subjective Assessment of Sitting Comfort, Coll. Anthropol. 21, pp. 387-395.

Deaconess Healthcare, December 2005 taken from http://www.deaconess-healthcare.com/btb.html

Freudenthal, A., 1999, The design of home appliances for young and old consumers, Series ageing and ergonomics 2, Delft University Press.

Flügel, B., Greil, H., Sommer, K., 1986, Anthropologischer Atlas, Verlag Tribüne, Berlin.

Greil, H., 1998, Normal weight and optimal weight – description and evaluation of body mass, Anthropol. Anz., Dec. 56 (4), pp. 313-34

Hettinger, T., 1991, Occupational hazards associated with diseases of the skeletal system, Ergonomics 28/1, pp. 69-75.

HGTV, 2005 in: http://www.hgtv.com/hgtv/ah_personal_care_other/article/0,1801,HGTV_3148_1391008,00.html

Jobs, S., 2005, quoted in Young, J. and Simon, W., Icon Steve Jobs: The Greatest Second Act in the History of Business, John Wiley & Sons, Indianapolis

Karhu, O. et al., 1977, Correcting working postures in industry, A practical method for analysis, Applied Ergonomics 8,4, pp. 199-201.

Knußmann, R., (ed.) Anthropologie, Band I: Wesen und Methoden der Anthropologie, Teil 2: Physiologische, psychologische, genetische und mathematische Methoden, Gustav Fischer Verlag, Stuttgart, p. 673, 1992

Kuorinka, I. et al., 1987, Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms, Applied Ergonomics 18.3, pp. 233-237.

Looze, M.P. de, Kuijt-Evers, L.F.M. and Dieën, J.H. van, 2003, Sitting comfort and discomfort and the relationships with objective measures, Ergonomics 46, pp. 985-997.

Marras, W.S., 2003, The future of research in understanding and controlling work-related low back disorders, on Ergonomics in the Digital Age, IEA CD-rom, Proceedings of the XVth Triennial Congress of the International Ergonomics Association, Seoul.

Mital, A. et al., 1993, A Guide to Manual Materials Handling, London, Taylor & Francis

National Institute for Occupational Safety and Health (NIOSH), 1981, Work practices guide for manual lifting, Dept. Health and Human Services, Publ. No. 81-122, Cincinnati.

National Institute for Occupational Safety and Health (NIOSH), 1997, Control of Health and Safety Hazards in Commercial Drycleaners - Chemical Exposures, Fire Hazards, and Ergonomic Risk Factors, U.S. Department of Health and Human Services, Public Health Service Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, December 1997, DHHS (NIOSH) Publication No. 97-150 in: http://www.cdc.gov/niosh/97-150.html#ergo

Norman, D., 1988, The Psychology of Everyday Things, Basic Books, New York.

Norman, D., 2004, Emotional Design – Why we love (or hate) everyday things, Basic Books, New York

North Eastern Rehabilitation Network, 2005, in: http://www.northeastrehab.com/Guides/goodtoback.htm

Pekkarinen, A., Anttonen, H., 1988, The effect of working height on the loading of the muscular and skeletal systems in the kitchens of workplace canteens, Applied Ergonomics 19, pp. 306-308.

Philips Design, 2003, newvaluenews, number eighteen, October.

Procter & Gamble, 2005, in: http://www.scienceinthebox.com/en_UK/research/washabits_en.html

Proper, K.I., Bongers, P.M. and Grinten, M.P. van der, 1999, Longitudinaal onderzoek naar rug-, nek- en schouderklachten, Deelrapport 5: Lokaal ervaren ongemak. De relatie met en de voorspelling van klachten aan het bewegingsapparaat, Hoofddorp: TNO Arbeid.

Richards, L., 1980, On the psychology of passenger comfort, in: Oborne and Levis (eds.), Human Factors in Transport Research, vol. 2, pp. 15-23, Academic Press, London

Safety Gram for Laundry & Housekeeping Staff, 2002, Volume 1, No. 1, January

Slater, K., 1985, Human comfort, Charles C. Thomas, Springfield, IL.

Snook, S.H., Ciriello, V.M., 1991, The design of manual handling tasks: revised tables of maximum acceptable weights and forces, Ergonomics, Vol. 34, No. 9, pp. 1197-1213.

Statistisches Bundesamt Deutschland (eds.), 2001, Statistisches Jahrbuch für die Bundesrepublik Deutschland und für das Ausland, Ausstattung privater Haushalte mit elektrischen Haushaltsgeräten, Metzler-Poeschel Verlag.

Trochim, W., 2005, http://www.socialresearchmethods.net, 2005

Vink, P., 2005, Comfort and design: principles and good practices, CRC Press, Boca Raton.

Vink, P., Overbeeke, C., Desmet P., 2005, Comfort Experience, Vink, P. (ed.), Comfort and design: principles and good practices, CRC Press, Boca Raton.

Vormer et al., 2005, Comfortable view in an earth moving machine of 2015, Vink, P. (ed.), Comfort and design: principles and good practices, CRC Press, Boca Raton.

Waters, T. et al., 1993, Revised NIOSH equation for the design and evaluation of manual lifting tasks, Ergonomics, nr. 36, pp. 749-776.

Webster, B., Snook, S., 1994, The Cost of 1989 Workers' Compensation Low Back Pain Claims, Spine 19 (10), pp. 1111-1116.

Whirlpool, 2004, project f – fabric care of the future, Richard Eisermann (ed.).

# 4 Comfort of washing

## when loading and unloading machines in a field study

Paper submitted to Applied Ergonomics

**Authors: Nicole Busch[a], Peter Vink[a,b] and Johan Molenbroek[a]**

[a] Delft University of Technology, Faculty Industrial Design Engineering, Landbergstraat 15, 2628 CE Delft, The Netherlands

[b] TNO Work and Employment, P.O. Box 718, 2130 AS Hoofddorp, The Netherlands

**Abstract**

Washing is a daily task that could give inconvenience, especially for elderly people and people with back pain. An earlier laboratory study showed that optimising the opening height improved both the posture during loading and unloading and the subjectively experienced comfort. The aim of this study is to find out if the favourite laboratory height is also favoured at home.

In this study, 24 subjects participated in loading and unloading a real washing machine on an elevated platform in their home setting and compared this to the usage of their own washing machine. The comfort experience was recorded on a 7-point scale. The subjects rated their favourite height as 100 cm with a provision for their basket. Their own home setting and the height of 60 cm (which is similar to a conventional washing machine) are disliked most. Therefore, innovative new washing machine designs are recommended.

**Keywords:** everyday product, user comfort, product design.

### 4.1 Introduction

Comfort is an issue, which is important for everyone, especially in household appliances for everyday use. It is important for the end-user's experience of comfort, but also important for the manufacturers as they could increase sales by improving their products. A household appliance nobody can do without is the washing machine. The current washing machine in Europe has the middle of its opening at a standard level of about 60 cm high. The height of this opening has not been changed in years and certainly shows room for improvement. This is an opportunity for washing machine manufacturers that are interested in a greater market share.

In a previous study, it was shown that the height and the position of the opening of a washing machine influence the experience of comfort as well as the biomechanical load (Busch and Vink, 2006). In detail:

- Less hazardous body postures appeared at the heights between 100 and 123 cm above the floor. From 86 to 63 cm, people used avoidance postures, e.g. flexing the upper body, squatting or even kneeling.
- Loading the washing machine was fastest at the heights between 105 and 69 cm with a strongly tilted opening. By contrast, the fastest unloading took place at 86 cm and 63 cm with a slightly or 69 cm with strongly tilted opening.
- Subjects rated their favourite height as 105 cm, followed by 114 and 86 cm.
- Older subjects used comfortable body postures at heights between 123 and 105 cm more often than younger subjects.

These results were found in a laboratory study and gave a theoretical guideline. However, the question is whether in a natural setting the results can be verified. A field study has to prove if the results are feasible in the actual home situation. Especially the way of handling and moving, and as a result the body postures, can differ between laboratory and field studies.

Other studies have also shown the differences in body postures between a laboratory and field study. For example, a study on the physical comfort of a car seat demonstrated this difference. Psychophysical discomfort of body postures was determined and also the length of a sitting period was included (Chaffin, 2001). Using RAMSIS manikins on the driver's side, the most probable body posture for defined circumstances can be predicted (Bubb, 1998). BMW uses RAMSIS for realistic prognosis, but dynamic movements still cause problems (Kolling, 1998). In real life, people appeared to behave differently than the assumed sitting in a standardised posture. If passengers have the opportunity, they will sit in a slightly slumped or more relaxed way (Han et al., 1998; Zhao & Tang, 1994). Bronkhorst et al. (2005) observed 1500 passengers in a train study. Only very few people sat in the straight upright position like the ergonomic manikins. The others use their seat in various ways, for example for reading, sitting with stretched legs, folded legs, or sleeping.

These findings support the necessity of a field study in a naturalistic setting. The aim of this study is to measure different heights of washing machines in a field study. Test subjects were asked to rate their favourite height in real life within their own environment, including inhibiting factors or unexpected situations. Dekker et al. (2005) pointed out that younger and older subjects show different body postures when handling personal hygiene. Busch and Molenbroek (2006) observed differences in comfort experience and body postures for younger and older individuals when using a washing machine. That is why older and younger subjects were chosen for this field study.
The research question is: Is the preferred 105 cm opening height of the washing machine found in the laboratory study, also the preferred height in the home situation?

### 4.2 Method

In this research, subjects had to rate their comfort experience for loading and unloading a washing machine at their homes. The conditions were varied by changing the height of the washing machine. People had to rate their comfort experience on a standardised scale.

#### 4.2.1 Subjects

24 German subjects (15 female and 9 male) of the age between 24 and 64 years participated in this field study (7 subjects of 24-39 years, 6 subjects of 40-49 and 11 subjects of 50+ years old). The average age overall was 46.4 years. The average age for the 15 women was 46.5 and for the 9 men 44.7 years. All had experience in washing. The study took place in Northern Germany and included a stochastically selected sample. They were asked to load and unload the washing machine. The older men appeared to have relatively less experience in washing. Other characteristics of the subjects are shown in table 1 and figure 2.

Tab. 1: Data of the 24 studied subjects clustered by age and gender, body height measured according to Flügel et al. (1986)

| Generation | N | Gender | Av. Body height |
|---|---|---|---|
| 24-39 years | 4 | Male | 187,7 |
| | 13 | Female | 170 |
| 40-49 | 3 | Male | 176 |
| | 4 | Female | 165,3 |
| 50+ | 7 | Male | 177,7 |
| | 6 | Female | 163,9 |

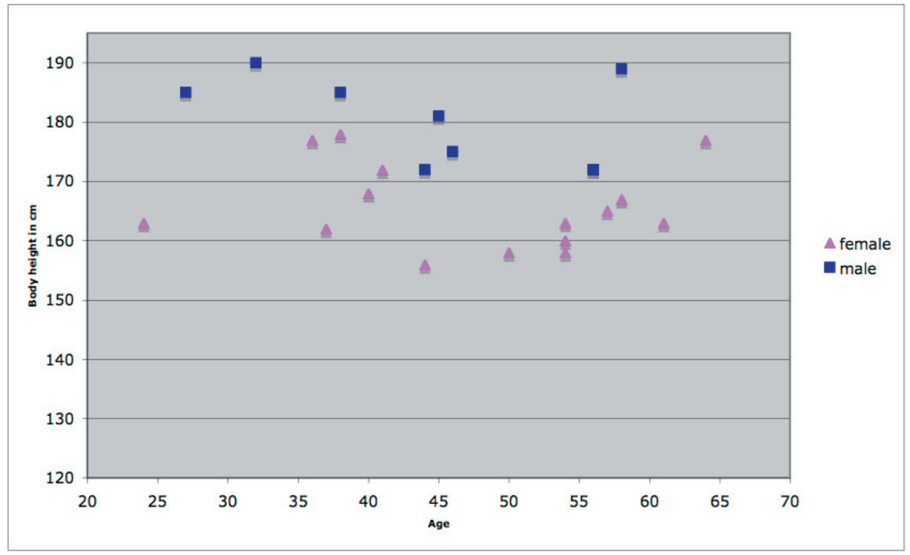



Fig. 1: Data of the 24 studied subjects clustered by gender depending on their age and body height.

#### 4.2.2 Mock-up description

Washing machine manufacturers may not have extensively studied the use of their machines and the comfort they offer yet, but they are interested in determining the ideal comfortable height and angle of the drum. A pre-study of a washing machine company lead to the conclusion that it is preferable to stay close to the design of a built-in washing machine when testing comfort, as this type of washing machine is very common.

For this field study, the subjects were instructed to load and unload their own washing machine at home first. After that they had to use a real washing machine on an elevated platform in their home setting. If their machines were built in, the test machine was placed in front of their own one. In all other cases, the test washing machine was positioned in the same place as their own one. 14 machines were built-in, 10 were freely accessible. As test washing machine a Bosch Max was used with standard dimensions.

Three different heights were tested (see figure 2): 60 cm (conventional), 80 cm (intermediate) and 100 cm (progressive). The heights were measured from the ground to the middle of the drum opening. The progressive height was measured twice, once with a stool to place the washing basket on and once without the stool. The measurement with the stool was added to this field study when one subject incidentally used a stool, which was available in her home setting (see figure 3). It was seen as more comfortable to place the washing basket directly underneath the washing machine opening when loading and unloading. As a result of this first observation, the stool was included in all measurements. To reduce learning effects one third of the subjects started with the 60 cm and went upwards, one third started at 80 cm and either went up or down, and the third group started at 100 cm and went downwards. Every height had to be loaded and unloaded once.

4.2.3 Task description

The subjects were asked to load and unload the washing machine as they thought best suitable for them. They were only told to do the laundry. No explanation was given about the body posture analysis to avoid that the subjects became conscious and thought about their body postures at different heights. They were given 3 kg of laundry

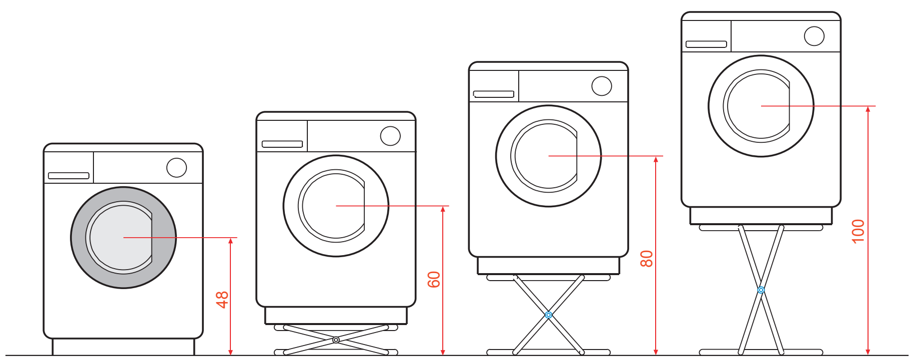



Fig. 2: Tested washing machine on elevated platform. First washing machine shows normal drum height used at home. Drum heights measured from the ground to the centre of the drum

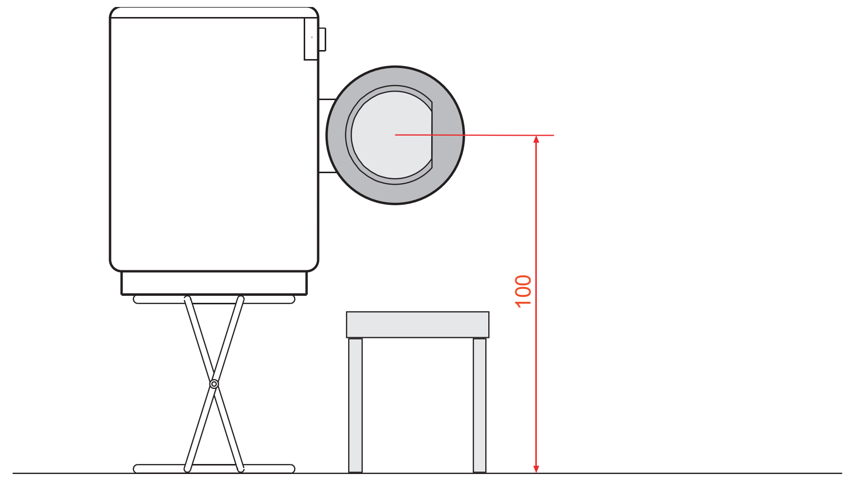



Fig. 3: The 100 cm height was measured twice once with a stool to place the washing basket directly underneath the washing machine opening and once without the stool.

in a basket for loading. Unloading took place with 5 kg of wet laundry (3 kg laundry plus 2 kg water in the laundry). The wet laundry was supposed to be placed (or thrown) into the basket.

4.2.4 Comfort recording

Comfort is a subjective phenomenon, which depends on different individual factors and on the environment (Looze et al., 2003). For the measurement of comfort experience, subjects were asked to rate their experience of comfort on a verbally defined 7-point scale, which was described by Chrisiansen (1992 and proposed by Schoeffel (1985), directly after loading and directly after unloading. This scale was preferred over the 6-point scale from the laboratory test. Compared to the laboratory test where subjects did not take the time to read it properly, in the real life test it was decided for a more detailed and well-described scale about the experience of comfort (see figure 4). People were asked to take time to read and judge properly. With this scale, subjects could rate the degree of comfort depending on feeling, movements and body posture for loading and unloading a washing machine. Video recordings were made of all the subjects loading and unloading the washing machine. Furthermore, remarkable body postures, comments or situations were recorded in writing.

### 4.2.5 Interrelation

An interrelation between different drum heights and subjective comfort ratings was tested, as well as a relationship between the age of the subjects and different ratings. Correlations between drum height and subjective comfort rating were tested with the Wilcoxon Test (**p<0.01, *p<0.05, (*) trend). They were used to verify the observed differences in comfort rating.

It was assumed that with increasing age, loading and unloading of a washing machine at different height would have an effect on the comfort rating. It was also assumed that genders have different preferences. Correlations between age and subjective comfort rating of every usage height were calculated with the Spearman rank correlation coefficient (Correlations ≤ 0.05 are defined as significant. Correlations ≤ 0.1 are defined as trend). In this context, gender differences were tested. It is assumed that there is no relation between body height and different comfort rating, as the laboratory test did not show a relation either. Correlations between body height and subjective comfort rating were calculated with the Spearman rank correlation coefficient (Correlations ≤ 0.05 are defined as significant. Correlations ≤ 0.1 are defined as trend).

### 4.3 Results

The difference of male and female average ages of the subjects in this study is stochastical (Mann-Whitney-U-Test, Z = -0.42 P = 0.693).
The body heights of the subjects varied, especially within the gender (see table 2). As the distribution of the body height was not normally distributed, the Mann-Whitney-U-Test for the comparison of the averages was used. The differences of body heights

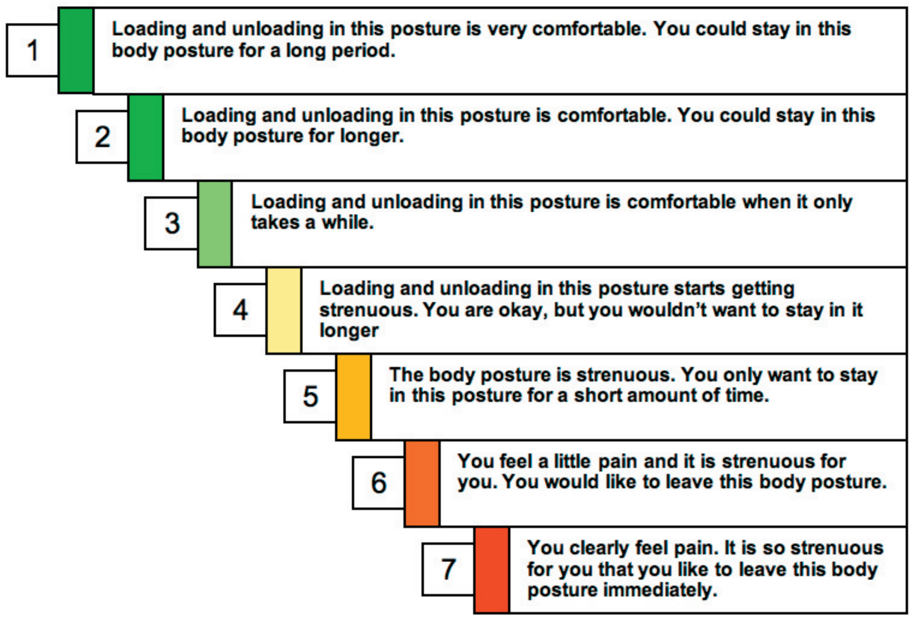



Fig. 4: 7-point scale for individual comfort rating

Tab. 2: Distribution data of body heights for women (n = 15) and men (n = 9)

| | Minimum | Maximum | Median | Average | SD |
|---|---|---|---|---|---|
| All | 156 cm | 190 cm | 172 cm | 171,2 | 10,1 |
| Women | 156 cm | 178 cm | 163 cm | 165,8 | 7,2 |
| Men | 172 cm | 190 cm | 181 cm | 180,1 | 7,5 |

between men and women were highly significant (Z = -3.23; P = 0.001). This means that the male subjects in this study were significantly taller than the female ones. So, it makes sense to look at the comfort rating of the different drum heights for the whole sample and then separately for each gender.

#### 4.3.1 Comfort experience and loading height

In table 3 and figure 5, the average ratings of comfort are summarised for the different heights. The best comfort rating is found at the opening height of 100 cm with a stool for the basket, for both loading and unloading. Table 7 shows that for loading as well as for unloading, the median reaches rating 2, i.e. 50% of the whole sample ranked this height with the mark 1-2.

The Wilcoxon Tests confirmed the differences of comfort rating at different heights reaching significant levels. See table 4 for the comfort rating while loading, and table 5 for the comfort rating when unloading. Exceptions are the comparison of loading and unloading for 60 cm and the home machines. These ratings were not significant. Unloading at a height of 80 and 100 cm did not show significant differences either. Loading at a height of 100 cm and the home machine were not ranked significantly different either.

The averages of the gender samples were compared as well. Women and men did not show significant differences between the ratings of the drum heights. Interestingly, there

Tab. 3: Distribution data of the comfort rating of each drum height for the whole sample (n = 24; in = loading, out = unloading, with = with stool for basket, home= subject's own washing machine).

| | Minimum | Maximum | Median | Average | SD |
|---|---|---|---|---|---|
| 60 in | 2 | 7 | 4,0 | 3,9 | 1,3 |
| 60 out | 2 | 7 | 3,5 | 3,8 | 1,2 |
| 80 in | 1 | 6 | 3,0 | 3,0 | 1,1 |
| 80 out | 1 | 5 | 3,0 | 2,7 | 0,9 |
| 100 in | 2 | 5 | 3,0 | 3,4 | 0,7 |
| 100 out | 1 | 5 | 3,0 | 3,0 | 1,0 |
| 100 in with | 1 | 4 | 2,0 | 1,8 | 0,7 |
| 100 out with | 1 | 4 | 2,0 | 1,8 | 0,8 |
| home in | 2 | 7 | 4,0 | 3,7 | 1,2 |
| home out | 2 | 7 | 4,0 | 3,8 | 1,2 |

was no differentiation in the rating of comfort, even though the body heights of both genders vary significantly. To explain this further, a secondary analysis was made on the correlation of comfort rating and body height.

### 4.3.2 Comfort experience and body height

As the comfort rating was mainly not Gaussian, the interrelation was analysed by the Spearman rank correlation coefficient. To guarantee an overall comparability, the whole sample was also analysed for correlation. Neither in the whole sample nor in the gender samples could any correlations between body height and comfort rating of each drum height be found. So, this study shows that body height does not influence the comfort rating of the drum height for differences between 60 and 120 cm.

### 4.3.3 Comfort experience and age

A significant correlation of the whole sample between age and comfort ranking was found for loading at a height of 100 cm without a stool for a basket (rho = 0.41; P = 0.047). The rating mark became higher with rising age of the subjects, i.e. the older the subject is, the worse the rating of this drum height becomes.

The female sample shows an even clearer, highly significant correlation between age and the rating for unloading at a height of 60 cm (rho = 0.664; P = 0.007), which means that women with rising age dislike unloading a washing machine with a drum height of 60 cm most.

| Relation | Z | P | Significance | Explanation |
|---|---|---|---|---|
| 60 in - 80 in | -3,025 | 0,002 | ** | 80 cm clearly better ranked |
| 60 in -100 in | -1,918 | 0,065 | * | 100 cm better ranked |
| 60 in - 100 in with | -3,923 | 0,000 | ** | 100 cm with clearly better ranked |
| 60 in - home in | -0,741 | 0,433 | | No significance |
| 80 in -100 in | -1,842 | 0,085 | (*) | 80 cm slightly better ranked |
| 80 in - 100 in with | -3,436 | 0,000 | ** | 100 cm with clearly better ranked |
| 80 in - home in | -2,413 | 0,012 | * | 80 cm better ranked |
| 100 in - 100 in with | -3,919 | 0,000 | ** | 100 cm with clearly better ranked |
| 100 in - home in | -1,178 | 0,273 | | No significance |
| 100 in with - home in | -3,798 | 0,000 | ** | 100 cm with clearly better ranked |

Tab. 4: Loading: Significances between rating at different heights (Wilcoxon test for comparing averages, **p<0.01, *p<0.05, (*) trend).

Tab. 5: Unloading: Significances between rating at different heights heights (Wilcoxon test for compa-ring averages, **p<0.01, *p<0.05).

| Relation | Z | P | Significance | Explanation |
|---|---|---|---|---|
| 60 out - 80 out | -3,316 | 0,000 | ** | 80 cm clearly better ranked |
| 60 out -100 out | -2,436 | 0,015 | * | 100 cm better ranked |
| 60 out - 100 out with | -3,79 | 0,000 | ** | 100 cm with clearly better ranked |
| 60 out - home out | -0,047 | 1 | | No significance |
| 80 out -100 out | -1,58 | 0,115 | | No significance |
| 80 out - 100 out with | -3,002 | 0,000 | ** | 100 cm with clearly better ranked |
| 80 out - home out | -3,319 | 0,000 | ** | 80 cm clearly better ranked |
| 100 out - 100 out with | -3,362 | 0,000 | ** | 100 cm with clearly better ranked |
| 100 out - home out | -2,647 | 0,007 | ** | 100 cm clearly better ranked |
| 100 out with - home out | -3,816 | 0,000 | ** | 100 cm with clearly better ranked |

### 4.4 Discussion

This study is a correlative study and interprets the results. It refers to the used sample and is probably not representative for the total population.

Regarding the research question of whether a washing machine opening is preferred at 100 cm height, this study shows that this height is indeed preferred in a field study. However, a basket on a stool in front of the washing machine is a prerequisite.

The results of this paper are summarised as follows:

- The subjects clearly identified the drum height of 100 cm with a stool for the basket as the one with the best rating for loading and unloading.

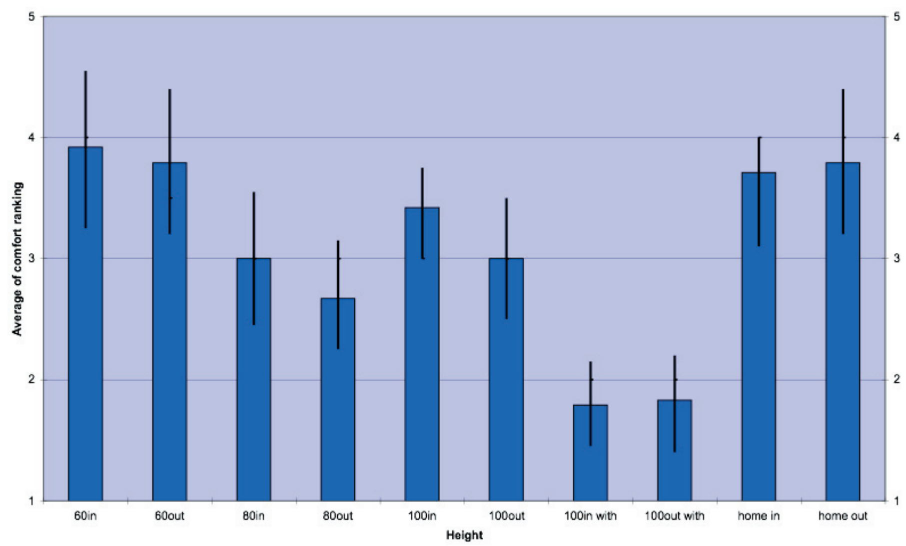



Fig. 5: Distribution data of the comfort rating of each drum height for loading (in), unloading (out) and the possibility at the height of 100 cm with stool for basket = with, 1 = high comfort, 7= low comfort. p<0.01, *p<0.05, (*) trend).

- The subjects confirmed the differences of comfort rating at different heights, reaching significant or highly significant levels with exceptions:
  - Loading and unloading between 60 cm and the home machines,
  - unloading at a height of 80 and 100 cm, and
  - loading at a height of 100 cm and the home machines.
- In this field study, body height did not influence the comfort rating of the drum height and
- no gender differentiation in the rating of comfort could be found.
- Elderly people disliked loading the washing machine at a height of 100 cm without a place for their basket.
- Older women clearly disliked unloading at a height of 60 cm.
- Elderly women were inclined to feel uncomfortable when unloading at a height of 100 cm without a stool for the basket.
- Older women have a tendency to criticise loading their machines at home and
- older men were inclined to criticise comfort when unloading at a height of 80 cm.

### 4.4.1 Ideal height

This study shows similar results as the laboratory study (Busch and Vink, 2006). The subjects preferred the same height of 100 cm in their home settings, but only with a stool for their basket. The advantage of a field study is that people behave more typically. The choice for the stool was logical in the naturalistic setting and was a very instinctive idea to ease the handling. Vink and Koningsveld (1990) have shown the positive effect of reducing the lifting distance. The comfort experience while positioning bricks at 100 cm height was influenced significantly by the height of the set out bricks. Picking up the pricks at 30 and 50 cm improved the comfort significantly. It also reduced the oxygen uptake significantly and resulted in more upright postures.

This preference did not depend on people's body height - even the male subject of the p90 and the female of the p10 had the same preference. Furthermore, it is described in literature that the distance between the height of picking up a load and placing the load influences the experienced loading. Reducing this difference reduces the energy needed for the task. One of the factors in the NIOSH lifting equation is this distance (Waters et al., 1993). The fact that 100 cm is preferred by all subjects of different heights indicates that a height-adjustable washing machine may not be necessary here, while in many other ergonomics studies height adjustability is promoted (Molenbroek, 2006).

To avoid learning effects from one cycle to the other the order within the test was changed. Learning effects could be possible, but we tried to overcome them with changing the order and time between the cycles. However, all subjects were familiar with washing. All subjects of this research had experience with washing.

### 4.4.2 Age – young versus old

Washing is a task, which is difficult to do for the elderly (Freundenthal, 1999). Older subjects rated the height of 100 cm without a stool as less comfortable, but showed significant differences for 100 cm when they had a support for their basket. The distribution of the average ranking (see table 8) shows moreover, that people, even though they are used to their home setting, rated every height better than their home height. Only the conventional height of 60 cm was rated badly, as it is very similar to their home setting. As already analysed in the laboratory study (Busch and Vink, 2006), people use more comfortable body postures at the height of 100 cm, which helps especially the elderly to reduce the workload.
Based on these results, the new design of a washing machine requires a drum at the height of 100 cm and a facility to place the basket close to the bull eye.

## 4.5 Conclusion

This field study shows that designers, ergonomists and engineers should reconsider an innovative construction of a washing machine. This study validates the laboratory study that the best height for the opening door of a washing machine is about 100 cm. Furthermore, it became apparent that it is very important with this height to provide a support for a washing basket as well.
Innovation is necessary because this new machine may not fit under a normal height counter top. Looking at the built-in situation of some washing machines, space becomes an issue. But as can be seen already in the case of refrigerators, which now do not have standard heights anymore, manufacturers now offer various tall built-in sizes. Any space underneath an appliance, for example in the elevated platform of the washing machine, can be used as additional storage space, either for washing supplies, the washing basket support systems and laundry bags.

**Acknowledgements**

We would like to thank G. Rüscher for the discussions in the process of analysing the data of this study. And finally we are grateful to C. and H. Busch for the technical support and the people acquisition in this field study.

**References**

Bronkhorst, R., Krause, F., Vink, P., 2005, Designing comfortable passenger seats, in: Vink, P. (ed.), Comfort and design: principles and good practices, CRC Press, Boca Raton.

Bubb, H., 1998, in: Strassmann, B., Mensch trifft Maschine - Virtuelle Arbeitnehmer helfen, Montagebänder und Fahrzeuge zu verbessern, Die Zeit, 44/1998.

Busch, N., Molenbroek, J., 2006, Comfort and body posture of elderly in washing machine loading and unloading (Paper submitted), 16th International Ergonomics Association Congress, Maastricht.

Busch, N., Vink, P., 2006, Comfort, body posture and speed in washing machine loading and unloading (Paper submitted), Applied Ergonomics.

Chaffin, D, 2001, Digital human modelling for vehicle and workplace design, Society of Automotive Engineers Inc., Warrendale.

Christiansen, K., 1992, Psychologische Tests und Explorationsmethoden, in: R. Knußmann (ed.), Anthropologie, Handbuch der vergleichenden Biologie des Menschen, vol. I/2, Fischer Verlag, Stuttgart, pp. 205-278.

Dekker, M. et al., 2007, Hand support to assist toilet use among the elderly, Applied Ergonomics 38, pp.109-118.

Flügel, B., Greil, H., Sommer, K., 1986, Anthropologischer Atlas, Verlag Tribüne, Berlin.

Freudenthal, A., 1999, The design of home appliances for young and old consumers, Series ageing and ergonomics 2, Delft University Press.

Gupe et al., 2005, Anthropologie, 6. Verhaltensbiologie, Springer Verlag, Berlin.

Han et al., 1998, Psychophysical methods and passenger preferences of interior designs, Applied Ergonomics 29(6), pp. 499-506.

Kolling, J., 1998, in: Strassmann, B., Mensch trifft Maschine - Virtuelle Arbeitnehmer helfen, Montagebänder und Fahrzeuge zu verbessern, Die Zeit, 44/1998.

Looze, M.P. de, Kuijt-Evers, L.F.M. and Dieën, J.H. van, 2003, Sitting comfort and discomfort and the relationships with objective measures, Ergonomics, 46, pp. 985-997.

Molenbroek, J., 2006, Anthropometrics in toilet environment, in: Developing an adaptable toilet for the future for disabled and elderly people, IO Press, Amsterdam, to be published in 2006.

Schoeffel, R. et al., 1985, Psychologische-ergonomische Grundlagenbeiträge für die Optimierung wehrtechnischer Mensch-Maschine-Systeme, Wehrpsychologische Untersuchungen, Heft 1/85, 20. Jg., Bundesministerium der Verteidigung – PII4

Swanson, N. et al., 1997, The impact of keyboard design on comfort and productivity in a text-entry task, Applied Ergonomics 28(1), pp. 9-16.

Vink, P., 2005, Comfort and design: principles and good practices, CRC Press, Boca Raton.

Vink, P., Koningsveld, E., 1990, Bricklaying: a step by step approach to better work. Ergonomics, 33 (3), pp. 349-52

Waters, T. et al., 1993, Revised NIOSH equation for the design and evaluation of manual lifting tasks, Ergonomics, Nr. 36, S. 749-776.

Zhao, J., Tang, L., 1994, An evaluation of comfort of a bus seat, Applied Ergonomics 25(6), pp. 386-392.

Published in the International Ergonomics Association 2006 proceedings

**Authors: Nicole Busch and Johan Molenbroek**
nicole.busch@hamburg.de and j.f.m.molenbroek@io.tudelft.nl
Delft University of Technology, Faculty Industrial Design Engineering, Landbergstraat 15,
2628 CE Delft, The Netherlands

**Abstract**

Today elderly people are seen as a huge potential for more business. Nevertheless, marketing and product design seldom focus on including the abilities of elderly people. This generation is sometimes called the silver age or 50+ generation. This generation has more money to spend than earlier generations and is willing to do so. An elderly person nowadays is fit and wants to be independent. In this study, body movements and postures and comfort were analysed during an everyday task, loading and unloading a washing machine. Part of this study focused on how the elderly can fulfil this task. First, elderly persons were observed in a senior residence while they were using the washing machine along with the problems that came up. This was compared with an older study in which 54 subjects including 13 subjects of the 50+ generation tested a mock-up of a washing machine. Finally, it was compared with a previous study in which a washing machine prototype was tested in a real setting and compared with their home setting. As a result, some settings of the mock-up and prototypes were further evaluated, which resulted in a final design for a washing machine making washing easier for the elderly.

**Keywords:** applied ergonomics, field study, comfort, aging, everyday product, inclusive design, product design.

# 5 Comfort and body posture

## of elderly people in washing machine loading and unloading

### 5.1 Introduction

The elderly are seen as a huge potential for the future market. Marketing came up with the name '50+ generation' to differentiate this group in a 'neutral' way from the 14 to 40-year-old target group (Göbel and Neth, 2004) they normally focus on. Demographics show that the ratio of healthy elderly people in developed countries is increasing. Currently, 23% of the German and 22% of the Dutch population are older than 60 years old, and in the year 2030 this will increase in Germany to 40% and in the Netherlands to 43% (Statistisches Bundesamt, 2003, Centraal Bureau voor de Statistiek, 2005). Similar trends have been found in nearly all developed countries: 20% of Europe's inhabitants are currently older than 60 years and the percentage will double until 2030 (Birg, 2000). Statistically, the elderly have a high spending capacity (e.g. 80% of senior households in the German state North Rhine-Westphalia have an above average income) and are willing to spend money on products that fit their needs.
The question is how products need to differ between elderly and younger people? There is some scientific evidence that ergonomic requirements will become more important. Steenbekkers and Beijsterveldt (1998) found that the physical strength reduces with age, the area of reach is limited, the ability to bend and carry weight decreases. Freudenthal (1999) found that home appliances should be designed for the limited physical abilities the elderly have. Sensory perceptions, mental abilities and body fitness decrease steadily. On top of that, at an average age of about 75 years, one or more disabilities appear.

This requires adjusted devices and products (Göbel and Neth, 2004). Ackermann (1987) and Lehr (2003) found that behaviour-induced performance differences increase with increasing age; e.g. diminished body flexibility can lead to less liked, less often performed or total avoidance of household tasks like gardening.
On the other hand, product design can build on increasing qualities like life experience. With growing age, vocabulary, knowledge and wisdom grow as well, the ability to engage in reflected communications and to solve socially-related problems increases (Ilmarinen, 2001).
The desire for more comfort is important for everyone, especially for the elderly, who want to stay independent longer. Household appliances should address these issues and needs. One often-used household appliance is the washing machine, the subject of this paper. Freudenthal (1999) puts washing among the top ten list of everyday products, which are relevant for senior citizens at home. She describes washing as problematic for the old (70/80 to 80/90 years) and oldest-old (80/90 years and up), but for younger senior citizens (55/60 to 70/80 years) it does not cause problems.
The current washing machine in Europe has an opening at a standard level of about 60 cm above the floor. The height of this opening has not been changed in years and offers opportunities for improvement.

The aim of this study is to point out the differences between younger and older individuals in behaviours of using a washing machine as well as to give basic ergonomic principles for a new design of a washing machine which fulfils the needs of consumers, especially of the elderly.
The research aims to answer the question, whether the height of the washing machine opening becomes more crucial with increasing age and limited physical abilities, e.g. reduced physical strength, limited area of reach, decreasing ability to bend and carry weight.

## 5.2 Method

To answer the research question, the data of two previous studies (chapter 3 and 4) were interpreted again with special attention for the elderly.
In the first laboratory study, objective and subjective analysing methods (Christiansen, 1997) were combined to establish the comfort experience: the body postures while loading and unloading a washing machine were analysed and the speed of these tasks at different heights were recorded. Next to objective methods, subjective methods were used like a standardised 6-point scale to rate the individual feeling of comfort. A detailed description can be found in chapter 3. Additional analysis for this chapter concern observed postures that are qualified as more comfortable for older and younger subjects and perception of the drum angle by older and younger subjects. Also, the idea was to carry out additional observations in using the mock-up at a senior residence.
The results of the laboratory study were verified in a field study. In this second research, the same subjective method was used as in the laboratory setting (Busch and Vink, 2006) to study comfort. The subjects had to rate their individual comfort experience on a standardised descriptive 7-point scale within their own surrounding, including inhibiting factors or unexpected situations after loading and unloading a washing machine. A detailed test description can be found in chapter 4. In this paper, both previous studies were specifically analysed for differences in age.

### 5.2.1 Subjects

In the laboratory study of chapter 3, 54 healthy subjects (34 female and 20 male) in the age range between 18 and 62 years old participated (17 subjects between 18-29, 18 between 30-39, 6 between 40-49, and 13 between 50-62). The subjects had experience in washing and were asked to load and unload the washing machine. Additionally, they were asked to rate their expectations towards a washing machine with an angled drum. The mock-up was also tested in a senior residence. 10 elderly people between 58 and 78 years old took part.
In field study of chapter 4, 24 subjects (15 female and 9 male) of the age between 24 and 64 years participated (7 subjects between 24-39 years, 6 subjects between 40-49 and 11 subjects of 50+ years old.) All had experience in washing.



### 5.2.2 Task description

The subjects were asked to load and unload the washing machine at different heights. They were only told to do the laundry, instead of explaining the body posture analysis to avoid that subjects think about their body postures at different heights.

### 5.2.3 Posture recording and classification

In the laboratory study, video recordings were made of all subjects loading and unloading the washing machine mock-up. Afterwards, first the whole body posture was classi-

fied from the video. The body postures were classified into 7 modified OWAS categories (Karhu et al., 1977).
The idea was to use of the mock-up in the senior residents to study the effects in the environment of the elderly, to find out how they use the washing machine, which was recorded by photos and notes were taken.

### 5.2.4 Comfort recording

In all studies, subjects were asked to rate their experience of comfort on a standardised bipolar scale (Christiansen, 1992), directly after loading and unloading. In this chapter a combination of the comfort results of chapter 3 and 4 was studied dividing the elderly and younger subjects.

### 5.2.5 Interrelation

A relationship between the age of the subjects and different body postures was expected. Subjects were divided into three groups for statistical purposes, a young group of 18 to 29 years, a group of 30 to 50 years, and an older group of 50 to 64 years of age. The relationship between the age of the subjects and different subjective comfort ratings of different drum heights was calculated with the Spearman Rank Correlation coefficient. For this context the group was divided by gender. It was assumed that with increasing age, loading and unloading of a washing machine at lower heights causes more discomfort in the rating. Correlations between age and subjective comfort rating of every usage height were assumed.

## 5.3 Results

Evaluating the results of the laboratory study and the field study showed connections between age and body postures at different drum heights of a washing machine, as well as a relationship between age and different comfort ratings. The most comfortable body postures appeared at an opening height of 100 and 120 cm above the floor. It was fastest to load washing machines at heights between 60 and 100 cm with a tilted opening of the washing machine, but unloading was fastest at 80 and 60 cm. The favourite height of the subjects was 100 cm. In the field study of chapter 4 the preferred loading and unloading height for younger and older subjects was 100 cm was confirmed, but in the naturalistic setting it appeared that subjects wanted to use a basket, which resulted in a better comfort rating.

Fig. 1: Illustration of the use of equipment to support more comfortable body postures

### 5.3.1 Observations in the senior residence

In the senior home, citizens were asked to load and unload the washing machine mock-up. But the senior subjects refused to do so, because they found the setting too exhausting. Instead, they explained to the researcher which strategies they use to load and unload the washing machine. All of them had their own washing machine in their apartments. We found four different behavioural archetypes:

- aids to support more comfortable body postures,
- aids for the washing utensils,
- body movement support and
- avoidance.

Aids to support more comfortable body postures: Three subjects thought their toploader washing machine in their bathroom is the most comfortable, as they do not have to squat or bend down to the drum. One man placed a chair in front of the washing machine to be able to sit down while loading and unloading, holding the washing on his lap. Another woman used the same strategy, but sat down on the toilet in front of the washing machine, slightly bending forward to load the washing machine. In some homes (not in the senior home), people place their washing machine on an elevated understructure.

Aids for the washing utensils: Subjects with toploaders described the heavy lifting of the washing as problematic. So, two women used an additional stool next to the machine to place their basket on. One man used a similar method and placed his basket on the toilet next to the washing machine.
Body movement support: A different strategy is to work with supportive movements.

Instead of squatting or kneeling, people start to bend their upper body, supporting their movements by leaning with one arm on the top of the washing machine and using the other arm to load the drum of the washing machine. Another supportive movement is to lean with one arm on the leg of the same side, and to load the washing with the other arm. When unloading, people hold on to the top of the washing machine or to the door with one arm and unload with the other arm. These supportive movements could be analysed, especially for elderly persons using front loader washing machines.

Avoidance: One older man in the senior home avoided washing on his own. It could have been that he had never washed before, but after asking him whether he had ever washed before he answered that he washed when his wife became ill. Now he would rather pay for the extra service than have knee problems and back pain and be exhausted for the day.

### 5.3.2 Body postures and age

Re-evaluating the laboratory study, the three age groups (18 to 29 years, 30 to 50 and 50 to 64 years) were compared. As no differences between the groups 30 to 50 and 50+ could be found, the groups were combined into one group of 30+ years, which was called the 'older' group and compared to the group of 18 to 29, the young group. It was observed that at the higher loading levels (100, 110 and 120 cm), avoiding postures and qualified more hazardous body postures occurred less often than at the three lower loading levels (80, 60 cm with slightly and strongly tilted opening). Although the younger subjects used these postures more often than the older subjects at the high drum levels, older and younger subjects equalise their body postures at the lower drum levels (see figure 8 of chapter 3). On the contrary, older subjects were able to use the comfortable body posture at the high drum levels more often, as shown in figure 4.

Fig. 2: Illustration of the use of equipment for easier loading.

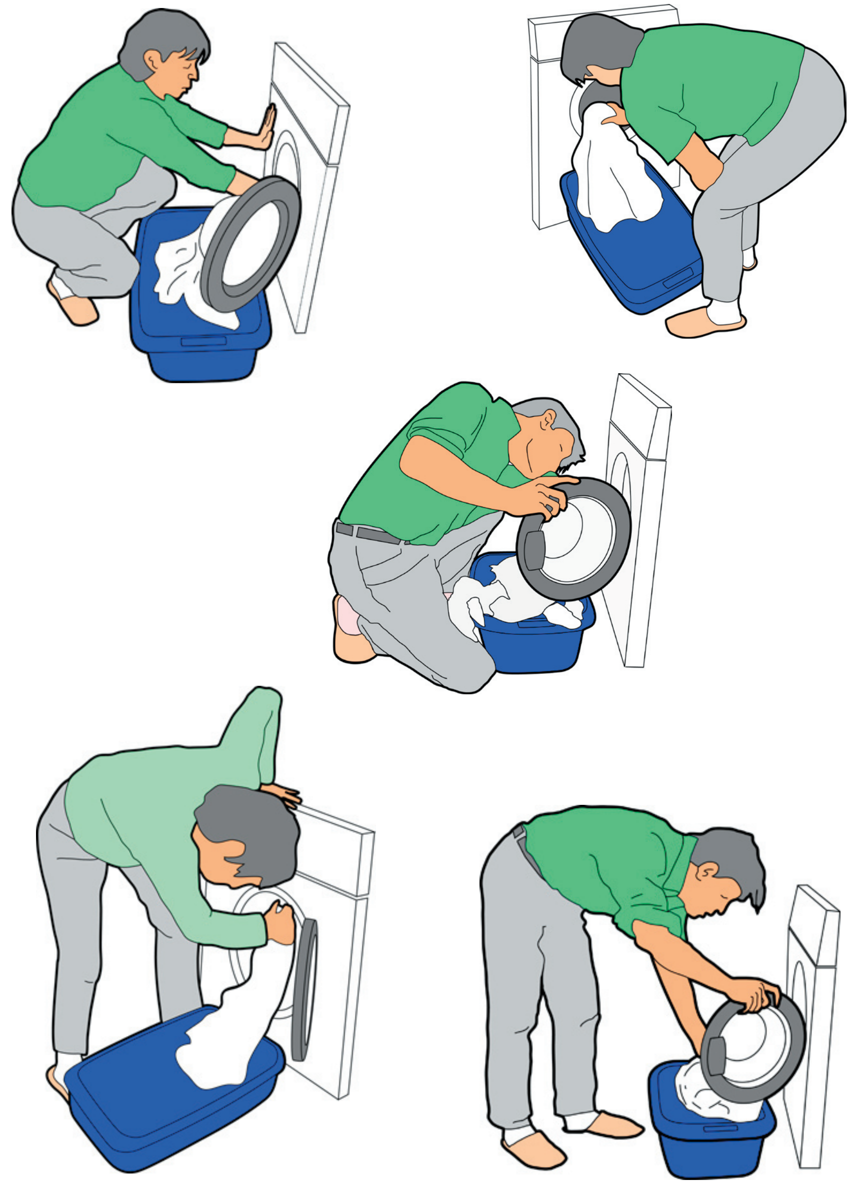


Fig. 3: Illustration of supportive movements

### 5.3.3 Perception of the drum angle

The ratings on the perception of the drum angle show that people favour a washing machine with an angled drum. Figure 5 shows that the ratings 1 and 2 (very positive and positive) are mostly given, that means the subjects like to use a machine with an angled drum.

Analysing the ranking of the drum angle by age, it appeared that younger subjects ranked the drum angle as noticeably less positive on the 7-point scale than the elderly. That means older subjects are even more convinced of the use of a washing machine with an angled drum than younger subjects (see figures 6 and 7).

### 5.3.4 Comfort experience and age

A significant correlation of the whole sample between age and comfort ranking was found for loading at a height of 100 cm without a stool for a basket (rho = 0.41; P = 0.047). That means that the older the subjects are, the more negative they rated this drum height. The female sample shows an even clearer, highly significant correlation between age and the rating for unloading at a height of 60 cm (rho = 0.664; P = 0.007), which means that women with increasing age dislike unloading a washing machine with a drum height of 60 cm.

## 5.4 Discussion

The aim of this study is to point out differences in behaviours between younger and older individuals when using a washing machine. Regarding the research question

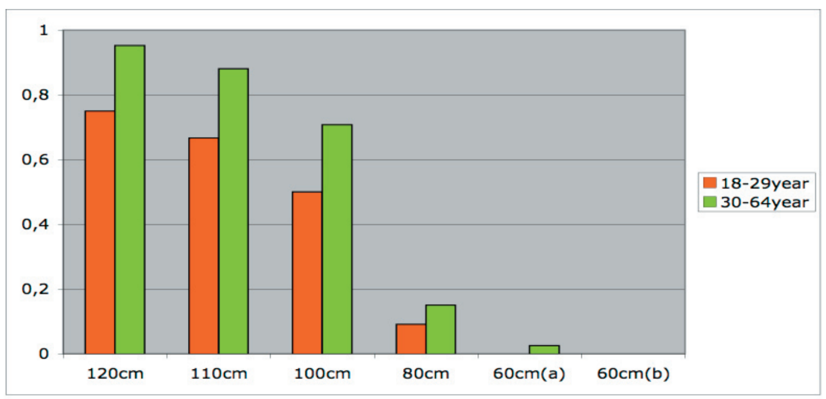
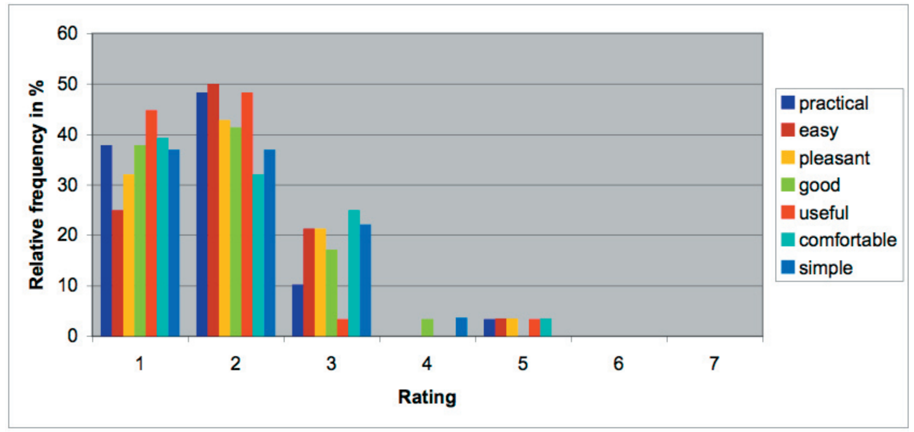



Fig. 4: The number of observed postures that are qualified as more comfortable for older and younger subjects. The number of postures is divided by the total number of observed postures.

Fig. 5: Overall subject ranking of the drum angle on a 7-point scale. X-axis: 1 = very positive (e.g. good), 7 = very negative (e.g. bad), Y-axis: number of ratings divided by the total number of subjects.



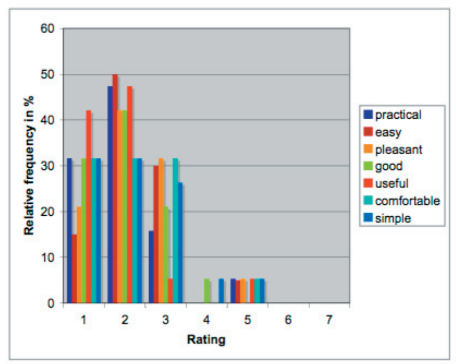

whether the height of the washing machine opening becomes more crucial with increasing age and limited physical abilities, this study shows that the opening height indeed becomes very critical. It was also examined whether behaviour-induced performance differences influence the use of a washing machine, which was indeed shown.

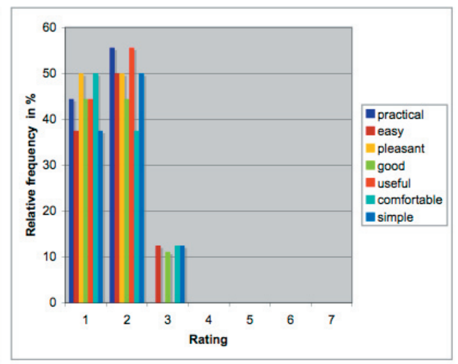
The results of this paper are summarised as follows:

- Older subjects from the senior home use support strategies to fulfil their washing task. We found four different behavioural archetypes:
  - aids to support comfortable body postures,
  - aids for washing utensils,
  - supportive body movement and
  - avoidance.
- Older subjects use comfortable body postures at heights between 120 and 100 cm more frequently than younger subjects. So, these heights are especially worthwhile for the elderly.
- Younger subjects rank the drum angle as clearly positive, but older subjects rate it as even more beneficial. They can see an angle of the drum as pleasant,

Fig. 6: Younger subject ranking of the drum angle: X-axis: 1 = positive (e.g. good), 7 = negative (e.g. bad). Y-axis: number of ratings divided by the total number of subjects.

Fig. 7: Older subject ranking of the drum angle: X-axis: 1 = positive (e.g. good), 7 = negative (e.g. bad). Y-axis: number of ratings divided by the total number of subjects.



comfortable, practical and useful. That means older subjects are even more convinced of using a washing machine with an angled drum than younger subjects.

- Elderly people dislike loading the washing machine at a height of 100 cm without a place for their basket, and elderly women are inclined to feel uncomfortable when unloading at a height of 100 cm without a stool for a basket.

Washing is a difficult task for the elderly, and cannot be fulfilled anymore by very old citizens (Freudenthal, 1999). But Freudenthal (1999) also concludes that using a washing machine does not cause problems for the so-defined “younger senior citizens” from 55/60 to 70/80 years. This may be the case for the usability of the interface, but this paper shows that the washing task certainly has room for improvement.

Different factors influence daily life. They can intensify each other and can result in a strategy to avoid certain activities, which could be hazardous. But they can also compensate each other, e.g. when driving a car increased driving experience compensates decreased sensory perception and reaction, so that in statistics older people do not drive more insecurely than younger ones (Göbel and Neth, 2004). Steenbekkers and Van Beijsterfeldt (1998) describe that elderly people use compensations to fulfil tasks or use products. This can be underlined by this research. The results of the observations in the senior residence show that people are using aids to overcome the hurdles of washing. So, the hurdles and support strategies need to be taken into account when designing a new washing machine.

In this research it was found that the older subjects have a stronger need for comfortable handling of washing than younger people. They use comfortable body postures at heights between 120 and 100 cm more frequently than younger subjects. These needs can be explained by the changing capacities of older citizens (Freudenthal, 1999). Maintaining balance, reaching, heavy pushing or pulling, bending and lifting can be issues when loading and unloading a washing machine. How reaching would affect the new washing machine is illustrated in figure 8. The drum opening would just be in comfortable reach; according to this picture approximately 97 % of the 50 to 74-year-old people are capable of loading and unloading at this drum height. However, the further part of the inside of the drum would still be hard to reach. This can be changed by mounting the drum at an angle of 30°. Compared to figure 9 where the wash-

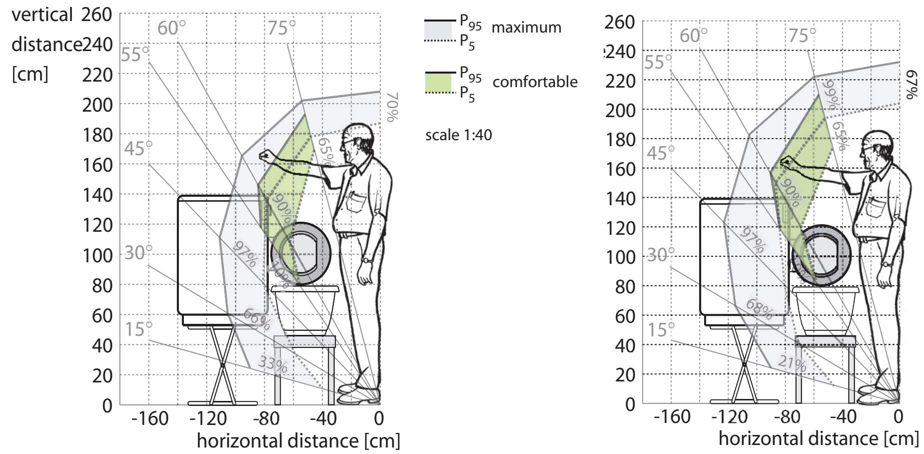



Fig. 8: Washing machine with drum at 100 cm included into reach envelope for vertical reach of people between 50 and 74 years of age. On the left, people smaller than 170 cm; on the right, people taller than 170 cm (reach envelopes according to Molenbroek and Steenbekkers, 1998).

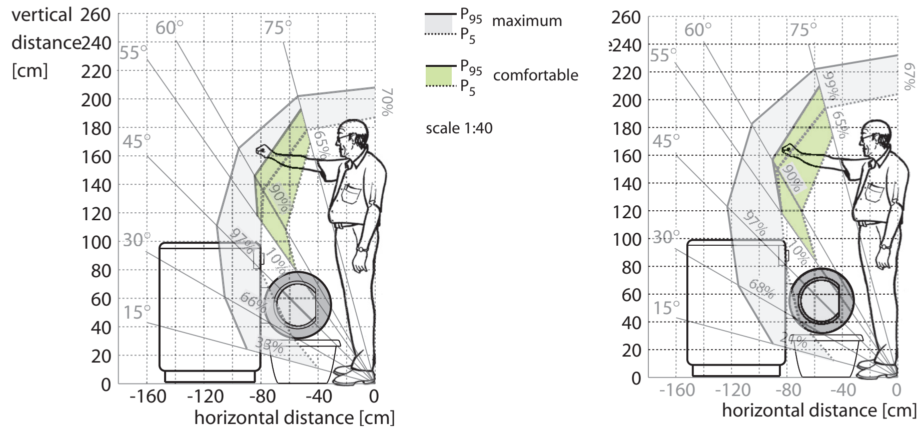



Fig. 9: Washing machine at ground level with drum at about 50/60 cm included into reach envelope for vertical reach of people between 50 and 74 years of age. On the left, people smaller than 170 cm; on the right, people taller than 170 cm (reach envelopes according to Molenbroek and Steenbekkers, 1998).

ing machine is placed on the ground, only about 66 to 68 % of the 50 to 74-year-old people would be capable of loading and unloading at this drum height. When they reach it, they are at maximum and not at comfortable reach distance.

Younger subjects ranked the drum angle as clearly positive, but older subjects rated it as even more beneficial. They can see an angle of the drum as pleasant, comfortable, practical and useful. That means older subjects see it as even more useful to load and unload a washing machine with an angled drum. A reason for this may be the wish for better reachability and better optical control. Reach envelopes, i.e. comfortable and maximum reach, decrease from the age of 60 years onwards (Molenbroek and Steenbekkers, 1998) and bending becomes more painful. Better visibility is important for about 90% of all everyday tasks (Jenner and Berger, 1986). For an optimal view, people roll their eyeballs, bend their upper body and flex the head, but the ability of bending forward decreases with age (Molenbroek and Steenbekkers, 1998).

Older subjects rated the height of 100 cm without stool as more sceptical, but were significantly convinced about this height when they had a support for their basket. Older women clearly disliked unloading at a height of 60 cm and have a tendency to criticise loading their machines at home. Despite the fact that they are used to their home setting, all subjects rated the alternative heights better than their home situation. Only the conventional height of 60 cm was rated low, as it is very similar to their home setting. As already analysed in the laboratory study (Busch and Vink, 2006), people use more comfortable body postures at the height of 100 cm, which helps especially the elderly to reduce the workload.

The aim of this study is to give basic ergonomic principles for a new design of a washing machine which fulfils the needs of consumers, especially of the elderly. When washing machines are designed so that the middle of the drum is at a height of 100 cm and is tilted at an angle of 30°, loading and unloading would be easier for everybody and would have strong benefits for the elderly. An important aspect of the new design is to provide a solution to raise the basket very close to the opening as well.

### 5.5 Conclusions

A new design of a washing machine would be very beneficial for older and younger people. This new machine may not fit under a normal height counter top. But as seen in the observations of the subjects, they already build understructures to elevate their washing machines. In general, people have accepted and made space available already for other home appliances that have become bigger and more comfortable in the course of their product development. Especially if older people are enabled to do their washing in a more convenient and less painful way, it could influence their buying decision. In the end, this means that fulfilling the comfort needs of older and younger consumers could influence the market share of white goods companies.

**Acknowledgements**

I would like to thank J. Keunecke especially, for the illustrations of the body postures in this study.

**References**

Ackermann, P., 1987, Individual differences in skill learning: An integration of psychometric and information processing perspectives, Psychological Bulletin, 102, pp. 3-27.

Birg, H., 2000, Perspektiven der Bevölkerungsentwicklung in Deutschland und Europa – Konsequenzen für die sozialen Sicherungssysteme, in: www.ibis.uni-bielefeld.de/personal/birg/BVerfG.pdf (from 20.Oktober 2005).

Busch, N. et al., 2006, Comfort of washing machines when loading and unloading in a field study, (Paper submitted), Applied Ergonomics.

Busch, N., Vink, P., 2006, Comfort, body posture and speed in washing machine loading and unloading, (Paper submitted), Applied Ergonomics.

Centraal Bureau voor de Statistiek, 2004, on 18th Nov. 2005 taken from http://www.cbs.nl/nl-NL/menu/themas/dossiers/vergrijzing/publicaties/artikelen/archief/2003/2003-1175-wm.htm.

Christiansen, K., 1992, Psychologische Tests und Explorationsmethoden, in: R. Knußmann (ed.), Anthropologie, Handbuch der vergleichenden Biologie des Menschen, vol. I/2, pp. 205-278, Fischer Verlag, Stuttgart.

Freudenthal, A., 1999, The design of home appliances for young and old consumers, Series ageing and ergonomics 2, Delft University Press, Delft.

Göbel, M., Neth K.-U., 2004, Junge Alte – Der demografische Faktor bei der Produktgestalltung, in: Bruder, R., Ergonomie und Design, GfA Gesellschaft für Arbeitswissenschaften und Institut für Ergonomie und Design, Tagungsband zur GfA Herbstkonferenz in Essen, Zeche Zollverein, Ergonomia, Stuttgart.

Ilmarinen, J., 2001, Aging Workers, Occupational & Environmental Medicine, 58, pp. 546-552.

Jenner, R., Berger G., 1986, Arbeitsplatzgestaltung und Körpermaße, (ed.): W. Lange, W. Doerken, Verlag TÜV Rheinland, 1986.

Lehr, U., 2003, Psychologie des Alterns, 11. Auflage, Quelle und Meyer, Heidelberg-Wiesbaden.

Molenbroek, J. and Steenbekkers, J., 1998, Physical variables, in: Steenbekkers, L. and

Beijsterveldt, C. van (eds.), Design relevant characteristics of aging users, Delft University Press, Delft.
Statistisches Bundesamt, 2003, Bevölkerung Deutschlands bis 2050, in: www.destatis.de/presse/deutsch/pk/2003/bevoelkerung_2050.pdf (from 20. Oktober 2005).
Steenbekkers, L., 1998, Activities of Daily Living, in: Steenbekkers, L. and Beijsterveldt, C. van (eds.), Design relevant characteristics of aging users, Delft University Press, Delft.
Steenbekkers, L. and Beijsterveldt, C. van (eds.), 1998, Design relevant characteristics of aging users, Delft University Press, Delft.

# 6 Comfort control with 3D measurements

**6.1 Introduction**

In the chapters 3, 4 and 5 static postures were analysed, while in reality loading and unloading of the washing machine is a dynamic activity with a series of body parts involved. In a large number of situations, the knowledge of a single angle is not sufficient to design a workplace. Instead, a frequency of angles should be the basis, i.e. the interrelated functioning of several interconnected joints. This phenomenon is called a kinetic chain or 'frequency of angles' (Babirat et al., 1998). Hackenbroch (1957) "define[s it] as the combination of several serial joints building a motor unit."

Since these angle chains are not theoretically or technically deducible, an empirical determination is necessary. In this study, the movements and postures during loading and unloading were recorded by the 'Flock of Birds system' (FOB) and compared with a 'golden standard' developed by Babirat et al. (1998). The comfort angle is defined as the physically reasonable angle of a joint within a frequency of angles.

Several authors (Bubb, 1992; Dupuis, 1983; Rebiffé, 1969) and organizations (DIN 33408, 1981; HdE, 1998) developed recommendations for the ideal joint angles, but all are defined for sitting in a passenger vehicle. For other than sitting postures, Babirat et al. (1998) is the only source on the variability of comfort angles. They systematically observed and recorded the movements and postures of the human being in order to analyse the most important angle chains. They made a graphic documentation that encompasses human measurements and proportions (from the female 5th percentile to the male 95th percentile) in relation to comfort. It is divided into 22 different movement sequences of sitting and standing persons. Of course this system has some drawbacks. The question could be asked whether this golden standard is valid. Therefore, it seems that measurements of postures is favourable. However, OWAS also has its drawbacks. One of the drawbacks is that the system is based on static postures. To overcome this problem an additional analysis was carried out with the FOB system. In theory the dynamics could lead to other comfort results. The dynamics of movements is very different from the static, leading consequently to a high probability that differences will occur (Chaffin et al., 1983). Also, important postures may be overlooked when only OWAS is used.

The hypothesis of this chapter is:
A dynamic analysis with the flock of birth system and Babirat's evaluation of the recorded OWAS postures while loading and unloading the drum, leads to other comfort values and thereby to other preferred drum positions.

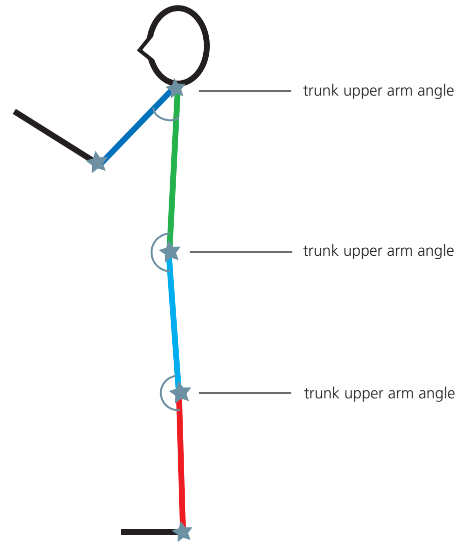
**6.2 Method**

To test the hypothesis an additional experiment is carried with movements simulating loading and unloading a drum. The observed body movements were analysed with the 3D system 'Flock of Birds' (FOB). The used FOB system is a non-contact tracing and detector system, which reads the position and orientation of 6 sensors, so-called birds (Ascension Technology Corporation, 1996).

6.2.1 The FOB system

The Flock of Birds system consists of five sensors (magnetic trackers) that send information on their position in space. Compared to other motion tracking systems, the FOB has the advantage that body parts do not block the signal. Most systems use cameras or likewise recording systems and when an arm comes before the sensor on the hip the sensor does not record the position anymore. The FOB has pulsed DC magnetic fields, which permeate all non-metallic objects - at the same time a disadvantage, when a metal mock-up is to be used. It has a static accuracy position of 1.8 mm root mean square (RMS) and a static accuracy orientation of 0.5° RMS. Each Flock receiver makes up to 144 position and orientation measurements per second. These track the motion of the sensors. As the device has only five sensors the important angle-movements were chosen.
In this case, the sensors were positioned on the points of rotation between the parts of the body, a system, which is often used in biomechanical analysis. The following were chosen: on the shoulder point of rotation (lateral), the elbow point of rotation, the Iliocristale (hip point), knee point of rotation (lateral) and lateral ankle rotation point.
The set up of the system and positioning of the markers takes about an hour, the measurements of all postures about two days for the test person.

Fig. 1: Manikin illustrates angles according to the data of Babirat et al. (1998). Stars illustrate the attached sensors.




6.2.2 Analysis of movements

The movements of the analysed OWAS postures 21, 31, 41, 51, 61 and x2 were studied. The movements were recorded by video in addition to the FOB recordings. They were used for the interpretation of the comfort angles. An accurate database to evaluate comfort based on these data is not available. The DIN 11226 (2000) concentrates on static body postures only and does not mention comfort angles. Therefore, the principle description of body postures done by Babirat et al. (1998) was used for comparison.

Chaffin et al. (1983) stated that replicated postures for various pushing and pulling tasks have very small variations in angles and distances. Using the mock-up was impossible as the metal disturbed the measurements of the FOB. So in this FOB test, the OWAS postures analysed in chapter 3 were re-enacted by a 35 year old p50 male subject with a 178 cm body height and a normal BMI of 239 who is used to washing. He was asked to re-enact the frequently used body movements when loading and unloading.
The movements were recorded from a standing position on both legs like in the laboratory test (chapter 3). Then the subject was asked to simulate the (un)loading movements. When the analysed position was reached and the subject used the arms for virtual loading of the laundry, the recording was stopped. If the person had moved back to the start position, the image would have overlaid the recorded body posture.

### 6.3 Results

The movements of the body postures 21 (standing upright with feet next to each other) and 31 (standing upright with one foot forward) are within the range of comfort angles (see figure 1), which are described by Babirat et al. (1998) for this frequency of angles (see table 1).

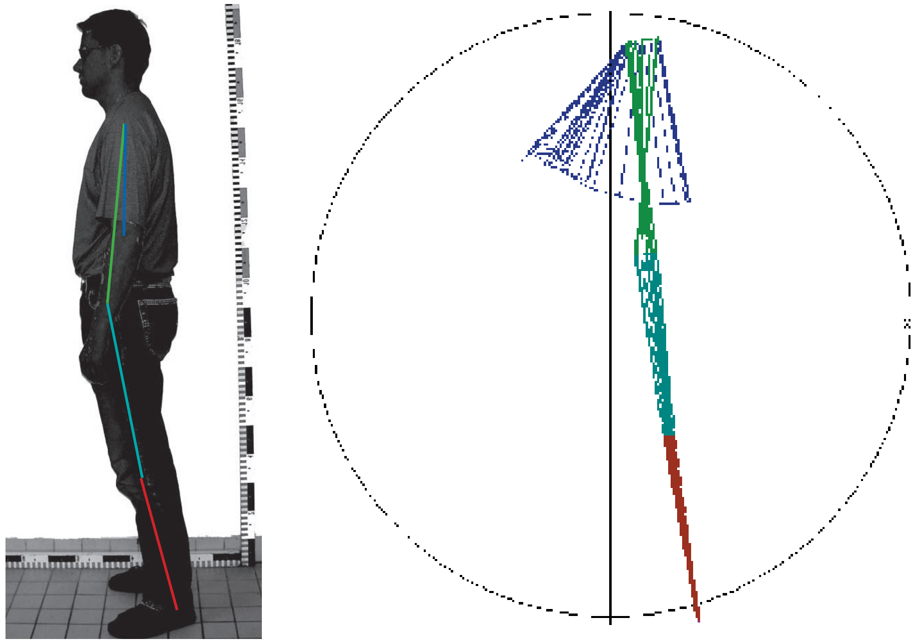


Fig. 2: Lateral movement illustration of the 3D frequency of angles of the 21 and 31 body posture including the loading and unloading arm movement.

| Comfort angle in a frequency of angles | Comfort value (opening angle) |
|---|---|
| Trunk-thigh angle* | 170° |
| Knee angle | 160° |
| Ankle joint angle | 94° |
| Trunk-upper arm angle** | 87° |

Tab. 1: Comfort angles within the frequency of angles of the body posture: Comfortable standing (with non-supporting leg) according to the data of Babirat et al. (1998). * is the leading angle which is defined as the angle with the biggest influence on the performance of the described movement. ** Reference angle of the task: ‚movement of the upper extremities: reaching forward' according to Babirat et al. (1998).

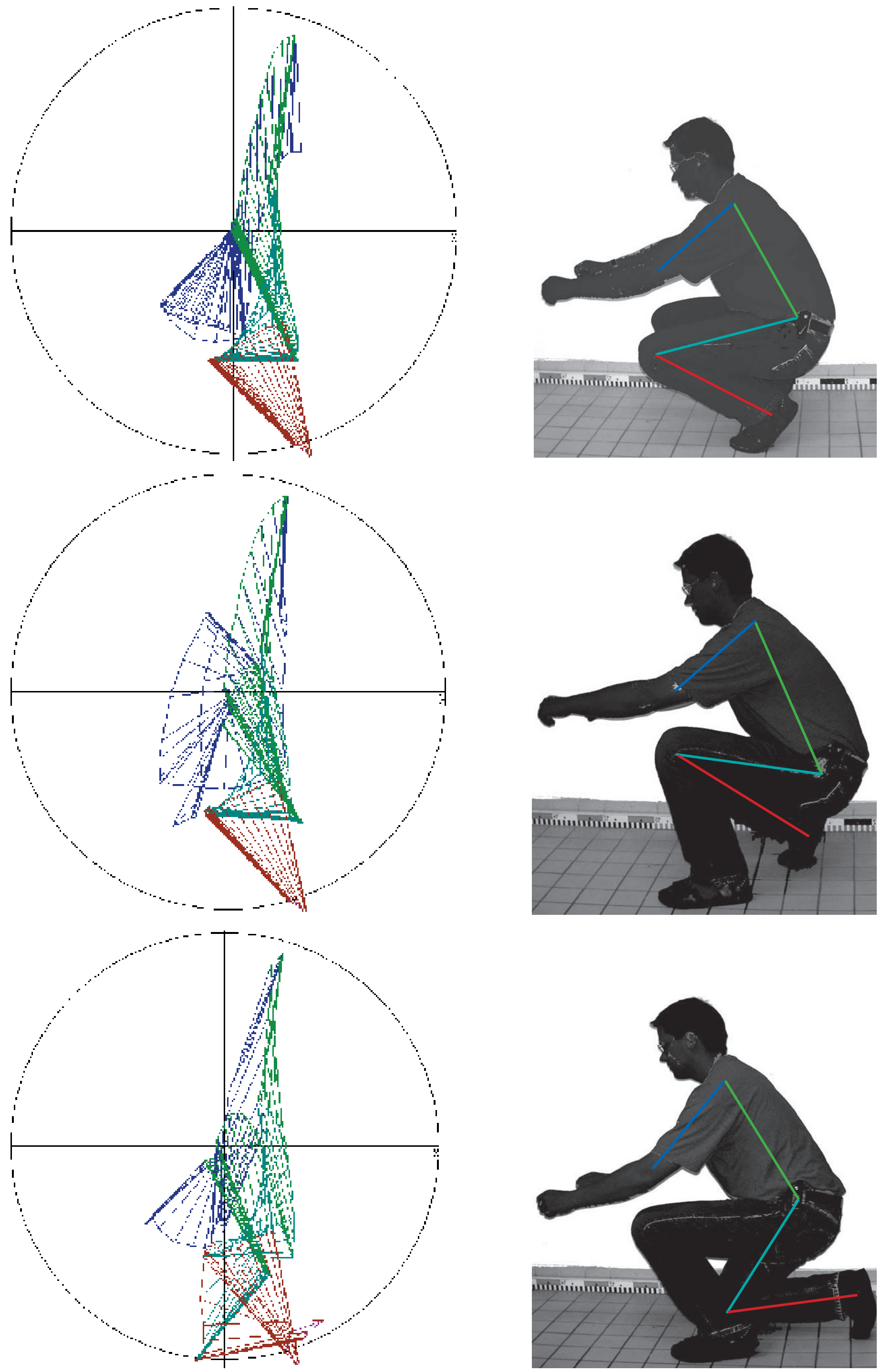


Fig. 3: Lateral movement illustration of the 3D frequency of angles of the positions 41 (top images), 51 (middle images) and 61 (bottom image) with the loading and unloading arm movement from a standing position 21.

| Comfort angle in a frequency of angles | Comfort value (opening angle) | |
|---|---|---|
| Trunk flexing angle | 30° (derived from the load) | |
| Trunk-thigh angle | 60° | |
| Knee angle | 17° | Values outside comfort areas for individual joints |
| Ankle joint angle | 70° | |
| Trunk-upper arm angle | 70° | |

Tab. 2: Opening angle for the task: lifting a load according to Babirat et al. (1998).

The body postures squatting with feet next to each other, position 41, squatting with one foot forward, position 51, and kneeling on one leg, position 61 are not within the range of comfort according to Babirat et al. (1998). The comfort angles of the arms and the head are within the comfort range. Problematic, however, are the comfort angles of the hip joint, the knee and the ankle joint, which clearly exceed the comfort range at full flexion. This is especially noticeable for the kneeling body posture, when the weight is shifted to the supporting leg and the knee aperture angle is clearly outside the limits.

The body postures with trunk flexions, position x2, show a flexion of 10° from the perpendicular up to 90°, with 0° defined as standing upright. In particular when unloading the washing machine, flexions of 90° and more could be observed. These extreme flexions exceed the comfort angle of 12° by far.
Comfort angles have not been measured for flexed and twisted body postures, position x4, not even by Babirat et al. (1998), nor for the ‚Kieler Puppe' (1977). It is problematic to ascertain comfort angles, because with the frequency of angles the trunk, the hip, the legs and the feet get twisted as well. So comfort angles cannot be specified in this thesis.

| Comfort angle in a frequency of angles | Comfort value (opening angle) |
|---|---|
| Trunk flexing angle | 30° (forward) |
| Trunk-thigh angle | 60° (supporting leg) |
| Trunk-thigh angle | 17° (non Supporting leg) |
| Knee angle | 70° (supporting leg) |
| Ankle joint angle | 70° (both sides) |

Tab. 3: Opening angle for the task: major trunk flexion according to Babirat et al. (1998).

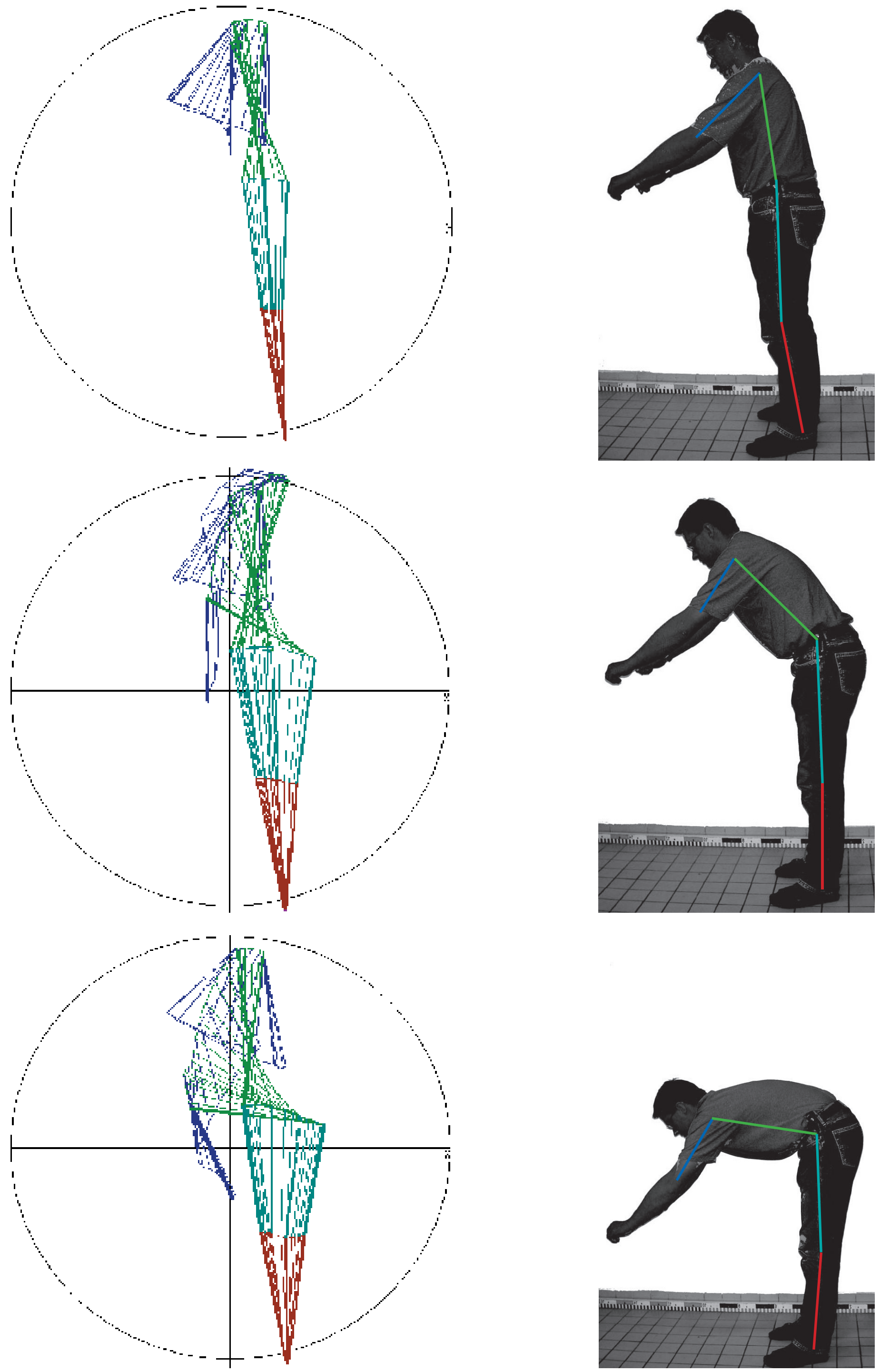


Fig. 5: Lateral movement illustration of the 3D frequency of angles of the position x2 with the loading and unloading arm movement from a standing position.

### 6.4 Discussion

The hypothesis that the FOB system would lead to other preferred comfort positions is falsified. The FOB system was used to acquire and analyse the frequency of angles and find out which angles fit within the comfort range described by Babirat et al. (1998). This did not lead to other results. For the interpretation of the comfort angles, images from the video analysis were used additionally. A drawback of this study is that no other accurate database about the variability within angle frequencies except Babirat's (1998) could be used for comparison. Another disadvantage is that the measured data could not be validated with significances. Only one subject was measured as the FOB system was in very demand and the research is time consuming, even though Chaffin et al. (1983) stated a very small variation in angles for several trials. For falsifying the hypothesis only one example is enough. However, it is possible that if we use extreme anthropometrics or unusual or very specific motion patterns another preference could be found. In this area there is urgent need for further research. The results could have been more precise if more than only one subject had been studied. Additionally, a cardboard washing machine could have been used to actually fill in laundry, instead of only re-enacting the body movements.

The FOB system shows that some postures were not acceptable according to the data of Babirat et al. (1998). The OWAS study shows that at the higher drum heights, upright body postures are frequently used with and without stepping position of the feet. Analysed with the FOB system, both body postures show frequencies of angles, which stay within the range of comfort according to Babirat et al. (1998). The opening height of 103 cm results in movements that are within the comfort range.
In general the postures 21 and 31 are within the comfort range. Though exceptions can occur for these basic upright postures, especially when subjects are unloading bigger pieces of laundry. The range of comfort can been exceeded for the task 'reaching forward' (Babirat et al., 1998). The comfort angles can be exceeded if subjects stretch the arm in front of their body above shoulder height, for example when unloading bigger pieces from the washing machine. Then, with the maximal extension of the arm, the comfort angle of the elbow-shoulder joint can be exceeded.
Furthermore, during extreme bending of the head laterally, ventrally or dorsally, the head/neck comfort angle can be exceeded. For this comparison reference to the comfort angles of the head/neck area of the ‚Kieler Puppe' was made.

| Comfort angle in a frequency of angles | Comfort value (opening angle) |
|---|---|
| Head / Neck * | 130° to 225° |
| Trunk-upper arm angle | 87° |
| Trunk flexing angle | 185° (5°to the back) |
| Elbow angle | 138° (derived from the aiming point) |
| Trunk-thigh angle** | 183° |

Tab. 4: Comfort angles of the body task: ‚movement of the upper extremities: reaching forward', *reference angle of the ‚Kieler Puppe' according to Helbig and Jürgens (1977) and ** reference angle of the task: ‚Leaning backwards for optical control when standing' according to Babirat et al. (1998).

The third exception is an extension of the trunk backwards, when the lumbar vertebral column can be overextended. These three cases are minor issues and were observed only once in the laboratory test.

For the lower drum heights, though, frequencies of angles appear, which do not correspond to the described comfort angles.
Flexions of the upper body especially when lifting heavy loads should be avoided in general (NIOSH, 1981). This is particularly relevant for body postures with flexed and twisted trunk, position x4.
Interestingly many people if asked, especially the elderly, prefer bending their upper body to squatting or kneeling (Scheffler, 2001). For a subjective rating this would make a difference, for the objective assessment e.g. the DIN 11226 (2000), both postures are rated equally as not recommended. Dieën et al. (1999) could not prove either that lifting with a squatting body movement is healthier than with a bending movement of the upper body.

The FOB analysis corresponds well with the subjective comfort rating of the subjects (chapter 3). So the objective and subjective evaluation of comfort show the same results. People clearly identified the higher drum heights, especially the height of 100 cm with a stool for the basket, with the best rating for loading and unloading.

**Acknowledgements**
I would like to thank the Industrial Anthropology Research Group at the Christian-Albrechts University of Kiel for supporting the 'Flock of Birds' tests, especially Stefan Schwab for his help with the measurements.

**References**

Ascension Technology Corporation (Ed.), 1996, The Flock of Birds TM, Position and Orientation Measurement System, Installation and Operation Guide – Stand-alone and Multiple Transmitter/Multiple Receiver Configurations, Vermont.

Babirat, D., Küchmeister, G., Nagel, K., 1998, Körpermaße des Menschen - Komfortbereich der Gelenkwinkel der Körpergelenke, in: Schriftenreihe der Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (ed.), -Forschung- Fb 818, Wirtschafts verlag NW, Dortmund/Berlin.

Bubb, P., 1992, Ergonomics in car development, VDI-Report 968, VDI-Verlag, Düsseldorf.

Chaffin et al., 1983, Volitional postures during maximal push/pull exertions in the sagittal plane, Human Factors, no. 25, pp. 541-550.

Dieën, J. v. et al., Stoop or squat: a review of biomechanical studies on lifting technique, Clinical Biomechanics, Vol. 14, Issue 10, December 1999, pp. 685-696.

DIN 33408, 1981, Körperumrißschablonen [Body contour templates], Deutsches Institut für Normung e.V., Beuth-Verlag, Berlin.

Dupuis, H., 1983, Erkenntnisstand zur Beurteilung der Körperhaltung bei der Fahrzeugführung im Sitzen [Knowledge on assessing sitting postures while driving a vehicle], Auftragsstudie für das Bundesamt für Wehrtechnik und Beschaffung, report no. 21. Bundesamt für Wehrtechnik und Beschaffung, Koblenz.

Hackenbroch, M., 1957, Grundlagen der Orthopädie, in: Hohmann, Hackenbroch, Lindemann (Ed.): Handbuch der Orthopädie, Band 1, Thieme Verlag, Stuttgart.

HdE, 1989, Handbuch der Ergonomie [Handbook of Ergonomics]. Bundesamt für Wehrtechnik und Beschaffung, Hanser-Verlag, Koblenz.

Helbig, K., Jürgens, H., 1977, Entwicklung einer praxisgerechten Körperumrißschablone des sitzenden Menschen, ed.: Bundesanstalt für Arbeitsschutz und Unfallforschung, Forschungsbericht Nr. 187, Wirtschaftsverlag NW, Dortmund.

International Institute for Standardisation, 2000, ISO 11226, Ergonomics – Evaluation of static working postures, International Standard, ISO 11226:2000E, International Organisation for Standardisation.

National Institute for Occupational Safety and Health (NIOSH), 1981, Work practices guide for manual lifting, Dept. Health and Human Services, Publ. No. 81-122, Cincinnati.

Rebiffé, R., 1969, Le siège du conducteur: Son adaption aux exigences fonctionelles et anthropometriques [The driver seat: Its functional and anthropometric adaptation], Ergonomics, 12(2).

Scheffler, C., 2001, Bewegungsmuster in Alltagssituationen, ed. Greil, H., Scheffler, C., Mensch – Technik – Umwelt, Forschungsforum Anthropologie, Schriftenreihe des Zentrums für Umweltwissenschaften der Universität Potsdam, Potsdam.

# 7 Pro and contra of the research

### 7.1 Introduction

In this discussion each measurement method used is checked for its suitability for the laboratory research as well as for the field study (part 1). Furthermore, the answers to the research question are discussed in this chapter (part 2) and general remarks are made regarding ergonomic research (part 3).

In this thesis, various measurement methods were used to collect ergonomic data for the loading and unloading of a washing machine. These were categorized in the following modules:

- Module 1: The anthropometric data, gender and age of the subjects.
- Module 2: The movement description with the modified OWAS- system extended for the module speed.
- Module 3: A standardised, subjective rating of the movement sequences and posture comfort of subjects.
- Module 4: The 3D movement measurement system 'Flock of birds'.

### 7.2 Were the four chosen modules useful?

The methods used were not innovative but were used frequently in other studies and have a proven suitability for this study (Koerhuis et al., 2003, Xiao, G. et al., 2004, Teraoka, T. et al., 2005, Eikhout, S. et al., 2005). OWAS was slightly modified for application in this study, because it is in fact developed for typifying work postures and the degree of bending the upper body was not taken into account. Suitable means in this case that the method supported the observation, which opening height and angle established the preferable postures.

Data on postures while loading and unloading a washing machine have not been described in literature before. Strangely enough, while all families in the whole world do their laundry. In every well-developed country a washing machine is used in the household as found in most areas of the world. Washing machine manufacturers can use these data to innovate their current design.

The data are about:

- the preferred washing height (chapter 3 and 4),
- speed at different heights (chapter 3),
- individual comfort ratings at different heights (chapter 3 and 4),
- correlations between anthropometric data and preferred body postures (chapter 3),
- proven laboratory data in a field test (chapter 4),
- correlations between age and comfort (chapter 5),
- elderly people with specific problems regarding loading and unloading (chapter 5), and
- analysis of the frequency of angles when loading and unloading a washing machine (chapter 6),
- solutions for the innovation of washing machines in the future (chapter 8).

The main overall conclusion is that the combination of the four established modules provided a complete insight into the applied ergonomics of washing, especially loading and unloading a washing machine.

### 7.2.1 Module 1 - Differences caused by anthropometrics, age or gender?

Within module 1, anthropometry, age and gender are measured. It was found in this study that anthropometry had less influence than gender and age. Movement patterns and special archetypes of loading and unloading could be found, but they were not related to anthropometric data. This result is not unusual compared to the findings in literature. Adjustability an adaptation to anthropometrics and body dimensions is more important for static postures (Vink and Kompier, 2005, Rhjin et al., 2005, Teraoka et al., 2005) than for body movements. Bronkhorst and Krause (2005) found for sitting behaviour in commuter trains that movement patterns were of more importance than anthropometry, Schröder (1997) ascertained differences in sitting behaviour depending on the used furniture, and Gransitzki (1994) and Busch (1998) identified behavioural patterns when getting in and out of a car as being independent of anthropometric measurements.

Differences were found in the laboratory test as well as in the field study for different age groups, older subjects who used 'comfortable' body postures at heights between about 120 and 100 cm more often than younger subjects. 'Comfortable' in this case means less physically demanding postures. When rating their comfort experience, elderly people more explicitly disliked loading and unloading the washing machine at a height of about 100 cm without a suitable place for their basket.

The only gender differences could be found for comfort rating when differentiating between older men and women. Elderly women clearly dislike unloading at a height of 60 cm and loading their machines at home, whereas older men criticise the comfort of unloading at a height at 80 cm. Overall, clear differentiation could not be found.
It was useful to measure anthropometrics, age and gender. Only with these measurements the influence of age and gender could be explained, or for anthropometrics rejected.

### 7.2.2 Module 2 - Was OWAS useful?

The OWAS system (Karhu, et al., 1977 and 1981) was used in module 2 for the exact analysis of body movements and postures in this study. It was modified to include the degree of flexion of the upper body as this could have an influence on the comfort angles analysed with the 'Flock of Birds' (FOB) sytem.
In retrospect it is to say, that the degree of flexion was not the determining factor for the categorisation of the body postures. It was expected to have a stronger influence as flexion has a strong relationship to the biomechanical loading of the back.
Additionally, the duration of the task of loading and unloading was measured to find out if it correlates with the analysed body postures. This duration measurement was very interesting, as the quickest completions of the task were done at lower heights when subjects used uncomfortable body postures more often. It is possible that people dislike these postures and speed up the process so that they remain in a specific posture only for a short time.



Speed or posture separately could not explain the most comfortable posture chosen. However, the combination better explains the most comfortable choice. People probably try to find an optimum between best posture and fastest handling.

Additional information from subjects was taken into account, e.g. "All of these movements seem to be uncomfortable for me. Normally I use a toploader". This motivation could have an influence on the subjective comfort rating. Influences of subjects' preconceptions could not be found, as subjects were still able to define their comfort experi-

ence according to the used comfort rating scale. It might be also positively influence by the design research, as the subjects had to compare all the new situations. This added information also qualified the comfortable body postures at drum heights of 110 and 120 cm as people commented on it as being too high.
Additionally, OWAS was combined with module 1, anthropometrics, age and gender, as it was assumed that the analysed body postures could be caused by correlations to individual body measurements, age or gender.
OWAS can normally be used to evaluate the analysed body postures according to their hazards on health as well. It was developed by OVAKO, a Finnish steel mill, to evaluate heavy labour tasks (Karhu et al., 1977) and also takes repetitive movements into account. Therefore, it was not used for the evaluation of movements in household tasks as the workload is not comparable.
The posture analysis with OWAS was suitable. An important benefit is that this system is affordable combined with the ease of use for the analysis of body postures and the outcome of precise results.

### 7.2.3 Module 3 - Why subjective rating of comfort?

So far it was measured if the product fits to the anatomy of the user. The effort of the user was analysed and the behaviour while using a product was recorded. Vink et al. (2005) describe that "the comfort of a product can be evaluated only by the user. A product itself never can be comfortable." They postulate, "the end user should be involved because [she or] he is the expert on [her or] his task."

With the subjective rating and verbalisation the user had the chance to personally rate her or his comfort sensation. In retrospect the used 6-point and 7-point scales should not have been changed between different experiments. Based on the first experiment the scale was optimised, causing the disadvantage that the comparability of the outcomes is reduced and can cause confusion for the reader.
Sometimes the objective assessment of a neutral researcher and the subjective rating can be contradictory (Christiansen, 1997). For example when lifting a heavy load, subjects rate lifting with a flexed upper body as more comfortable, while from an orthopaedic and ergonomic perspective, lifting from a squatting position is defined as healthier (Deutscher Verband für Physiotherapie, 2001). Regarding this point also much debate is going on in the literature (e.g. Kingma, 1998). In this study, however, the subjective comfort rating of the subjects underlined the objective measurements. This was especially interesting in the field study, when people gave their comfort rating with the new heights in their home setting. That study validated the laboratory study with the best height for the opening door of a washing machine being at 100 cm. It was very important in this case to provide people with a support for their washing basket and to do the experiment in a natural setting.
It was useful to take the subjective verbalisation of the subjects into account because "only the user can evaluate a product" (Vink et al., 2005). The users helped to evaluate a washing machine, which is easy to load and unload, according to their comfort sensation.

### 7.2.4 Module 4 - Is there an objective way of measuring comfort?

The simulation tool for three-dimensional recording, 'Flock of birds' (FOB), was used in this study. The 3D measurement system was used to analyse the frequency of angles within a body movement. These angle frequencies were used to find out the objective comfort of the body movements. Several authors (Bubb, 1992; Dupuis, 1983; Rebiffé, 1969) and organizations (DIN 33408, 1981; HdE, 1998) developed recommendations for the ideal joint angles, but all are defined for sitting in a passenger vehicle. For other than sitting postures, Babirat et al. (1998) is the only source for the variability of comfort angles. Due to accessibility and budgeting reasons only one subject was tested to demonstrate the angles of frequencies. That is why only limited conclusions can be drawn from it.

This objective way of measuring comfort overlaps with the results from the OWAS analysis as well as the subjective comfort rating. The objective data underline the subjective data of the comfort rating. The higher drum heights could be identified for loading and unloading as the heights with body postures where the comfort angles are within the comfort range. The body postures of the lower heights exceeded the limits for comfort described by Babirat et al. (1998). Only these results are not as precise for each body posture at all heights, while users could rate their comfort feeling at each height. The question is, is there any objective comfort? And is it worthwhile to put more effort into the research of this objective way of measuring comfort angles, when comfort is something only the users themselves can measure?
Was the objective way of measuring comfort with FOB system useful? The database

about comfort angles is very limited for this study. However, it underlined the outcome of the body analysis with OWAS and the subjective rating of the subjects that the height of about 100 cm is comfortable while the lower heights especially 60 cm cause discomfort.

**7.3 Main outcomes of this thesis**

Which location is preferable for the opening of the drum and does this fit into a household situation? The research hypotheses phrased in this thesis are answered in this chapter. These were:

- Movements and body postures are influenced by changes in design of the washing machine.
- Indeed the opening height and angle of the drum did influence the postures significantly.
- Body postures and anthropometric data are correlated.
- In this study the antropometrics did not have significant influence. Probably because the dynamics of the movement and because the differences were not that large.
- Body postures and age or gender correlate.
- It was shown that age has influence on posture choices.
- Physical stress or comfort problems can be influenced by design.
- The comfort ratings differed significantly between the different opening heights. It is assumed that unfavourable postures increase the physical loading, which is especially relevant for elderly and back pain patients.
- A relationship between comfort and typical body postures when loading and unloading a washing machine exists.
- Posture alone couldn't explain the comfort postures. It was found that the combination of posture and speed define the comfortable postures
- Relationships between subjective comfort and anthropometric data, age or gender occur.
- In this case also comfort and age were related. Other relationships were not found in this study.
- A relationship between speed of loading and unloading and comfort exists.
- Speed alone couldn't explain the comfort postures. It was found that the combination of posture and speed define the comfortable postures.

Based on these results, the washing machine can be innovated:

- People wash everywhere in this world, but no global washing culture exists. However, an innovative washing machine is needed in almost all parts of the world. Local needs vary, even within countries and in the same cultural back grounds (chapter 2).
- The most comfortable body postures appear at the opening height of 105 and 123 cm above the floor (chapter 3).
- The fastest heights to load washing machines are between 69 (with a strongly tilted opening) and 105 cm. The fastest unloading height was at 89 and 69 cm (with a strongly tilted opening) (chapter 3).
- The preferred washing height of subjects was 105 cm (chapter 3) for loading and unloading.
- In their home setting, the subjects rated their favourite height as 105 cm with a place for their basket (chapter 4).
- The height of 63 cm, which is similar to a standard washing machine, is disliked most (chapter 4).
- Older subjects from a home for the elderly use support strategies to do their washing task. Four different behavioural archetypes were found (Aids to support comfortable body postures, Aids for washing tools, Supportive body movement and Avoidance) (chapter 5).
- Older subjects use comfortable body postures at heights between 120 and 100 cm more frequently than younger subjects (chapter 5).
- Younger subjects ranked the drum angle as clearly positive, but older subjects rated it as even more beneficial (chapter 5).
- Elderly people dislike loading the washing machine at a height of 100 cm without a place for their basket, and elderly women are inclined to feel uncomfortable when unloading at a height of 100 cm without a stool for a basket (chapter 5).
- Older women clearly dislike unloading at a height of 60 cm and have a tendency to criticise loading their machines at home (chapter 5).
- Older men instead are inclined to criticize the comfort when unloading at a height of 80 cm (chapter 5).
- The FOB study showed that, at the higher drum heights, upright body postures are used with and without a stepping position of the legs. Both body postures show frequencies of angles, which stay in between the range of comfort angles (chapter 6).

| Pro | Contra |
|---|---|
| - Laboratory and field studies show the same results<br>- Subjective (comfort) and objective (posture/ speed) data point the same optimal opening height<br>- Used methods have been proven useful in other settings<br>- Ergonomic and comfort data about washing for loading and unloading are now available<br>- Assumptions about discomfort in washing are confirmed<br>- Concrete data available for redesign the washing machines<br>- Answering Siemens Home Appliances questions<br>- Dynamic analysis and OWAS point in the same direction | - Used methods each have their disadvantages (validation is limited)<br>- Comfort rating scales varied and limit comparability<br>- Sample of study was recruited in Germany, which gives uncertainty about extrapolation to other cultures<br>- Studying the dynamics needs further research<br>- Long term effects on the back complaints and supporting the independency of elderly of favourable washing should be studied further |

Tab. 1: Summary of general pro and contra of the research done in this thesis

For the lower drum heights, though, frequencies of angles appear which are not in conformity with the described comfort angles. Many people, especially the elderly, preferred flexing their upper body to squatting or kneeling. For a subjective rating this would make a difference, for the objective assessment, e.g. the DIN 11226 (2000), both are rated equally as not recommended (chapter 6).

In general terms this study also had its drawbacks. In table 1 an overview of advantages and drawbacks of this study is given. Especially the validation of the used methods and the long-term effects of the improved opening height need attention in future research. The main advantages of this study are that various methods point the same direction. The laboratory as well as the field study shows the same ideal height. The objective and subjective method both show the same height and this resulted in clear guidelines, which could be made regarding the ideal opening height.

**References**


Bronkhorst, R., Krause, F., 2005, Designing Comfortable Passenger Seats, in: Vink, P., Comfort and Design, CRC Press, Boca Raton.

Bubb, P., 1992, Ergonomics in car development, VDI-Report 968, VDI-Verlag, Düsseldorf.

Busch, N., 1998, How to exit a car, in: Proceedings of the 4. International Congress on Physiological Anthropology, Zagreb.

Busch, N., 2000, Thermography as a Method for Describing Different Processes of Thermoregulation, in: Proceedings of the 5. International Congress on Physiological Anthropology, Seoul.

Christiansen, K., 1997, Subjective Assessment of Sitting Comfort, Coll. Anthropol. 21, pp. 387-395.

DIN 33408, 1981, Körperumrißschablonen [Body contour templates], Deutsches Institut für Normung e.V., Beuth-Verlag, Berlin.

Deutscher Verband für Physiotherapie, 2001, quoted in: Scheffler, C., Bewegungsmuster in Alltagssituationen, ed. Greil, H., Scheffler, C., Mensch – Technik – Umwelt, Forschungsforum Anthropologie, Schriftenreihe des Zentrums für Umweltwissenschaften der Universität Potsdam, Potsdam.

Dupuis, H., 1983, Erkenntnisstand zur Beurteilung der Körperhaltung bei der Fahrzeugführung im Sitzen [Knowledge on assessing sitting postures while driving a vehicle], Auftragsstudie für das Bundesamt für Wehrtechnik und Beschaffung, report no. 21, Bundesamt für Wehrtechnik und Beschaffung, Koblenz.

Eikhout, S. et al., 2005, Comfort effects of Participatory Design of Screwdrivers, in: Vink, P., Comfort and Design, CRC Press, Boca Raton.

Gransitzki, K., 1994, Biomechanics of Entering a Car, in: Proceedings of the 2. International Congress on Physiological Anthropology, Kiel.

HdE, 1989, Handbuch der Ergonomie [Handbook of Ergonomics]. Bundesamt für Wehrtechnik und Beschaffung, Hanser-Verlag, Koblenz.

Karhu, O. et al., 1977, Correcting working postures in industry, A practical method for analysis, Applied Ergonomics 8, no. 4, pp. 199-201.

Karhu, O. et al., 1981, Observing working postures in industry: Examples of OWAS application, Applied Ergonomics 12, no. 1, pp. 13-17.

Kingma, 1998, Challanging gravity, Vrije Universiteit, Amsterdam, PhD thesis

Koerhuis, C. et al., 2003, Neck mobility measurement by means of the Flock of Birds electromagnetic tracking system, Clinical Biomechanics, No. 18, pp. 14-18.

Rebiffé, R., 1969, Le siège du conducteur: Son adaption aux exigences fonctionelles et anthropometriques [The driver seat: Its functional and anthropometric adaptation], Ergonomics, 12(2).

Rhijn, J. et al., 2005, Productivity and Discomfort in Manual Assembly Operations, in: Vink, P., Comfort and Design, CRC Press, Boca Raton.

Schröder, I., 1997, Variations of sitting posture and physical activity in different types of school furniture, Coll. Antropol. 21, pp. 397-403.

Teraoka, T. et al., 2005, Comfort in Furniture at Home, in: Vink, P., Comfort and Design, CRC Press, Boca Raton

Vink, P., Overbeeke, C., Desmet, P., 2005, Comfort Experience, in: Vink, P., Comfort and Design, CRC Press, Boca Raton.

Vink, P., Kompier, M., Reducing Discomfort in Office Work, in: Vink, P., Comfort and Design, CRC Press, Boca Raton

Ziao, G.-B. et al., 2004, Study on Musculoskeletal Disorders in a Machinery Manufacturing Plant, Journal of Occupational & Environmental Medicine, no. 46(4), pp. 341-346, April.

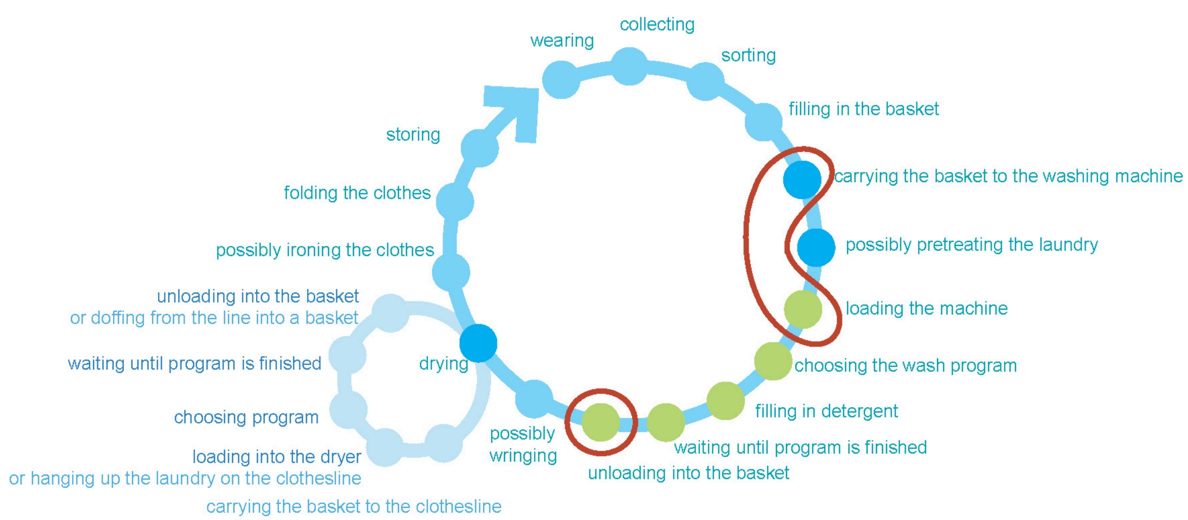



Fig. 1: Washing cycle with a drying sub-cycle (see chapter 1). The green steps mark the tasks, which involve the washing machine. The darker blue steps indicate steps, which might involve the washing machine. The pale blue sub-cycle illustrates the drying cycle.

# 8 Translating the knowledge into design

## 8.1 Introduction

As is shown in previous chapters in nearly every household worldwide, people do their laundry, though local circumstances, patterns, automation or washing machine constructions vary. Washing machines are often used as an example for everyday things people have problems with (Norman, 1988). Most of the time these problems focus on user interface issues. However, Steve Jobs (2005) searched for an innovative washing machine in terms of good usability and design. So, actual washing machines have room for improvement, also in design. Strangely enough, studies about innovations on doing the laundry are very limited (Whirlpool, 2001; Philips, 2003). James Dyson (2002) invented a washing machine with two cylinders rotating in opposite directions, but focused on a better result while using fewer natural resources. Todman (2001), Whirlpool's European president, is examining new ideas trying to achieve innovation in the field of fabric care, because the customer demands it. Users have new needs, tastes and preferences, which can only be fulfilled by bringing new exciting and valuable washing machines to the market.

## 8.2 Possibilities in the washing cycle

The washing cycle described in chapter 1 offers the possibility to examine each step for possible innovations. These possibilities for innovation are marked in the cycle. The immediate possibilities for innovation are marked red, future opportunities are marked orange and yellow marks indicate possibilities for future detergents, technology or automation.



As pointed out in the washing cycle, some of the possibilities are short-term, others are medium- or long-term innovations. In the following, the results of this study will be implemented in design concepts. Additionally, new user needs are pointed out and a short insight into the long-term future is given.

## 8.3 Implementation of the results

Nowadays European washing machines offer a very good washing result (P&G, 2005).

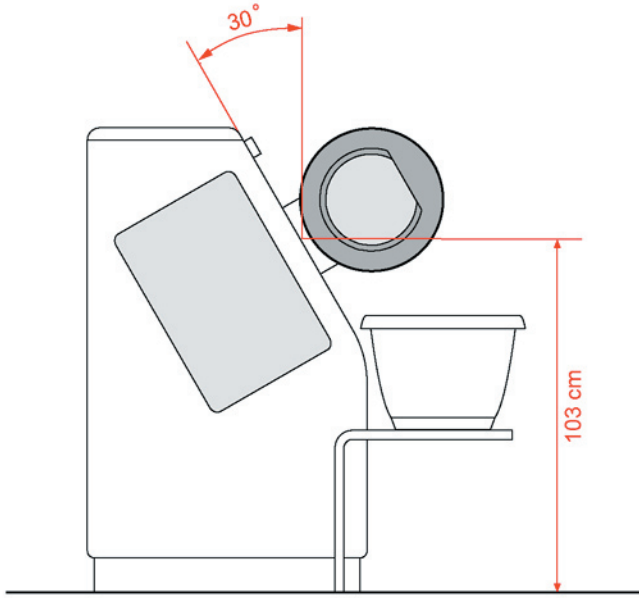



Fig. 2: Outline of a washing machine taking the basic findings of this research into account.

Chapter 2 shows that these machines fit within the washing habits of the majority of users worldwide. But as can been seen in chapter 3, 4, 5 and 6 washing machines could fulfil the need for more comfort and ergonomics. The outcome of this study was (see figure 2):

- The tilted drum, which gives the advantage of comfortable access and the ability to look into the drum.
- The optimal height of about 100 cm, which results in comfortable body postures
- and a possibility to place the basket directly underneath the drum opening.

Building on these results, a number of washing machines concepts were created (see figures 7, 8 and 9).

### 8.3.1 Ergonomic and comfort concepts

The findings made in this research can be introduced to the market in near future. First of all there is a consumer demand for these concepts. They would make loading and unloading more comfortable. Introducing a washing machine into the market that fulfils a demand of the users could win market share for the manufacturer.
Secondly, parts of the innovation suggested in this thesis can be found worldwide. The Japanese company National already researched the technology for building a drum with

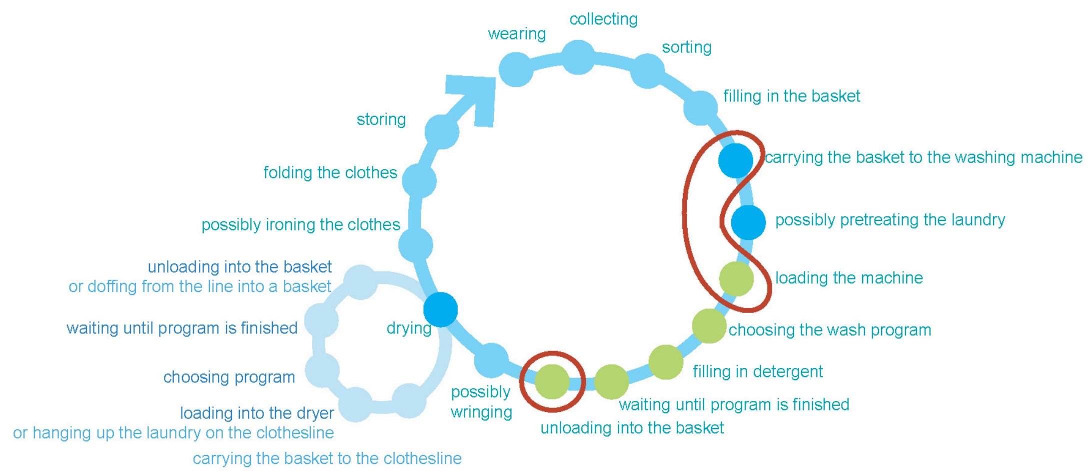



Fig. 3: Washing cycle with new ergonomic and comfort improvement areas

an implemented angle. They sell this innovative machine with the proposition that the whole family, including wheel chair users can use it (see figure 4). Meanwhile Bosch Siemens home appliances build the washing machine, which was centre of this study. They advertise it as back friendly washing without bending. This proves that the ideal washing machine is feasible. However, the total concept is not build yet. The combination of the tilted drum, the ideal height and a basket holder still needs to be made.
Whirlpool advertises a washing machine, which is elevated on a socket and built in. The space underneath the machine has a drawer for storage, for example for washing powder or dirty clothes. It is built-in like a refrigerator in today's kitchens at a reachable level.


Fig. 4: Advertising by the Japanese company National for a washing machine with a tilted drum (left), Bosch Logixx World-washer with tilted drum advertised as washing without bending.

With this machine, though, users will have to overcome the increased vertical distance of about 30 cm between washing basket and drum when loading and unloading.
The results of the real life test in this thesis show that a place for the basket is important as this was rated significantly better than without basket. That is why solutions have to be found on how and where to place the washing basket.
As a first solution, the machine could offer hooks, magnets or a table to either hang or place the basket on, directly underneath the opening.
For the future, the basket could be used for collecting the washing first, then carrying or rolling it to the washing machine, then placing it into the drum in one go, by either being the drum itself or an insert or cartridge.
So, parts of the ideal products are feasible and available. However, a complete new concept of a washing machine according to this study still needs to be developed.

### 8.3.2 Design concepts

To support the washing machine industry some concepts have been developed and drawn to show possibilities of integrating the tilting, washing basket support and higher opening. Based on the basic findings that the height of 103 cm was most appreciated, combined with a drum angle of 30° and a place for the washing basket, new concepts for washing machines were created.
Thus, the new ergonomic concepts can be realised in the short term and would fulfil the users' need for comfort and better ergonomics. People who wash often, elderly people, back pain patients or even service personnel would profit tremendously from these changes. Depending on the design concept these washing machines have a worldwide market as it fits in the washing process found on most continents. The concepts in figure 7 and 8 require space, concept in figure 9 though can be smaller as well and would fit into smaller flats, which are found mainly in Asian markets. These design concepts might be implemented in the near future.
When people use separate dryers the same principle of the height, drum tilting and basket support can be recommended. In this case wet laundry has to be loaded (in stead of unloaded when washing) and the dry laundry gets unloaded. Of course it would be good if this has effects on the body postures.

Fig. 5: The results of the Elevated washing machine by Whirlpool, built-in concept for the kitchen area

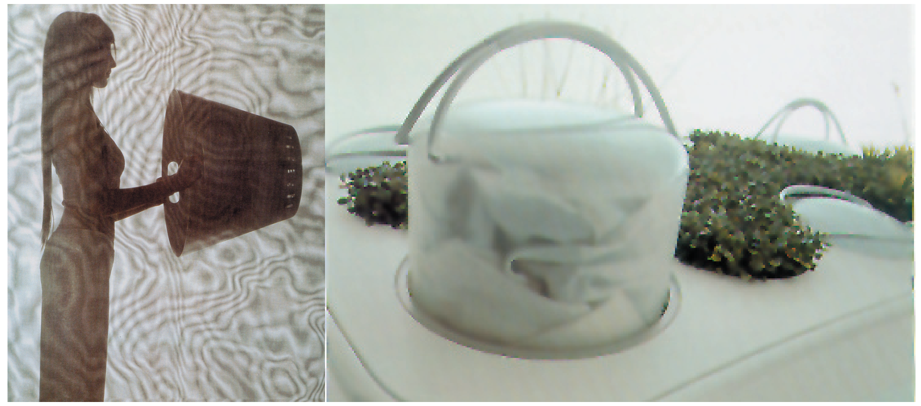


Fig. 6: Images of concept studies for Whirlpool washing machines (2001) with exchangeable washing baskets

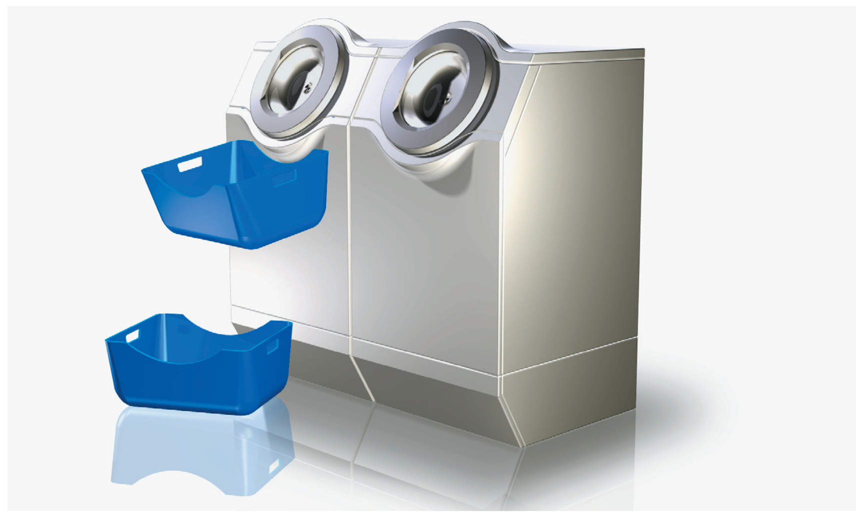


Fig. 7: Basic washing machine rendering concept with an opening at 103 cm and a 30° angle. This machine could be integrated and built in.

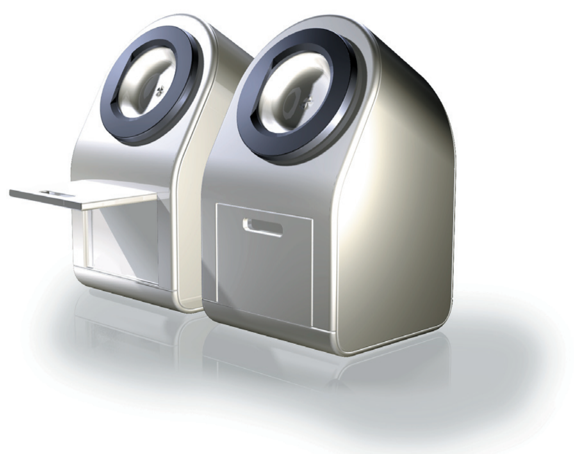


Fig. 8: Washing machine rendering concept with an opening at 103 cm and a 30° angle. This machine could be built into a kitchen, bathroom or other location. It could have a storage space underneath.

## 8.4 New needs

So far, washing machines have only one task to fulfil: clean the laundry with a focus on the washing result. Looking at the washing cycle, more steps are included than cleaning. Some steps in the washing cycle are a hassle for users or even troublesome. Is it possible that a washing machine could fulfil some of these tasks?

- Before people start to wash, the laundry has to be collected. So what if the washing machine had a laundry chute or container, where dirty laundry is collected?
- This could be combined with the task of sorting the laundry. There could be two options. Either the washing would not be sorted at all. The washing machine would have a gentle, caring and also efficient washing cycle (with possible new technology), so that all the pieces could be washed together. Or, in the nearer future, the machine would sort the laundry itself according to RFID chips (Radio Frequency Identification) integrated into the washing labels.
  Siemens and designafairs thought about this scenario, too. Toussaint (2003)

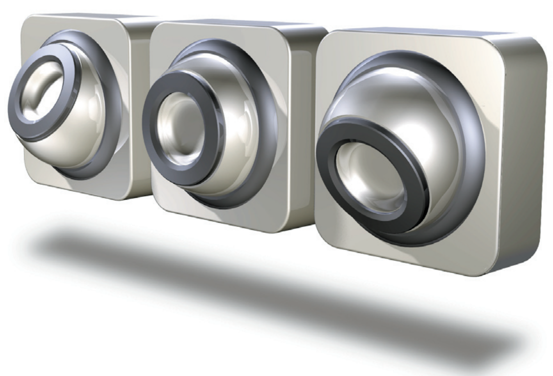


Fig. 9: Washing machine rendering concept with an opening at 103 cm and a 30° angle. This machine could be mounted on the wall. With an adjustable drum opening, it could offer easy access for loading and unloading.

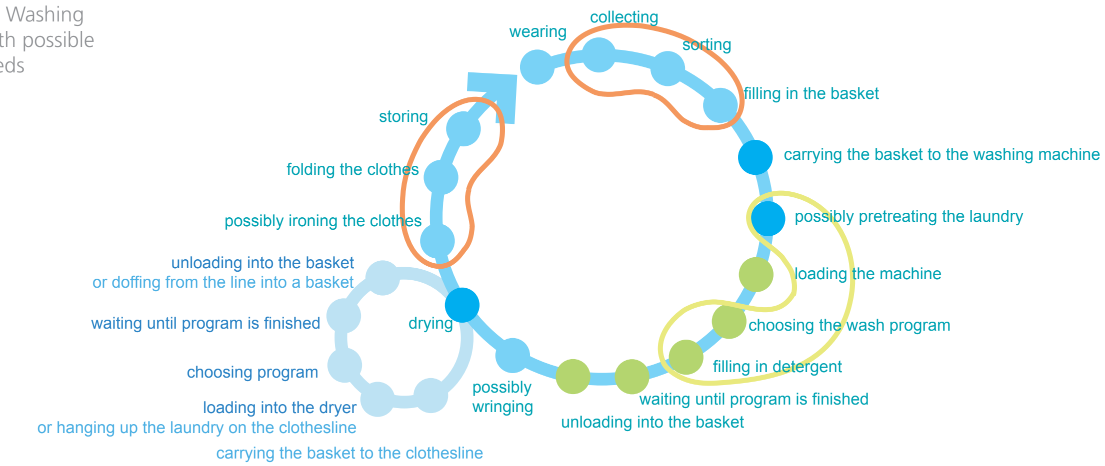



Fig. 10: Washing cycle with possible new needs

called it an ideal solution if the washing machine recognised the laundry and chose the appropriate programme for it. He imagined a communicating machine, which talks to the laundry, "This is a silk shirt. I should not centrifuge it". When sorting is eliminated, sorting know-how is not necessary anymore and fewer mistakes can be made.

- If the washing is collected and sorted directly in the machine, then at least the washing basket is not necessary for loading anymore. If baskets are still used, how could a basket be integrated into the machine?
- As figure 6 shows, baskets could be used as containers that can be lowered directly into the drum. The container might have different sizes, shapes, proportions or locations.
- Several washing machine manufacturers already examined how to integrate washing powder or other detergents into the machine. Depending on the degree of staining, water hardness, type of fabric and amount of filling, the machine automatically selects the right kind and amount of detergent. Additionally, the degree of water pollution can be detected. In this way, water can be reused and machines are more environmentally friendly.
- Some machines already have integrated dryers, but not all fabrics can be dried with a tumble dryer. For unloading the machine, dry or wet, a basket is necessary again. Even though many users let the washing drop into the basket, a smart way to integrate it into the machine has to be found.
- Ironing and folding are tasks people find bothersome. Siemens already offers wrinkle protection, which is still a far way from ironing. These remain issues, as well as sorting the clothes into cupboards, which have to be tackled in the far future.

## 8.5 Outlook

In the future, people will have more needs when washing. Some of them may be possible soon, but many possibilities may only be feasible in the long-term.

- Washing is still a task that is mainly done by women (Volkskrant, 2004). Though the demands of modern society can lead to changes, as men and women are sharing household tasks more and more. So washing machines cannot rely on old knowledge about washing. They have to be more preventive and be considered as more caring and intelligent machines. Agudelo (2004) developed a concept for a washing machine especially for men, which met their preferences for playful, technical gadgetry, but was also simple in its functions.
- When the washing task was still a time-consuming procedure (see chapter 2), it was also social. People shared information or gossip while they were doing their laundry. Washing machines could recall this experience of past generations. They could provide a social environment where people could do their laundry while simultaneously interacting with each other and engaging in other activities.
- The future of fabric care design could engage more senses to enhance the fabric care experience, as the emotional side of products became a sales argument (Overbeeke and Hekkert, 1999; Desmet, 2003). Nowadays, the appearance of a washing machine is rational: a white box. But people describe a fascination about washing when observing the water and the colours in a rhythmic motion.

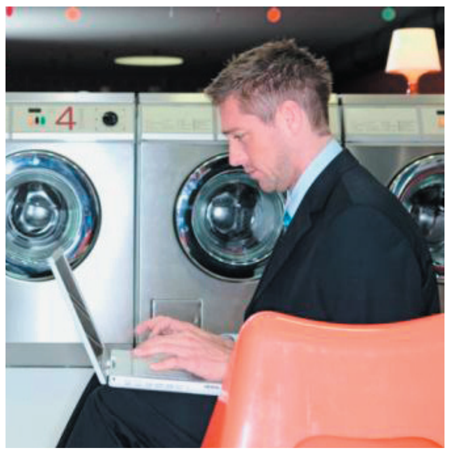


Fig. 11: Washing machine for men could contain washing know how and could be more entertaining

Fig. 12: Washing machines could facilitate interactive and social behaviour

Washing can provide people with sensual comfort through the smell of cleanliness and freshness, as well as the feeling of softness and the satisfaction of having done something good to take care of the family.
- Washing machines could provide alternatives to the traditional white box. They could represent people's lifestyles, cultural trends and preferences of living. Future washing machines will not be hidden away anymore, but will be present and interactive in an architectural space (Whirlpool, 2001).
- Today the basic technical formula for washing is still water in a container, agitation and detergent. But fabrics are changing. Future textiles might contain electronics (electrotextiles), various layers, each with particular functions. Then washing technology may have to clean without water, detergent or agitation, but with alternatives such as vacuum, fibre separation, ultrasonic cleaning. So completely new washing concepts have to be developed.

## 8.6 Something to think about

Comfort is a value in everyday life. People are looking for tools and appliances to make their life easier. Building on ergonomic variables of scientifically determined comfort, elements like psychological perception, sensual experience, emotions and pleasure are also driving the feeling of comfort.
Steve Jobs (2005) and his family took some time to decide on a new washing machine, but this decision gave him more pleasure than he expected, "I got more thrill out of them than I have out of any piece of high tech in years."
Household appliances, especially washing machines, have been neglected for a long while. A washing machine, which addresses the users' needs, based on this new ergonomic concept and combined with an innovative design can make consumers very

excited, as the example of Steve Jobs shows. An innovative concept is not only good for the user, but also a promising chance for the manufacturer.

**Acknowledgements**

J. Keunecke I would like to thank heartily for the thoughtful illustrations of the washing machine concepts building on and challenging the new ergonomic requirements from this study and proving that ergonomists and designers can work together.

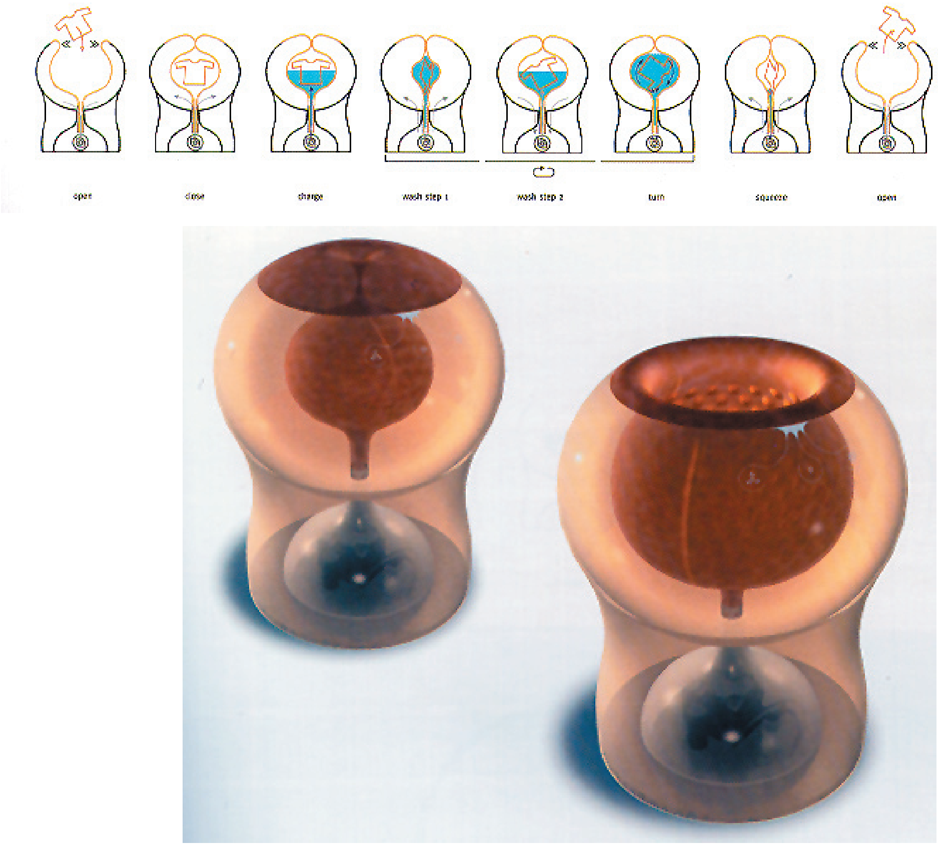



Fig. 13: Washing machine concept by Whirlpool building on a more gentle and caring way of washing (top image), expressed in an organic innovative shape (bottom image) (Whirlpool, 2001).

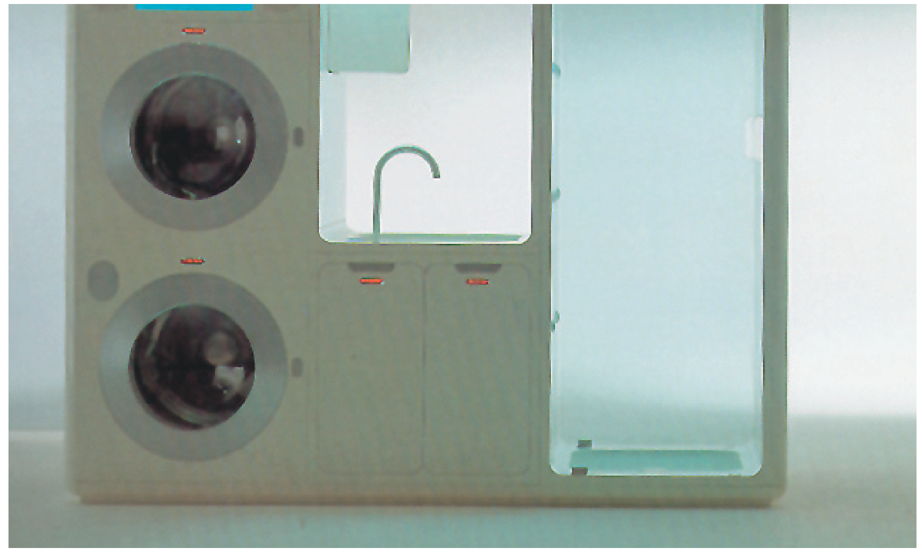


Fig. 14: Washing machine concept by Whirlpool integrated into interior architecture (Whirlpool, 2001).

**References**

Agudelo, N., 2004, October, Washing machine for men – Project Domus Home Products, Faculty Industrial Design Engineering, Delft University of Technology.

Busch, N. and Christiaans, H., 2006, Doing the laundry - different strokes for different folks, Paper submitted to the Design Journal

Desmet, P., 2003, Measuring emotion; development an application of an instrument to measure emotional responses to products, in: Blythe et al. (eds.), Funology: From Usability to Enjoyment, Kluwer Academic Publishers, Dordrecht.

Jobs, S., 2005, quoted in Young, J. and Simon, W., Icon Steve Jobs: The Greatest Second Act in the History of Business, John Wiley & Sons, Indianapolis.

Norman, D., 1988, The Psychology of Everyday Things, Basic Books, New York.

Overbeeke C., Hekkert, P., 1999, eds.: Proceedings of the 1st International Conference design and Emotion, University of Technology, Delft

Procter & Gamble, 2005, in: http://www.scienceinthebox.com/en_UK/research/washhabits_en.html

Philips Design, 2003, newvaluenews, number eighteen, October.

Todman, M., 2001, quoted in: project f – fabric care of the future, Richard Eisermann (ed.).

Toussaint, C., 2003, quoted in: designafairs - Designing Easy Interfaces, Siemens publication journal: Pictures of the future, Fall 2003.

Volkskrant, 2004, Huishoudelijke taken verdeeld tussen mannen en vrouwen, September, No. 28.

Whirlpool, 2001, project f – fabric care of the future, Richard Eisermann (ed.).

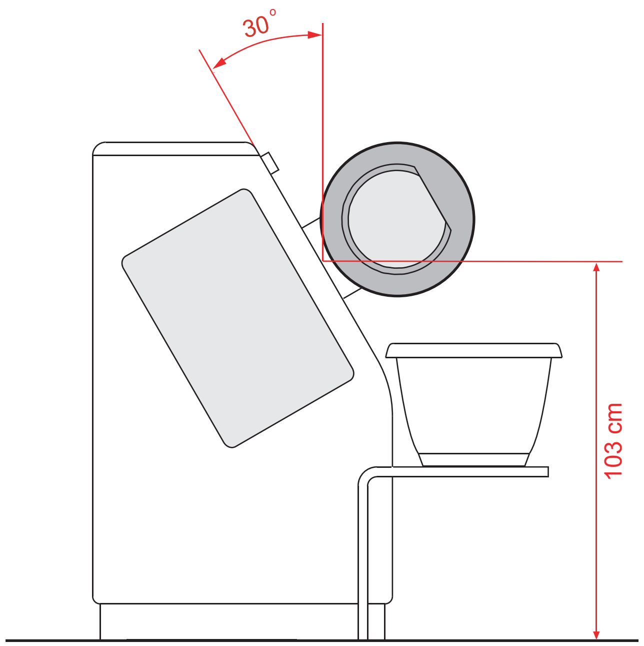



Fig. 1: Outline of a washing machine taking the basic findings of this research into account.

# 9 Summary

People do the laundry all over the world. About 500 million washing machines are in use at the moment. To reduce the heavy workload, washing machines were invented about 100 years ago, but the principle of cleaning with water, agitation and detergent is still the same. 50 years of innovations led to a reduction in water, energy and detergent consumption of washing machines. Moreover, the interface became easier to understand and to use. However, the overall usage of the machine is still the same.
There is some evidence found that washing can be uncomfortable or even hazardous for the elderly, people with back pain, people who do the laundry very frequently such as people washing for a large family, or service personnel. After a first exploration of the subject in literature, it became clear that there is hardly any scientific research in this area. Innovations are minimal as well. In fact, the design of washing machines looks almost the same as some 50 years ago – a white box with an opening height of 60 cm above the floor. The main reason for starting this study was that Siemens Household Appliances wanted to find out whether their consumers would appreciate an innovative washing concept and whether it was worth it to develop a new washing machine.

As there seems to be a need for innovation, this thesis aims to answer the following main questions:

- Does the opening height influence movements and body postures while loading and unloading a washing machine?
- Are body postures and anthropometric data correlated?
- Do body postures and age or gender correlate?
- Do physical stress or comfort problems occur?
- Is there a relationship between comfort and typical body postures when loading or unloading a washing machine?
- Are there relationships between subjective comfort and anthropometric data, age or gender?
- Based on these results, can a washing machine be innovated?
- Could this innovation be successful in other cultures as well?

Four research modules were used for the research:

- Module 1: The anthropometric data, gender and age of the subjects to examine whether coherences between movements and body postures exist.
- Module 2: The movement description with the modified OWAS-system to analyse and classify observed movements and to document frequencies of body postures.
- Module 3: A standardised, subjective rating of the movement sequences and posture comfort of subjects for the evaluation of comfort.
- Module 4: The 3D movement measurement system 'Flock of Birds' to identify comfort angles and strains within a movement sequence.

It was studied how washing differs around the world, depending on the washing machine design. This was done to find out where in the world an innovation would fit into the washing process.
In a laboratory research, loading and unloading the washing machine with laundry was observed using a height- and angle-adjustable washing machine mock-up. Additionally to an analysis of the observed body postures, the efficiency of loading and unloading was measured with speed recordings. The subjects had to rate their subjective comfort experience. Correlations between anthropometrics, age and gender and body postures were calculated.

In a real life test, the results of the laboratory study were verified in people's home settings when loading and unloading a real washing machine on an elevated platform. They compared this set up with the usage of their own washing machine. The comfort experience was measured.

Special attention was given to the older population. Body movements, postures and comfort were analysed for loading and unloading a washing machine. Part of this study focused on how the elderly can fulfil this task. First, elderly persons were observed in a senior residence while they were using the washing machine along with the problems that came up. Secondly, data of the previous two studies were analysed with special attention for the elderly.

The analysed body postures and movements during loading and unloading were recorded by the 'Flock of Birds' system. The analysed comfort angles were compared with literature for an objective comfort assessment.

**This approach led to the following results:**
People wash everywhere in this world, but no global washing culture exists. Local needs and habits vary, even for countries close to each other (chapter 2). It was found that the new machine could fit into the washing process almost around the world. However, special attention is needed for Asia as the machine should fit in small apartments, be mobile and have a special colour (e.g. pink in parts of China).

The most comfortable body postures appear at the opening height of 105 and 123 cm above the floor (chapter 3). The most efficient and fastest heights for loading are between 69 (with a strongly tilted opening) and 105 cm. The fastest unloading height was at 89 and 69 cm (with a strongly tilted opening) (chapter 3).
The preferred washing height of subjects was 105 cm (chapter 3) for loading and unloading.
In their home setting, the subjects rated their favourite height as 105 cm with a place for their basket (chapter 4). The height of 63 cm, which is closest to a conventional washing machine, is disliked most (chapter 4).

Older subjects from a senior residence use support strategies to do their washing task. Four different behavioural archetypes were found (chapter 5).
Older subjects use comfortable body postures at heights between 120 and 100 cm more frequently than younger subjects (chapter 5) and rated the drum angle as even more beneficial (chapter 5) than younger subjects. Elderly people dislike loading the washing machine at a height of 100 cm without a place for their basket (chapter 5). Older women clearly dislike unloading at a height of 60 cm and have a tendency to criticise loading their machines at home (chapter 5).

The 3D study showed that body postures were used at higher drum heights, which showed frequencies of angles that stay within the range of comfort angles (chapter 6). For the lower drum heights, though, frequencies of angles appeared which are not in conformity with the described comfort angles.

With the use of these four modules, a complete research of all aspects regarding the ergonomic and emotional factors of loading and unloading a washing machine was given. While recent research focuses on washing machine interfaces, this study was based on ergonomics and comfort, delivering data, which are new to the field of white-goods. This research provides a basis for many conclusions on health and comfort for the elderly, people with back pain and service personnel.

Moreover, it provides a basis for innovation, which can begin immediately. Comfort is a value in everyday life. People are looking for tools and appliances to make their life easier. Building on ergonomic variables of a scientifically determined definition of comfort, elements like psychological perception, sensual experience, emotions and pleasure are shown to define the feeling of comfort as well.

Household appliances, especially washing machines, have been neglected for a long time. A washing machine, which addresses the users' needs, based on this new ergonomic concept and combined with an innovative design, can make consumers very excited. An innovative concept is not only good for the user, but also a promising market opportunity for the manufacturer. The new washing machine should have:

- An opening height with the middle of 105 cm above the floor,
- a 30 degrees tilted drum and
- a possibility to position the basket heightened.

The tilted drum and heightened opening are now on the market, which shows its technological feasibility. The combination of all three demands is not found, but has a great potential as it fits in the washing process of users almost worldwide.

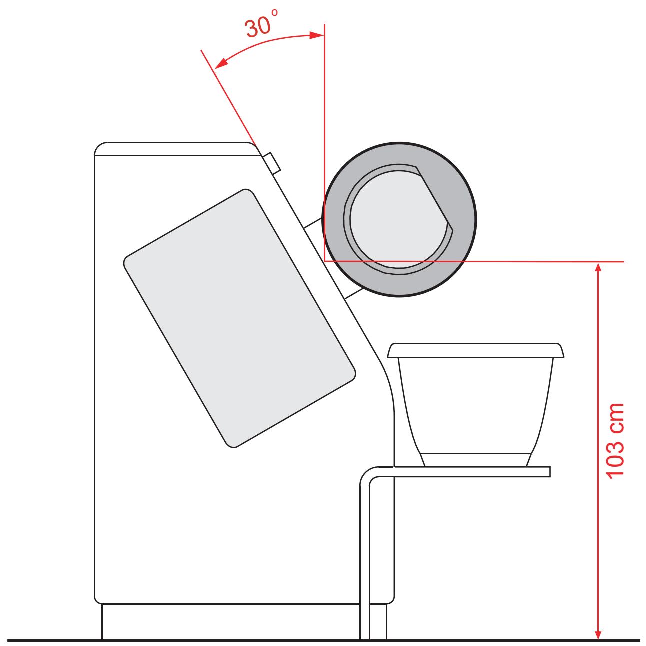


Fig. 1: Tekening van de wasmachine met nieuwe ergonomische concept.

# Samenvatting

Over de hele wereld doen mensen de was en er zijn 500 million wasmachines in omloop. Om dit zware werk makkelijker te maken, is 100 jaar geleden de wasmachine uitgevonden, maar het principe van het wassen met water, agitatie en wasmiddel is nog steeds hetzelfde. Sinds 50 jaar hebben innovaties geleid tot een reductie in water-, energie- en wasmiddelverbruik. Bovendien is de interface of schakelklok ondertussen makkelijker te begrijpen en te gebruiken. Maar al met al is het gebruik van de wasmachine gelijk gebleven.

Het laden of lossen van wasmachine gaat gepaard met bukken. Dat is oncomfortabel en leidt tot hoge belasting van de rug bij ouderen, mensen met rugklachten en mensen die heel vaak de was moeten doen, bijvoorbeeld in een groot gezin of in de dienstverlening. Na bestudering van de vakliteratuur werd duidelijk dat er amper wetenschappelijk onderzoek op dit gebied is. De innovaties zijn ook minimaal. Eigenlijk ziet het design van een wasmachine hetzelfde uit als 50 jaar geleden – een witte doos met het midden van de opening 60 cm boven de vloer.

De beweegreden achter deze studie was dat Siemens Household Appliances wilde weten of hun klanten een innovatief wasconcept zouden willen en of het de moeite waard was om een nieuwe wasmachine te ontwikkelen.

Dit proefschrift behandelt de volgende vragen:

- Beinvloedt de hoogte en hoek van de wasmachinetrommel de bewegingen en lichaamshoudingen bij het laden en ontladen van een wasmachine?
- Hangen lichaamshoudingen en antropometrische data samen?
- Zijn lichaamshoudingen en leeftijd of geslacht aan elkaar gerelateerd?
- Treden fysieke stress of comfortproblemen op?
- Is er een relatie tussen comfort en typische lichaamshoudingen bij het laden en ontladen van een wasmachine?
- Is er een relatie tussen subjectief comfort en anthropometrische data, leeftijd of geslacht?

- Kan een wasmachine vernieuwd worden op basis van deze resultaten?
- Zou deze innovatie in andere culturen ook succesvol zijn?

Vier onderzoeksmodules werden voor dit onderzoek gebruikt:
- Module 1: De anthropometrische data, geslacht en leeftijd van de testpersonen werden onderzocht.
- Module 2: De beschrijving van de bewegingen vond plaats met het gemodificeerde OWAS-systeem om de geobserveerde bewegingen te beoordelen.
- Module 3: Een gestandaardiseerde, subjectieve beoordeling van het comfort van de lichaamshoudingen van de testpersonen werd gebruikt.
- Module 4: Met het 3D meetsysteem voor bewegingen 'Flock of Birds' werden de comforthoeken en de spanningen binnen een bewegingsafloop geschat.

Eerst is nagegaan hoe het wassen wereldwijd wordt uitgevoerd. Dit was nodig om na te gaan in welke delen van de wereld een verbeterde machine zou kunnen passen in het wasproces.
In een laboratoriumonderzoek werden het laden en ontladen van een wasmachine met was onderzocht, met gebruikmaking van een in hoogte en hoek verstelbare wasmachine mock-up. Naast een analyse van de lichaamshoudingen werd de efficiëntie van het laden en ontladen gemeten. De testpersonen moesten ook hun subjectieve comfortbeleving aangeven. Correlaties tussen anthropometrie, leeftijd en geslacht en lichaamshoudingen werden berekend.

In een real life test werden vervolgens de resultaten uit het laboratorium geverifieerd bij mensen thuis. De proefpersonen werd gevraagd de verhoogde wasmachine te laden en leeg te halen. Deze opstelling werd vergeleken met het gebruik van de eigen wasmachine. De comfortbeleving werd gemeten. De bewegingen, lichaamshoudingen en comfortbeleving werden geanalyseerd bij het laden en ontladen van een wasmachine. Een deel van dit onderzoek richt zich op hoe ouderen deze taken kunnen uitvoeren. Ten eerste zijn ouderen geobserveerd in een verzorgingshuis terwijl zijn hun wasmachine gebruikten met de daarmee samenhangende problemen. Ten tweede zijn uit de voorgaande onderzoeken in het laboratorium en thuis de ouderen met jongeren vergeleken. Om na te gaan of er dynamisch andere houdingen voorkomen zijn lichaamshoudingen en bewegingen geanalyseerd tijdens het laden en leeghalen door middel van het 'Flock of Birds' systeem geregistreerd. De geanalyseerde houdingen werden vergeleken met de vakliteratuur voor een objectieve comfortbeoordeling.

**Deze werkwijze leidde tot de volgende resultaten:**
De mensen wassen overal ter wereld, maar er is geen mondiale wascultuur. Lokale behoeften en gebruiken zijn verschillend, zelfs voor landen die aan elkaar grenzen (hoofdstuk 2). In de meeste landen past de vernieuwde wasmachine wel in het was proces. Soms moet dan rekening worden gehouden met de kleur (roze voor delen van China) en afmeting (moet op balkon passen, verrijdbaar zijn of in kleine flats passen). De meest comfortabele lichaamshoudingen treden op bij het midden van de opening 105 en 123 cm boven de grond (hoofdstuk 3).

De meest efficiënte en snelste hoogtes voor het laden zijn tussen 69 (met de sterk gekantelde opening) en 105 cm. De snelste hoogte voor het leeghalen was 89 en 69 cm (met de sterk gekantelde opening) (hoofdstuk 3). De voorkeurshoogte van de testpersonen was 105 cm (hoofdstuk 3) voor het laden en ontladen.

In de thuissituatie gaven de testpersonen ook 105 cm als voorkeurshoogte aan, met de wasmand opgehoogd op bijvoorbeeld een krukje (hoofdstuk 4). De hoogte van 63 cm die het dichtst bij de standaardwasmachine komt, beviel het minst (hoofdstuk 4).
Oudere testpersonen van een verzorgingshuis gebruikten compenserende steunstrategieën om hun was te doen. Vier verschillende gedragstypes werden vastgesteld (hoofdstuk 5).

Oudere testpersonen gebruikten vaker comfortabele lichaamshoudingen bij hoogtes tussen 120 en 100 cm dan jongere testpersonen (hoofdstuk 5) en beoordeelden de kanteling van de trommel als nog belangrijker (hoofdstuk 5) dan de jongere testpersonen. Het laden van een wasmachine met een openingshoogte van 100 cm zonder plek voor de wasmand beviel de oudere testpersonen niet (hoofdstuk 5). Oudere vrouwen houden helemaal niet van het ontladen bij een hoogte van 60 cm en hebben de neiging om het laden van hun eigen wasmachines thuis slecht te beoordelen (hoofdstuk 5).

Het 'Flock of Birds' onderzoek toonde aan dat lichaamshoudingen bij hogere openingshoogtes gebruikt werden met ketens van hoeken die in de comfortzone bleven (hoofdstuk 6). Maar voor de lagere openingshoogten traden ketens van hoeken op die niet overeenstemmen met de beschreven comfortzone.

Met gebruikmaking van de vier modules werd een volledig onderzoek van alle aspecten met betrekking tot de ergonomische en emotionele factoren van het laden en leeghalen van een wasmachine beschreven. Terwijl recente onderzoeken zich concentreren op de interface van de wasmachine, richtte dit onderzoek zich op ergonomie en comfort en leverde data op die nieuw zijn in het gebied van witgoed. Bovendien biedt het een basis voor innovatie waarmee meteen een start gemaakt kan worden. Comfort is waardevol in het leven van alledag. De mensen zoeken naar werktuigen en gereedschappen die hun leven makkelijker maken.

Verbeteringen aan de wasmachine, zijn lange tijd verwaarloosd. Een wasmachine die de behoeften van de gebruiker vervult, gebaseerd is op dit nieuwe ergonomische concept en gecombineerd is met innovatief design, kan heel goed bij de consument aanslaan. Een innovatief concept is niet alleen goed voor de gebruiker, maar biedt ook veelbelovende kansen voor de fabrikant. De belangrijkste eisen waar de nieuwe wasmachine aan moet voldoen volgens de gegevens van dit proefschrift is:

- het midden van de openingshoogte bij laden en lossen 103 cm vanaf de grond
- de trommel 30 graden gedraaid, en
- een steun voor de wasmand.

Zowel de hoogte als de gedraaide trommel zijn recent op de markt gekomen. Dat bewijst dat het ontwerp haalbaar is. Alle drie de eisen zijn nog niet in één product verenigd verkrijgbaar. Dit is voor een wasmachinefabrikant een kans, ook omdat de nieuwe wasmachine past in het wasproces van een groot deel van de wereldbevolking.

# Acknowledgements

This thesis was not build in a day. In fact it took me eight years, a long and often steep way to go. But now I feel as if I'm standing on the top of the highest mountain - I am really proud that I finally made it to the top. But like Sir Edmund Hillary climbed the Mount Everest with the great help of Tenzing Norgay, I would not have been able to finish this thesis without the help and contribution of so many great companions.

I want to thank all of you.

My promoters Peter Vink, Johan Molenbroek and Daan van Eijk.
Johan, I'll never forget your confirming email that I could finish my dissertation at the Delft University of Technology. You gave me the chance to continue and took the risk of handling me, being my "Doktorvater". Your willingness to discuss and to share ideas with me gave me great inspiration for this thesis. Thank you for your never-ceasing optimism until the very end. Peter, for your everlasting motivation, which kept stimulating me to keep on working, giving me directions, when I lost track, for inspiring my performance, pushing the scientific envelope further, and still making jokes when I lost the ability to laugh. Daan, for your design perspective on my human factors heavy view, and of course for the support and possibility to finish my thesis within the Applied Ergonomics and Design department and for supporting the funding of this thesis.

All the members of the committee I wish to thank for taking the time and effort to be part of the committee. Jan Schoormans for your very valuable comments on the manuscript, Holle Greil for your enthusiasm to spontaniously dive deep into my thesis. With all of you I'm looking forward to the celebratory finale.

It was Bosch Siemens Home appliances, which initiated this project and funded the start of this research. Prof. Jürgens and Dr. Schoeffel, you introduced me to the ergonomic world in- and outside the university and challenged me. You made me wiser and stronger.

I wish to thank the anthropological working group of the University of Kiel. You taught me everything I needed to know about industrial anthropology and how to do scientific research. Thank you Norbert Vogt for building the mock-up, Susanne Frohriep for being such a great friend, also around the world, Stefan Schwab for being so patience and my photo model, Inge Schröder for all your scientific knowledge, for teaching interesting bio-statistics, for your female centred evolution theory and your always-open doors, Gerd Küchmeister for our really fruitful discussions, I enjoyed all of them and finally Dr. Helbig for your always helpful supervision.

Many thanks for the information on washing cultures from all the correspondents around the world. Henri Christiaans, thank you for the valuable conversations on culture and your friendly support.
Many thanks to all the participants who loaded and unloaded laundry multiple times and for letting me into your homes. Without your "work" I would not have gotten a scientific basis.

For your patience especially in emergencies with this PhD procedure I like to acknowledge the help of the beadles Ria Kersbergen-Vermeulen and Petra Peek-Charlier.

My paranimphs, Gitta Rüscher and Jasper van Kuijk, thanks for being my friends in all life stages. Gitta, I could always count on you. You took the time and effort to scrutinise my research and helped me to stay on top of the statistics. Thank you as well for all your mental support, nobody could understand better. Jasper, thanks for being such a pleasant and welcoming friend explaining how to live the "Nederlandse" way.

Your love eased my way.

My parents, Christel and Heino Busch - thank you for all your love, for giving me the possibility to grow in the way I liked, to become what I am, and all your unquestionable confidence in me.
Jens Keunecke, thank you for giving me your love and energy to continue my work and your tolerance with me in this time. I love you for the "clearing the head beach walk talks", your creative ideas and your translation of my weird sketches into great outlines and designs making this thesis so precious and valuable.

And last but not least what would I have done without friends, fellow students and fantastic roommates. Your late night translations, served dinners when coming home, tolerance for emergency calls, open ears and strange moods will not be forgotten. Thank you, Peggy, Inger Marie, Ricci, Anneke, Ingrid, Laura, Wil and Rob.

# Curriculum Vitae

Nicole Busch was born in Hamburg, Germany, on August, 31st 1970.
After finishing a two-year bank clerk training 1992, she started biology studies in the same year at the Christian-Albrechts-University, Kiel, Germany. 1998 she received her diploma in biology with the main subjects anthropology, zoology and biochemistry. During her studies she worked for several years as a bank clerk at the Vereins- und Westbank in Hamburg and as research assistant for the zoological, polar ecology and marine biology departments.

In 1999-2001 Nicole worked as an ergonomics specialist for the German design company designafairs GmbH, the former design department of Siemens in Munich. Parts of her work were ergonomic studies, e.g. she introduced the "Age Simulator" as a "feel-it-yourself" experiment for anthropological research in design.
In parallel she started 1999 her PhD project in natural sciences at the Christian-Albrechts-University, Kiel, Germany and continued in April 2003 at the Delft University of Technology in the department Industrial Design Engineering. This project has resulted in the present thesis.

In 2001-2005 Nicole worked for the prestigious innovation and design company, IDEO in Munich as human factors researcher and project manager being responsible e.g. for human factors studies for Adidas, BMW, Bosch Siemens Home appliances, Nestlé, Smith & Nephew and Procter & Gamble. Within this time she was based for international projects in San Francisco, Palo Alto, Chicago, Boston and London.
Since 2006 Nicole is a senior consultant in the well-known German Trendbüro, a consultancy for trend research and social changes in Hamburg. She is an invited speaker and lecturer at cultural and academic institutes and universities.

In her leisure time Nicole is addicted to water in all states of aggregation: Skiing, diving, sailing, surfing and hiking. She never goes without a book, loves to travel and to experience foreign cultures, bringing back exotic recipes.