Three evaluations of task-surface heights in elderly people’s homes

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Received 4 June 1997; accepted 11 July 1999

Abstract

The aim of the study was to compare subjective evaluations of the heights of some kitchen facilities and furniture with an expert’s opinion of the same heights and with the height recommendations derived from the subjects’ anthropometric data. Experiments were conducted in a mock-up simulator, where the subjects, a group of the Finnish elderly (N = 55), performed small tasks similar to the typical daily living activities at home. The mock-up room consisted of “task-surfaces” whose heights were adjustable to various fixed positions. For example, three identical chairs with different heights were available. In their subjective assessments, the elderly systematically rated the 450 mm-high chair as the most suitable. The lowest (350 mm) and the highest (550 mm) chairs were not liked. The other two evaluations supported this conclusion. The height of the lowest kitchen shelf should not be lower than 300 cm. A work surface height of 850 mm seems preferable for most of the Finnish elderly. The different evaluation procedures gave relatively consistent results, but some important differences were also noticed and are discussed. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Ageing; Evaluation; Anthropometry

1. Introduction

The number of elderly people is markedly increasing in all the developed countries. Unfortunately, the ageing population will have to cope with the associated progressive loss of physiological capabilities, which may dramatically reduce the individual’s ability to participate in everyday activities. This decrease in capabilities and mobility tends to confine the elderly and most of their activities to their homes (Meindl and Freivalds 1992). The time spent at home is hence increasing, as are also the demands on home conditions. Knowledge about human body size is important, but not alone sufficient for the ergonomic design of home facilities for the elderly. Information about functional capabilities, mobility, abilities or limitations to perform certain tasks as a function of changes in biomechanical, physiological, psychological and mental characteristics and in attitudes and behaviour is also needed (Kelly and Kroemer 1990).

1.1. Age-related changes in body

Anthropometric data must be taken into consideration when the adequacy of furniture and fixtures is assessed. Older populations have different body measures compared to younger people. Stoudt (1981) found that 65–74-year-old male subjects were also an average of 61 mm shorter than young subjects (aged 18–24 years). Elderly women were about 51 mm shorter than a younger group. Other studies have shown that the height of every adult individual declines with age (Borkan et al. 1983; Damon and Stoudt 1963; Damon et al. 1972; Friedlander et al. 1977). Sitting height (Fig. 1) also declines with age (Borkan et al. 1983) in parallel to the decline in stature (Stoudt 1981). A significant decline begins to appear in the 40–44-year-old age group (Friedlander et al. 1977) and continues throughout later life. However, neither shoulder-to-elbow length, nor elbow-to-middle-finger length are affected by age (Stoudt 1981). Arm span, instead, shows a significant decline (Borkan et al. 1983; Friedlander et al. 1977). Stoudt (1981) noted that functional reach is diminished, at times severely.
Fig. 1. Illustration of anthropometric measurements relevant to sitting: (1) popliteal height (lower leg length), (2) elbow height, (3) thigh height, (4) patellar height, (5) orbital (eye) height, (6) shoulder height. According to Chaffin and Andersson (1991) who adapted the figure from Engdahl. Sitting height (7) was added by the authors.

The flexibility of the joints of the body decreases dramatically with age (Pheasant 1988). Sanders and McCormick (1993) conclude that the types of disability receptive to the design of facilities and products for the elderly and the handicapped include poor balance, lack of coordination, limited stamina, difficulty in handling and fingering, in bending and kneeling, and inability to use the lower extremities.

Not only body measures but also the condition of the musculoskeletal system of the elderly is one of the determinants of the ability to move and manage independently at home. A decrease in the body’s ability to maintain balance and a decrease in both stride length and steppage height were reported by Kivelä et al. (1994). According to Rundgren (1991) the muscle force of men decreases by 40–50% between 40 and 80 years of age. Changes in muscle function are most remarkable after 70 years of age, but begin before (Berg 1986). The study of Nygård et al. (1991) showed significant changes in musculoskeletal capacity between middle-aged subjects during 4 years (from 51 to 55 years).

1.2. Evaluation and aims of the study

Evaluation research is similar to experimental research in that its purpose is to assess the effect of “something”. In evaluation research, the “something” is usually a system or a product. The variants of a system or a product are often most practicably realized in or through a simulator. Evaluation can also be part of the overall systems design process. Evaluation has been defined as the measurements to verify that a product will do what it is supposed to do. For a true test of the “goodness” of a product, the test should be conducted under conditions representative of those under which the thing being tested will ultimately be used. The evaluation of human factors should be done in actual operational situations or in circumstances that approximate the operational conditions. (Meister and Rabideau 1965; Sanders and McCormick 1993).

It is sometimes difficult to illustrate a work situation using an anthropometric model, because the standard anthropometric measures are static. In the real world, human actions include many dynamic features. To evaluate the functional aspects of a work station appropriately, one may construct a full-scale mock-up. The purpose is then to have people of different sizes testing out the work station by moving their body and simulating tasks. Through a full-scale mock-up it may be possible to identify, for example, features of the work station which need to be redesigned. (Helander 1995).

In the present study, home work and other activities were investigated in a home simulator, utilizing daily activities and subjects for evaluation. The subjects were observed and interviewed while they were performing some typical small tasks according to oral instructions. The small tasks all involved household furniture and fixtures typically used by the Finnish elderly. The study is part of a larger project which aims at improving the possibilities of the elderly to move safely and to manage independently in their homes by gerontotechnological means (Väyrynen et al. 1996). In Finland, furthermore, there is a lack of adequate anthropometric data on the elderly. It was thus possible simultaneously to use a group of elderly persons as subjects in a functional simulator experiment and to obtain their static anthropometric measures. These could be utilized to estimate the frequency distribution of the stature of old Finnish people.

After each small task, the different heights of the furniture and fixtures in question were rated by each subject. The heights were the work surface heights of a kitchen base unit, shelf heights and seat heights. The main purpose of this evaluation was to define how old people assess various clearly different heights after a short-term trial with task simulation using furniture or fixtures. Slight differences in height may even go unnoticed, because individuals sitting at a work station do not have the sensitivity to judge changes smaller than 10 mm (Helander 1995). The second purpose was to compare the subjectively acceptable heights with the recommendations given in the anthropometric literature. The third data set for comparisons consisted of the ratings made by an occupational physiotherapist.

Based on the individual opinions, the acceptance of each height was analysed with regard to the whole group, not separately for tall and short or for male and female subjects. All heights can be taken as “task-surface heights” analogous to how Sanders and McCormick (1993) speak about work surface heights.
2. Material and methods

2.1. Subjects

The evaluations were made by 55 subjects, of whom 41 were healthy (i.e. normal musculoskeletal system with regard to age) 70–80-year-old (\(\bar{x} = 74.4\) years, sd = 3.1) subjects (\(N_{\text{female}} = 22\) and \(N_{\text{male}} = 19\)), while 14 were people (\(N_{\text{female}} = 9\) and \(N_{\text{male}} = 5\)) of the same age (\(\bar{x} = 77.1\) years, sd = 3.3) needed a cane to move around. At the start of this project in 1995 the subjects were first tested clinically. The experts of gerontology in our multidisciplinary research team believe that the group represented well the corresponding Finnish elderly population.

In the clinical tests, the height, i.e. stature (\(\bar{x} \pm \text{sd}\)), of the subjects was 1568 ± 55 mm for the women, 1692 ± 85 mm for men, and 1621 ± 93 mm for all subjects. Table 1 shows the estimated frequency distribution for the Finnish elderly. The present old Finnish female subjects were very much like female British adults aged 65–80 years, whose stature (50th percentile) was 1570 mm (Table 1). The men were also similar to male British adults aged 65–80 years. During the task simulation, however, the subjects were wearing standard shoes which added 20 mm to their stature.

2.2. Mock-up simulator

The evaluation was carried out in a static mock-up simulator, which is a room where the subjects could perform different tasks typical of the home environment. The room contained furniture and fixtures whose heights could be adjusted stepwise or with various task-surface heights. Each subject had to perform the tasks with every task-surface height. The different heights were taken from the common heights of the environment the elderly lived in and from structures that are commercially available. Three video cameras were set up in the room for recording the whole body movements of the subjects.

The different pieces of furniture or fixtures and the small tasks related to their normal daily use were the following:

Four general-purpose chairs (Fig. 2): Three of the four chairs used differed only in seat height (350, 450 and 550 mm), while the fourth chair was 450 mm high with armrests. As Fig. 2 shows, the cover material was constant for each chair. No additional variable could hence have any remarkable effect on the assessments of each chair (c.f. Zhang et al. 1996). With the seat heights of 350 and 450 mm, the subjects had to sit down, change shoes and get up, and with the height of 550 mm they were instructed to sit down and get up after a while, which they also did with the 450 mm chair with armrests. The middle height was chosen according to Grandjean (1973) who recommends a seat height of 430–460 mm, depending on whether the seat is inclined or flat. For a general-purpose chair, he proposed a height of 450 mm. Relevant

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Table 1

Some body measures (in cm) of the subjects compared with those of British adults aged 65 – 80 years (Pheasant 1988)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5th %ile</td>
<td>50th %ile</td>
</tr>
<tr>
<td>Stature (subjects)</td>
<td>149.6</td>
<td>170.3</td>
</tr>
<tr>
<td>Stature (British)</td>
<td>157.5</td>
<td>168.5</td>
</tr>
<tr>
<td>Knee height (subjects)</td>
<td>46.0</td>
<td>55.0</td>
</tr>
<tr>
<td>Knee height (British)</td>
<td>48.0</td>
<td>52.5</td>
</tr>
<tr>
<td>Popliteal height (subjects)</td>
<td>37.2</td>
<td>44.6</td>
</tr>
<tr>
<td>Popliteal height (British)</td>
<td>38.5</td>
<td>42.5</td>
</tr>
<tr>
<td>Elbow height (subjects)</td>
<td>94.2</td>
<td>106.1</td>
</tr>
<tr>
<td>Elbow height (British)</td>
<td>97.5</td>
<td>105.5</td>
</tr>
</tbody>
</table>
data about chairs have been published by Chaffin and Andersson (1991). According to them, the popliteal height (Fig. 1) of people (male and female, aged 18–70) in a Swedish study was (a) 385 mm for the 10th percentile, (b) 421 mm for the 50th percentile and (c) 465 mm for the 90th percentile. Helander (1995) reminds designers of the fact that in an ideal static sitting situation

\[(\text{optimal})\text{ chair seat height} = \text{popliteal height} + \text{shoe height}.\] (1)

Kitchen facilities with base and wall units adjusted at two heights (Fig. 3): The upper cupboard had heights of 1250 mm and 1350 mm measured from the lowest corner of the wall unit to the floor, the work surface heights were 800 and 900 mm, and the kettle shelf was at a low level of either 165 or 265 mm. Grandjean (1973) recommended for light manual work in the kitchen a table height of 900–950 mm for men and 850–900 mm for women. In Finland, as in the UK, the standard for kitchen base unit and sink height is 900 mm. In the kitchen simulation, the subject took a kettle from the lower cupboard, filled the kettle halfway from the faucet, carried the kettle to the cooker, took three cups, one from each shelf, from the upper cupboard, rinsed the cups and put a cup on each shelf of the draining cupboard.

2.3. Data collection and analysis

Structured interviews were carried out after each small task to find out each subject’s evaluation of the heights of chairs and fixtures. A seven-step scale was used to find out how the people rated the heights of the furniture and fixtures. The scale intervals for the subject’s scores (SS) were the following: much too high (1), too high (2), slightly too high (3), suitable (4), slightly too low (5), too low (6) and much too low (7). This scale was shown when evaluation was asked after each task with different height. In addition to their structured interviews for score assessment, the subjects also gave free comments concerning the chairs and sitting and reaching.

For a comparison with the anthropometric literature, anthropometric compatibility (AC) was determined with the following procedure:

(a) patellar height (cf. Fig. 1) was measured in the clinical tests for each subject,

(b) corresponding popliteal height (cf. Fig. 1) was derived in congruence with the data on British adults aged 65–75 years by using the computer software People Size (1994) (the percentile of the subject was derived from patellar height, and using that percentile popliteal height was obtained),

(c) the height of the heel was added (20 mm), and hence

(d) the optimal chair seat height (OSH) could be determined, and further,

(e) for each chair the subject’s \(\Delta h\) was calculated, representing AC, as the actual difference in centimetres between each simulator chair’s height and OSH, using the equation \(\Delta h = \text{actual seat height} - \text{OSH}\).

In addition, the stature of each subject was utilized for some comparisons of the heights of the kitchen base and wall units, and elbow height was also derived from the stature using PeopleSize (-Human data software) (1994).

For comparison, an occupational physiotherapist replayed all video recordings and gave his professional ratings (expert’s score, ES) using the same seven-step scale 1 . . . 7 that the subjects used in their own ratings. The rating were based on the analyses he made and the general impressions he obtained when thoroughly

Fig. 3. (a) Base and wall units of a standard kitchen fixtures and accessibility classification of storage spaces (Pheasant 1988). (b) The main heights of the lower and higher kitchen facilities in the present study. The heights of the shelves (highest and lowest) are presented with a dotted line. The heights are in mm.
observing each subject carrying out the tasks at different heights. The criteria of the expert are presented in the Appendix A. Both SS and ES were compared with AC as well as with each other.

The following statistics or methods were utilized for statistical inference: arithmetic mean (\(\bar{x}\)), standard deviation (sd), paired t-test, scattergrams, correlation coefficient (r) (Pearson’s product moment), regression analysis (line of best fit) and Wilcoxon’s rank test (Howell 1992). The statistical analyses were made using SPSS computer software.

3. Results

3.1. Score evaluation of task-surface heights

Table 2 shows the main statistics of the ratings of each task-surface height as evaluated by the subjects and an expert.

Table 2
The main statistics of subjects’ scores (SS) and expert’s scores (ES) (\(N = 55\))

<table>
<thead>
<tr>
<th>Furniture or fixture</th>
<th>SS</th>
<th>ES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\bar{x})</td>
<td>sd</td>
</tr>
<tr>
<td>Chair</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35 cm</td>
<td>5.5</td>
<td>1.0</td>
</tr>
<tr>
<td>45 cm</td>
<td>4.0</td>
<td>0.3</td>
</tr>
<tr>
<td>55 cm</td>
<td>2.9</td>
<td>1.1</td>
</tr>
<tr>
<td>45 cm with armrests</td>
<td>4.0</td>
<td>0.3</td>
</tr>
<tr>
<td>Kitchen facilities:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper cupboard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>3.6</td>
<td>0.7</td>
</tr>
<tr>
<td>High</td>
<td>2.8</td>
<td>1.0</td>
</tr>
<tr>
<td>Work surface</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80 cm</td>
<td>4.1</td>
<td>0.4</td>
</tr>
<tr>
<td>90 cm</td>
<td>3.9</td>
<td>0.3</td>
</tr>
<tr>
<td>Kettle shelf</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.5 cm</td>
<td>4.4</td>
<td>0.9</td>
</tr>
<tr>
<td>26.5 cm</td>
<td>4.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

The score mean (\(\bar{x}\)) can consist of the scale values of each task-surface height. Standard deviation (sd) can be calculated as a measure of the distribution of judgements for a given piece of furniture or fixture. It gives a deviation of 34.13% at both sides of the mean point (i.e. the middle 68.26% of the judgements). When there is only a scant inherent variability among the subjects in judging heights, sd is small, as most of the scores are at the same level.

3.2. Scores on chairs

As seen from Table 2, the chair of 350 mm was considered “too low” by the subjects (score value 5.5) and even lower by the expert (6.4). Sd was great, however, which means that the ratings of height varied quite notably. The chair of 450 mm was considered “suitable” by the subjects and the expert. The opinions were quite similar among all the subjects. The chair of 450 mm with armrests also had a “suitable” score value. The chair of 550 mm was rated as “slightly too high” by the subjects (2.9), while the expert considered it “too high” (2.2) for the subjects. The range was very great according to sd, as some subjects did not like this height at all. They said that the chair would cause pain in the lower extremities if used for a long time. There should be a support for the feet in the chair. Some, however, preferred this chair, because it was easier to get up from this chair than from the lower ones.

The difference between the expert’s and the subjects’ scores was analysed by the t-test for paired samples (Table 3). The null hypothesis \(H_0\) was that there is no difference between the scores. The t-tests showed that there was a difference between the scores, except in the case of the chair 45 cm in height with armrests, at both \(\alpha = 0.05\) and 0.01 significance levels.

3.3. Scores on kitchen facilities

The top shelf of the upper cupboard was usually considered to be “too high”. The cupboard fixed higher on
the wall unit got a value of 2.8, which can be considered “slightly too high”. The expert rated it as “too high” (1.9). Clear reaching difficulties were only seen with the top shelf of the upper cupboard. There was a high sd, i.e. a lot of disagreement in the ratings of the higher facilities.

The work surface heights and the kettle shelf heights did not show much difference when rated by the subjects. They were considered to be “suitable”. However, the expert evaluated the 900 mm work surface height to be between “slightly too low” and “too low”. The kettle shelf of 265 mm, instead, was considered to be “slightly too low”, while 165 mm was “too low” for the subjects.

The t-tests showed that there was a difference between the expert’s and the subjects’ scores, except with regard to the work surface height of 900 mm, at the α = 0.01 significance level, there was no difference found between the scores (Table 3).

3.4. Subjective comparison of two different task-surface heights

Wilcoxon’s matched-pairs signed-ranks test was used to compare the differences between the subjects’ ratings of two heights of the same furniture or fixture. The null hypothesis $H_0$ was that there is no difference between the ratings of the two heights of furniture. First, the difference between the ratings of the two heights was calculated. The numbers were then ranked, and on the basis of the positive and negative rankings, the sums were taken as follows.

$T_+ = \Sigma$ ranks with a positive difference
(scores of the 1st — scores of the 2nd),

$T_- = \Sigma$ ranks with a negative difference
(scores of the 1st — scores of the 2nd).

If the minimum $T(T = \min(T_+, T_-))$ is less or equal to the value of $T$ (Howell 1992), the null hypothesis will be rejected, i.e. there is a significant difference between the ratings. According to the test, all the ratings of the subjects concerning the two heights showed a statistically significant difference (Table 4). However, when we compared equal heights, i.e. the chairs 450 mm high with and without armrests, there was no difference between the ratings.

3.5. Human evaluations by the subjects and the expert vs. anthropometric compatibility

The expert’s scores were related to $\Delta h$. All the ratings of 350, 450 and 550 mm chair heights were included, and these assessments together were combined into $ES_{comb}$ ($\bar{x} = 4.3$). Further, correlation and regression were calculated between $ES_{comb}$ and $\Delta h$. A clear linear association of $ES_{comb}$ with $\Delta h$ emerged. Hence, the regression line can be used to predict $ES_{comb}$ on the basis of $\Delta h$ (Fig. 4). The correlation between $ES_{comb}$ and $\Delta h$ shows the degree to which the points cluster around the regression line (in other words, the degree to which the actual values of $ES_{comb}$ agree with the predicted values). The same was also done between the subjects’ scores $SS_{comb}$ ($\bar{x} = 4.2$) and $\Delta h$ (Fig. 5).

The regression equation, the correlation coefficient ($r$) and the significance level of $r$ ($\alpha$):

$ES_{comb} = -0.191159 \Delta h + 4.550914$,

$r = -0.89(\alpha = 0.000),$

$SS_{comb} = -0.119564 \Delta h + 4.311099,$

$r = -0.76(\alpha = 0.000).$

On the basis of the equations and figures, it can be said that $ES_{comb}$ is changed more by $\Delta h$ than $SS_{comb}$. The constant gives the rating when $\Delta h$ is zero (i.e. should be equal to the scores for “suitable”). However, the expert opinion according to the regression equation is that the seat height is near the scores for “slightly too low”, i.e. seat height should be higher than the optimal chair seat height (Eq. (1)). The correlation between $SS_{comb}$

<table>
<thead>
<tr>
<th>Furniture or fixture</th>
<th>$n$</th>
<th>$T_-$</th>
<th>$T_+$</th>
<th>$T (\alpha = 0.05)$</th>
<th>$H_0$</th>
<th>$T (\alpha = 0.01)$</th>
<th>$H_0$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chairs: 35 vs. 45</td>
<td>38</td>
<td>730.4</td>
<td>10.5</td>
<td>235.3</td>
<td>Rej.</td>
<td>195.0</td>
<td>Rej.</td>
</tr>
<tr>
<td>45 vs. 55</td>
<td>35</td>
<td>630.0</td>
<td>0</td>
<td>195.3</td>
<td>Rej.</td>
<td>139.6</td>
<td>Rej.</td>
</tr>
<tr>
<td>45 vs. 45 with armrests</td>
<td>9</td>
<td>22.5</td>
<td>22.5</td>
<td>5.7</td>
<td>Not rej.</td>
<td>1.6</td>
<td>Not rej.</td>
</tr>
<tr>
<td>Kitchen facilities:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper cupboard low vs. high</td>
<td>32</td>
<td>9.5</td>
<td>518.6</td>
<td>159.1</td>
<td>Rej.</td>
<td>128.0</td>
<td>Rej.</td>
</tr>
<tr>
<td>Work surface 80 vs. 90</td>
<td>10</td>
<td>0</td>
<td>55.0</td>
<td>8.1</td>
<td>Rej.</td>
<td>3.1</td>
<td>Rej.</td>
</tr>
<tr>
<td>Kettle shelf 16.5 vs. 26.5</td>
<td>12</td>
<td>3.5</td>
<td>74.5</td>
<td>13.8</td>
<td>Rej.</td>
<td>7.3</td>
<td>Rej.</td>
</tr>
</tbody>
</table>
4. Discussion and recommendations

4.1. Chairs

According to the literature, fixed-height general-pur-
pose chairs with seat heights of 430–460 mm should suit
everyone with shoes on (Sanders and McCormick 1993).
This recommendation has been made to allow even the
lowest 5th percentile of adults to sit comfortably. Chaf-
Seat height ranges within 430–510 mm according to the
British standards. The other corresponding ranges were
390–540 mm (European standards), 420–540 mm (Ger-
man standards) and 390–510 mm (Swedish standards).
The seat heights of the present study were thus easy to
classify on the basis of the literature: (a) 350 mm too low,
(b) 450 mm quite good for most of the subjects, and
(c) 550 mm slightly too high even for tall subjects. The
subjective assessments of the present elderly study sub-
jects supported this general classification.

The popliteal height of old people (65–80 years) is
lower than that of young adults (19–45 years). In the
female and male British populations it is 410 vs. 425 mm
(Pheasant 1988). Concerning an individual, popliteal
height obviously does not diminish remarkably, as sitting
height does. Popliteal height, i.e. lower leg length can
obviously be considered similar to shoulder-to-elbow
length (Stoudt 1981). This fact supports the observed
agreement between adults’ general recommendations
and elderly subjects’ assessments.

Pheasant (1988) concluded contrariwise that, for many
purposes, the 5th percentile female chair seat height
(400 mm) represents the best compromise for a fixed seat
height. The seat height should be low enough to avoid
excessive pressure on the underside of the thigh. Avoid-
ing pressure and taking into account the slightly smaller
popliteal height of the older generations may give a
400 mm-high chair as good ratings as were given the
450 mm-high one in the present study.

This study also indicated that the elderly do not like
higher chairs, even though these would be easier to get up
from. Only 1/3 regarded the highest chair as suitable.
A high chair with a footrest can be a very good alter-
native for a normal chair for the elderly, as it combines
the absence of excessive pressure and the ease of getting up.

The armrests did not affect the suitability scores of the
450 mm-high chair. In addition, the subjects said that

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and $ES_{comb}$ was also calculated. It was high
($r = 0.76$, $z = 0.000$).

The correlation coefficient between patellar height and
stature was 0.85 ($z = 0.000$).

The correlation between the expert’s score and elbow
height as well as between the subjects’ score and elbow
height was also calculated when rating the work surface
heights (Table 5). It can be seen from the correlation that
the rating of the expert was based on elbow height (high
correlation, i.e. a “too low” or “much too low” rating
(high scores) for people with higher elbow height). The
subject’s score and elbow height showed very little de-
pendence on each other.

### Table 5

<table>
<thead>
<tr>
<th>Fixture</th>
<th>ES vs. elbow height</th>
<th>SS vs. elbow height</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r$</td>
<td>$z$</td>
</tr>
<tr>
<td>Work surface 800 mm</td>
<td>0.8559 0.000</td>
<td>0.0491 0.722</td>
</tr>
<tr>
<td>Work surface 900 mm</td>
<td>0.7157 0.000</td>
<td>0.1850 0.176</td>
</tr>
</tbody>
</table>

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Fig. 4. The estimated regression of the combined expert’s score ($ES_{comb}$) on $\Delta h$. The scattergram presents the expert’s scores ($y$-axis) for each subject with each chair on the scale 1–7, i.e. much too high – much too low. Individually determined anthropometric compatibility $\Delta h$ (seat height – lower leg length with shoes (OSH)) is presented on the $x$-axis.

Fig. 5. The estimated regression on the combined subjects’ scores ($SS_{comb}$) on $\Delta h$. The scattergram shows each subject’s scores ($y$-axis) for each chair on the scale 1–7, i.e. much too high – much too low. Individually determined anthropometric compatibility $\Delta h$ (seat height – lower leg length with shoes (OSH)) is presented on the $x$-axis.
they did not consider armrests necessary in a chair, but many of them said that if they have to sit for a long time on a chair, they prefer to have armrests. However, they felt they do not need armrests as a help for getting up from the chair. Almost all of the subjects said that they did not have armrests in chairs of this kind at home. Based on the literature reviewed in the introduction, many measures and ranges of movement as well as muscular capacity are diminished. From ergonomics expert’s point of view, therefore, armrests were needed.

The t-tests showed that there was a significant difference between the subjects’ and the expert’s scores. This may be due to the fact that the expert’s score was more clearly based on the biomechanical factors of the subjects. It has been found out that discomfort and comfort cannot be assessed on the same scale (Zhang et al. 1996). Discomfort was associated with biomechanical and physiological factors (joint angles, muscle contractions, pressure distribution). Comfort, instead, was associated with feelings of relaxation and well-being, whose factors were obviously also quite decisive among the subjects of the present study in addition to the basic anthropometric measures. However, the t-test was obviously very strong, because the subjects’ and the expert’s scores showed a good positive correlation, and both ratings could be logically and statistically inferred from the anthropometric incompatibility in centimetres. The incompatibility was measured as patellar height. Among the subjects, it correlated quite strongly and positively with stature. This suggests that stature can be used as a reasonable aid to estimate popliteal height when choosing chair seat height. The general variability of bodily proportions is high, which means that stature alone cannot predict popliteal height (Pheasant 1988). But as far as the elderly are concerned, the bodily proportions are different compared to younger adults (Pheasant 1988). This may be one reason for the present results.

4.2. Kitchen facilities

The subjects had some difficulties with the top shelf of the upper cupboard. According to the opinions given by the subjects during the kitchen task, 2/3 had problems reaching the top shelf of the cupboard of the higher facilities (Fig. 6). Twenty-five percent of the subjects also had problems with the 100 mm lower cupboard, where the top shelf was still at a height of 1740 mm. As seen in Fig. 3, the topmost shelf used in this study was situated – according to the general recommendations – in the area of very poor (Pheasant 1988). Hence, 1600 mm seems to be a good recommendation for the top shelf of the upper cupboard, as it suits almost all the elderly. Not all of the elderly subjects were able to straighten their ankles totally any more. Though the mean reaching height was 2136 mm for the right hand in clinical tests and the minimum was 1790 mm, most of the subjects complained of the height of the top shelf. The elderly did not seem willing to stretch to the extreme while working in the kitchen, though that could, in principle, be good training to keep the muscles supple.

Pheasant (1988) gives the following figures for predicted optimal heights of base unit surfaces for adults: men (50th percentile) 1015 mm and women (50th percentile) 930 mm. The figures are based on British anthropometric data, allowing 25 mm for shoes. Bostadstyrelsen (1982) has pointed out that the height of 900 mm is acceptable for both the elderly and the people who help them. The work surface heights of the Finnish elderly usually range from 800 to 900 mm (Uski et al. 1987). On many occasions, however, the height of 900 mm was said to be too high.

The present results showed that work surface heights of both 800 and 900 mm were considered to be quite suitable. According to the stature range of the subjects, the work surface height should be between 820 and 1070 mm (Grandjean 1981). The mean work surface height for the subjects was 932 ± 54 mm as estimated by the same formula. The height of 900 mm would therefore be better for the present subjects. Most of the short subjects, for whom the height of 800 mm would be more suitable than 900 mm, did not feel the 900 mm work surface to be too high, either.

Elbow height has been said to be an important reference value for the determination of work surface height (Pheasant 1988). According to Grandjean (1981) European adults have an mean elbow height of 980 mm for women and 1050 mm for men. A work surface height 150–200 mm below the elbow height level is a suitable height for cutting and mixing with the shoulders relaxed (Pekkarinen and Anttonen 1988). Accordingly, the appropriate height for women is 780–830 mm and that for men 850–900 mm. Because both 800 mm and 900 mm were assessed as suitable, a height of 850 mm can be recommended as a suitable height to accommodate most
of the elderly. However, the expert rated the 800 mm work surface to be clearly too low, supporting the results of the formula presented in the book of Grandjean (1981).

The lowest kettle shelf in the base unit can be considered to be good at 300 mm, but not lower, for the elderly. This has already been recommended by Grandjean (1973). The shelf height of 265 mm was considered suitable. However, the handle of the kettle was 100 mm higher than the shelf, which means that the subject’s hand was about 350 mm from the floor when he/she took the kettle. If there are kitchen utensils that are placed lower on the same shelf, the height of 265 mm is not so good any more, and 300 mm is better. As seen in Fig. 3, the lowest shelf in this study was situated – according to the general recommendations – in the area of fair or poor (Pheasant 1988). Grandjean (1973) recommended that the kitchen shelves should have as much adjustment as possible within the range of 300–1600 mm above the floor.

4.3. General discussion

Generally speaking, minor differences in anthropometric measures are not significant, because it has been concluded that it is usually possible to estimate measures with an accuracy of about 10 mm (Helander 1995). This natural inaccuracy results in additional variation in assessments, but does not, on the other hand, warrant such big steps in height as in this study. More studies should be carried out with more than 2 – 3 height variants and with about 50 mm steps between the heights.

Obviously, the study could reveal quite a good estimate for the Finnish elderly’s main anthropometric measures, e.g. the frequency distribution for stature (male, female, unisex). According to these, the subjects were 47 mm (men) and 63 mm (women) shorter than the average Finnish adults (according to Kuorinka et al, in Bouisset 1988). The corresponding figures for British adults were 60 mm and 45 mm (Pheasant 1988).

For the most part, the study methods applied here proved to be useful and practicable for studying task-surface heights. In this study, it took the subjects only a short time to perform the tasks and to develop an opinion on the heights. They should have had a possibility to spend more time with the furniture or the fixtures to develop a more comprehensive opinion and to bring out the possible discomfort and pains that may be caused by the tasks. The relationship between the discomfort and pains of the different body parts and the heights of the furniture people have at their homes might be worth investigating (cf. Zhang et al. 1996). People usually like the height that they have got used to, but they do not necessarily recognise that the discomfort or even pains in the shoulders or the back, for example, might be due to the kitchen facilities.

Stature alone is not an adequate basis for designing task-surface heights. The height of the elbow from the floor, popliteal height, the buttock-to-knee height, etc., should be measured. Anthropometric data of the elderly are only available for a few countries, e.g. the USA (Kelly and Kroemer 1990). And the data on the elderly are usually not sufficient. The data often only consist of means and standard deviations. Least the 5th and 95th percentiles of the measures of the population should be presented. Particularly, anthropometric data on elderly women are lacking, even though demographic data indicate that women constitute a larger percentage of the existing elderly population than men. The data are usually on elderly aged 65 years or more. However, the decrement of height for example, continues gradually throughout life. The height difference between 65-year-old and 80-year-old groups may be notable. Classifications made at five-year intervals would be more suitable. Even when static anthropometric data are available, there are many problems with the functional dynamic anthropometry of the elderly. Thorough investigation of the static and dynamic anthropometry of the Finnish elderly is also necessary, though the present study revealed basics of the Finnish elderly population’s anthropometrics.

Wilcoxon’s matched-pairs signed-ranks test was also used to assess the reliability of the study. Six of the subjects repeated the experiment after a couple of weeks, and their ratings of the furniture heights at the different times were compared with the test. The test showed that there was no statistically significant difference between the ratings made on the two occasions and that the simulator evaluations can hence be considered reliable. The main conclusion is that the height evaluations by the subjects’ rating could be supported by the expert’s evaluations, anthropometric exact data, their comparisons and also by the literature as far as reliability and even validity are concerned. Since some of the subjective assessments appeared to be illogical the authors recommend that assessments should not be used alone, because so many other variables apart from height can obviously affect the assessments (Zhang et al. 1996). An additional indicator of the reliability of the subjects’ ratings was an overall mean of scores (x = 4.2) which shows that the “normal” 450 mm-high chair was felt “suitable”, and 350 and 550 mm were rated as bad as can be supposed. This also means that the 7-step-score scale was functioning in a logical and realistic way. For the subjects, the estimated score when chair seat height was anthropometrically “right” (incompatibility Δh = 0) was 4.3 according to the regression analysis. This is quite near “suitable”, too, giving an evidence of reasonable reliability.

The motto of anthropometrics design can be expressed as two rules (Helander 1995):

(1) let the small person reach, and
(2) let the large person fit.

The present study was more concerned with the first rule, because task-surfaces were considered. But with
fixed task-surface heights, this rule can lead to unfair situation as far as middle-sized and tall people are concerned. In the elderly, the musculoskeletal abilities deteriorate with age and obviously also the ability to adapt oneself to various heights diminishes, giving evidence of precisely tailored height. This point of view together with the fact of diminished measures and abilities may mean that a fixed-height approach to the most important task-surfaces is not appropriate for the elderly generation. At any rate the heights should be fixed at a different level compared to younger adults. One solution could be that every aged person could choose for him/herself a proper fixed-height level from three alternatives. Or some of the most essential furniture or fixtures aimed at the elderly should be of adjustable height.

The onset and speed of the ageing process are fairly individual, depending on the decade of birth and health, nutrition, exercise, work and social activities throughout life. One possibility is to try to follow the principle “design for all”, i.e. design for the elderly in such a way that all those who are younger and stronger with a better eyesight, hearing or manipulative skills also find the products usable. In this sense, the motto of the Centre for Applied Gerontology is very interesting: “Design for the young and you exclude the old, design for the old and you include the young” (Haigh 1993). As far as anthropometric design is concerned, however, this motto cannot be supported as such on the basis of the present study. It is more applicable to cognitive characteristics than the basic human measures varying with the age of the users.

Appendix

The main criteria used by the expert to rate each subject’s interaction with the different pieces of furniture from video recordings. The general impression of functional fit also affected the rating. The expert was not aware of the corresponding subject’s scores.

Chair:
Too high, if the subject

- has to move to sit to the back of the seat surface with the help of his/her hands or buttock muscles,
- the feet do not touch the floor when sitting,
- the angle of the knees is over 90° when rising.

Suitable, if the subject

- is able to sit to the back of the seat surface without any helping movements,
- is sitting with the angles of the hip and the knees at around 90° and with the feet touching the floor,
- the lumbar region rests against the back support.

Too low, if the subject

- has to support his/her body or the chair especially with his/her hands when he/she sits down or stands up,
- has to bend his/her upper body notably when sitting down,
- has to bend his/her knees notably (over 90°) when sitting down and standing up,
- sits too back on the seat surface so that he/she has to move forward when starting to stand up.

Work surface of the kitchen base unit:
Too high, if the subject

- raises his/her elbow(s) sideways or forward away from the body notably more than usually (suitable height),
- raises his/her shoulder(s) while working more than with a normal, suitable surface.

Too low, if the subject

- has to bend forward more than normal while working,
- extends his/her forearm(s) below 70° or bends them over 120° with the upper arms close to the body and the shoulder(s) in a zero position (beside the trunk),
- has to support him/herself on the work surface with one hand for help.

Upper cupboard:
Too high, if the subject

- has to support him/herself with one hand,
- has to grope for the cup from the shelf for a moment,
- has to straighten his/her ankles to the extreme,
- has to stretch on his/her toes.

Suitable, if the subject

- can reach the cup from shelf and put it on the shelf without any abnormal stretching.

Kettle shelf:
Suitable, if the subject

- can take the kettle from the shelf easily.

Too low, if the subject

- has to bend his/her knees notably or squat,
- has to bend his/her upper body notably,
- has to support him/herself with his/her hands on his/her body or the kitchen facilities,
- has to force his body straight when rising.

References


