Novel Design of a Usable and Accurate Anthropometric Caliper

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Abstract

Background: Anthropometric kits are extensively used in workstation and product design projects, and with the advancement of technology, they have turned into highly complex and effective instruments. However, there are still many challenging problems in usability and reliability of application of these kits in real-world settings.

Objectives: To identify the usability and accuracy issues with a conventional anthropometric caliper, and to propose measurable design features to enhance the functionality of the caliper.

Methods: The measurement process using a conventional anthropometric caliper was systematically analyzed through detailed hierarchical task analyses. Also, six qualified anthropometry specialists performed heuristic evaluations to gain valuable insights into major usability issues in relation to the existing body measurement devices. Based on the resulting concepts, a mock-up was developed and evaluated against the desired specifications.

Results: Incorrect positioning angle of the caliper, as well as applying various amounts of force by different investigators to push the caliper branches against body parts, appeared to be the main factors introducing inaccuracy to anthropometric data. Installing a spirit level on caliper, and also a pre-programmed microprocessor for real-time saving of the obtained data, facilitated the measurement process for both investigators and subjects.

Conclusion: Accuracy, followed by usability is the primary concern in designing anthropometric instruments. However, expectations would vary from one specialist to another. Therefore, trade-offs should be made when incorporating innovative features in novel designed body measurement kits.

Keywords: Anthropometry; Usability; Accuracy; Hierarchical task analysis; Heuristic evaluation

Introduction

Anthropometrics has extensively been used in diverse academic and industrial projects, when usability and safety require a close physical fit between people and their environment.1,2 As well as conventional body measurement instruments, advanced technologies—mainly 3D scanning systems—have recently employed anthropometry surveys.3-7 Through application of such systems, the body measurement process has become quicker and more convenient for

both measurers and subjects. However, the required equipment appears to be considerably expensive and barely transportable outside laboratories. Therefore, there is still the need for a handy and equitable set of measurement devices.

The increased complexity of medical instruments in general, and body measurement devices in particular, has made usability an important design concern. It is not surprising that specialists are becoming less willing to tolerate uncomfortable and unusable instrument interfaces. It has become apparent that in highly competitive situations, where many alternate measurement devices differ little in terms of their functional capacity, it might be the usability to play the primary role to achieve optimum acceptability, satisfaction, and consequent success of the desired application. This, consequently, requires a deep understanding of what usability is in such a context, and what evaluation methods are suitable.

While subjective satisfaction was part of the original usability concept, comparable studies have also been concerned with empirical aspects. It has been highlighted that improving the objective performance might significantly enhance the design usability. However, the impression of an interface should be considered equally important. Among various inspection methods, heuristic evaluation (HE) has the potential to subjectively detect a large number of major and minor usability issues. In performing HEs, evaluators step through product interfaces to obtain a list of usability flaws with reference to predefined criteria. In addition, hierarchical task analysis (HTA) has been recommend as a complementary approach for further exploration into aspects of product interaction. HTA is often regarded as a practical process, through which the analyst collects information about a task and its context to reach a satisfactory outcome, where potential problems have been identified and appropriate solutions have been proposed. This report describes a program of work undertaken to investigate usability and accuracy issues with the conventional anthropometry instruments, and propose measurable specifications to be integrated in future designs of this equipment.

Materials and Methods

Concepts and solutions had to be developed in view of the problems with the existing instruments and expectations from a new design. The nature of the project corresponded with three primary phases of development plans to explore and understand needs and opportunities; identify design options and directions; and refine specific solutions. The measurement process, using a conventional anthropometric caliper, was systematically analyzed through detailed HTA. In addition, HEs were performed by six qualified anthropometry specialists to gain valuable insights into major usability issues in relation to the existing body measurement devices. Based on the resulting concepts, a mock-up was developed and evaluated against the desired specifications.

Hierarchical Task Analysis

A combinational analysis of tasks’ lists, sequences, and hierarchies was completed to develop a detailed HTA. A qualified anthropometry specialist performed the actual tasks with the conventional anthropometry caliper, including assembling and measuring two body dimensions—shoulder and hip breadths. All trials were performed on a manikin, which took nearly five minutes, and were frontally video-recorded without interruption. According to Shephered, the
obtained information was structured into flowcharts for further analysis. It should be noted that, exactly the same trials were performed on the developed mock-up to enable subsequent itemized comparisons.

Heuristic Evaluations

Expert HEs followed by semi-structured interview sessions were arranged to gain valuable insights into major issues in relation to the conventional body measurement devices. Based on the earlier recommendations on sampling strategies for early stages of product usability studies,17,18,28 six anthropometry specialists were invited to the study. All of these specialists were qualified to give special information directly relevant to the objectives of the study as a result of their unique experiences through diverse academic and industrial projects. This would generate a wider range of information through different perspectives. The questions and their sequence were predetermined in the interview guide. As well as answering some multiple choice and open-ended questions, the respondents were asked to rate and rank different issues based on their earlier HEs. In all interview sessions the actual anthropometry devices were also provided to help the participants communicate their ideas more efficiently. In general, the interactions were designed in such a way that both thematic and dynamic dimensions of a well-structured interview would be addressed. After processing the obtained information, the interview summaries were sent back to the respondents, so they had the opportunity to comment on author's interpretations, also to explain their own original statements in more details, where necessary. Finally, after applying the required corrections, the transcriptions were brought together regarding usability and accuracy issues.

Results

Hierarchical Task Analysis

The results of the analysis of measurements with conventional and developed caliper are represented in Figures 1 and 2. The main goal (task) was broken down into five sub-goals including assembling the device, measuring the dimension, recording the obtained measure, planning for next step, and disassembling the device. The mentioned sub-goals were re-described by subordinate sub-goals and plans. The measurement process (Fig 1: plans 2, 3 and 4) should be continued until no more dimensions are to be measured.
Heuristic Evaluations

All the specialists participated in the study, reported some problems with calibration of the measurement instruments. They also indicated that it was difficult to be sure if the caliper was being held at the correct angle (e.g., horizontally), while measuring body dimensions. Having dissimilar results due to application of different forces by different measurers to hold the caliper against body parts was another problem reported with the accuracy. It was also mentioned that adding extensions to the caliper might cause inaccurate or even incorrect measure readings by investigators. This problem was explained by the fact that sometimes measurers forget to add the needed measure to the reading or do the calculations in a wrong way. Regarding the calibration of the caliper, it was suggested that having signs on the scale (e.g., every 10 cm) would enable the investigator to calibrate the device against the marks very easily and frequently. In addition, installing a spirit level on the caliper was rated as a necessary feature to be considered in a new design. Also, digital or analog inclinometers were suggested as enhanced alternatives for the spirit level. All re-
respondents reported some problems with setting up the measurement instruments. It was also pointed out that the existing calipers were not large enough to measure people with larger body dimensions. It was emphasized that the instruments should be designed so that it would be possible to measure people with extremely deformed bodies, and people with uncontrolled body part movements (e.g., having Parkinson’s disease). Having a more friendly and professional appearance was another issue being expected from a new designed anthropometry kit. Regarding the design issues being rated by respondents, installing a pre-programmed microprocessor on the caliper to save and communicate the data with computers was another necessary feature to improve the usability of the device. Table 1 summarizes the results of ratings, according to which all design features

Table 1: Rating of design issues

<table>
<thead>
<tr>
<th>Design Issues</th>
<th>Ratings* by 6 Respondents</th>
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<tbody>
<tr>
<td></td>
<td>R1</td>
</tr>
<tr>
<td>1 Installing handles</td>
<td>3</td>
</tr>
<tr>
<td>2 Installing a spirit level</td>
<td>3</td>
</tr>
<tr>
<td>3 Installing a microprocessor to save the obtained data</td>
<td>3</td>
</tr>
<tr>
<td>4 Fixing the sliding pointer after each measurement</td>
<td>3</td>
</tr>
<tr>
<td>5 Printing the measures on the caliper to increase readability</td>
<td>0</td>
</tr>
<tr>
<td>6 Installing a magnifier on the reading focal point</td>
<td>2</td>
</tr>
<tr>
<td>7 Pointers to be folded along the caliper</td>
<td>3</td>
</tr>
<tr>
<td>8 Pointers to be covered by rubber polymer</td>
<td>1</td>
</tr>
<tr>
<td>9 Providing a small caliper for hand and foot measurements</td>
<td>3</td>
</tr>
<tr>
<td>10 Installing a press button on the caliper</td>
<td>2</td>
</tr>
</tbody>
</table>

*Ratings’ Borg scale ranged from ‘–3’ to ‘+3’ to represent “unnecessary” to “necessary,” respectively

Figure 3: Necessity scale plotted based on the z-scores for rating results (Table 1)
were plotted on a necessity scale (Fig 3).

**Product Design Specifications**

The information obtained through HEs and HTA was structured into product design specifications (PDS) concerning usability and accuracy issues. Also, measurable objectives were defined for further assessment of the proposed design concepts. The PDS, design concepts and measurable objectives are summarized in Tables 2 and 3.

**Discussion**

Accuracy and usability of conventional anthropometry instruments can be enhanced through several design modifications. It was found that the amount of force exerted to push caliper branches against body parts might vary from one measurer to another. This was identified as a major factor introducing inaccuracy to the results of anthropometric measurements. Moreover, the results of HTA showed that there was no feedback to show how much force the measurer was exerting to push the caliper branches (Fig 1). In other words, it was very likely that the obtained measures from the same dimension would vary among a group of measurers due to exerting different amounts of force. Therefore, it was attempted to devise a method to standardize the amount of force being exerted on the caliper branches while measuring body dimensions and compressing differing amounts of body tissue. As it can be seen in the suggested design concepts (Table 3), installing a press-button on one of the branches was considered, and implemented on the mock-up (Fig 4).

This would provide an audio feedback (e.g., a beep) when the spring inside the button was compressed to a certain length. Therefore, if all measurers stopped pushing the branches against the body after hearing the audio feedback, they would automatically exert the same amount of force on the caliper branches. The results of the HTA showed how investigators might interact with the press-button on the caliper (Fig 2).

According to the results, holding the caliper at a wrong angle was another source of inaccuracy in measurement results. That is to say, in relation to some dimensions, the caliper should be held at...
Table 2: Usability design concepts and corresponding measurable objectives

<table>
<thead>
<tr>
<th>Usability Issues</th>
<th>Concepts</th>
<th>Measurable Objectives</th>
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<tbody>
<tr>
<td><strong>Product Design Specifications</strong></td>
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</tr>
<tr>
<td>1. The caliper should be hold in a correct angle (e.g., horizontally) when measuring body dimensions.</td>
<td>A level will be installed on the caliper. Alternatively, a digital or analog inclinometer will be installed on the caliper</td>
<td>100% of the measurements will be done at the correct angle.</td>
</tr>
<tr>
<td>2. The measurer should be able to easily do the measurements without the need for assistant.</td>
<td>A microprocessor will be installed on the caliper so that the measures can be saved in its memory using a simple keypad. The data can also be communicated with a computer at the same time through cables or blue tooth technologies.</td>
<td>More than 90% of a group of investigators will rate the new design as being easy to be used for measurement without assistant. The time needed for a measurement will be no more than 20% longer than when the investigator is being assisted.</td>
</tr>
<tr>
<td>3. Users should not have any problems with assembling and using the instruments.</td>
<td>The design will be simple and easy to use. Training and clear instruction manual will be provided.</td>
<td>More than 90% of the measurers will rate the instruments as being simple and intuitive to use.</td>
</tr>
</tbody>
</table>

A certain angle (e.g., horizontally for measuring shoulder breadth). Additionally, all the respondents mentioned the need for a reliable feedback to ensure that the device was being held at the right angle. Installing a spirit level was rated as a necessary feature to be considered in the new design (Table 1). This issue was taken into account in designing the mock-up (Fig 5). The results of HTA confirmed how this design issue might help investigators ensure they were holding the caliper at the right angle (Fig 2). However, installing either a digital or an analog inclinometer might be more appropriate.

The possibility to handle the measurement process without the need for data entry assistance was a major concern. Among different design issues, providing a microprocessor to help saving the obtained data was related to this requirement. A processor would be installed on the caliper, being pre-programmed with a list of all the dimensions to be measured in the survey and other necessary information. The processor would help the investigator know what dimension to be measured, by showing it on a display. After entering the obtained measure, the next dimension would automatically appear. HTA results showed the effect of this feature on the measurement process (Fig 2). Although the number of tasks has not changed considerably, the measure-
The amount of force needed to push the pointers against the body should be standardized (i.e., the sliding pointer should be pushed with the same force by all measurers to obtain more accurate and reliable measures).

A push-button will be installed on the caliper so that all investigators have to exert the same amount of force to compress the spring to a certain length. A technology will be used to stop the sliding pointer as it touches the body. So, no manual force will be needed to push it.

After installing the spring, the average deviation of measures on one dimension will be less than 10% among a group of measurers.

The information about the size of different extensions will be clearly printed or engraved on them. The extensions will be painted in different colors.

100% of investigators will add correct measures regarding added extensions.

A button will be installed to fix the sliding pointer after each measurement (to eliminate the need for memorizing the measures). The technology of electronic digital calipers will be used to provide digital readouts.

More than 95% of the readings will be correct.

No error should be introduced in relation to the process of reading the measures.

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Conflicts of Interest: None declared.

References


