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DEVELOPING A COMFORT EVALUATION METHOD FOR WORK EQUIPMENT HANDLES

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1. Introduction

The human hand is constantly in contact with products. In particular, the handle of work equipment, as a direct interface to the user, greatly influences the perception of fatigue, pain and comfort [Lindqvist 2008]. The designer's job during handle development is to design handles that can be felt by the users to be comfortable. Comfortable handles need right decisions regarding handle design parameters such as shape, size, material and surface. In addition, the designer must consider many factors such as grip types, coupling types and target groups [Strasser et al. 2008]. This is only possible if representative subjects are used for evaluation of prototypes. This frequently fails in practice because of high temporal complexity and high development costs, coupled with the pressure of shorter development times. Finally, handle design has a strong subjective element rooted in the communication of comfort as sensation.

But handle design lacks a method to make comfort measurable. Take for example the case of vehicle seat comfort. A seat can be checked for comfortable pressure distribution and can be compared with other seats [Hartung 2006]. Research indicates that pressure distribution, which occurs when gripping, has a major impact on discomfort [Kuijt-Eversa 2007]. The aim is therefore to develop a standard method for comfort evaluation of work equipment, taking into consideration significant factors of work equipment in handle design. With this new method, the constructor should already receive information on the CAD model about handle design parameters for comfortable grip design of work equipment, thus enabling the number of test subjects and expensive prototypes to be reduced.

2. Literature review

2.1 Ergonomic handle design

Ergonomic handle design considers all important factors systematically (Figure 1). The hand-side of the handle design parameters of work equipment refers to the shape, size, material and surface. Before designing, always perform a rough and a fine analysis and question all conditions and factors that may finally have an impact on the design [Bullinger et al. 1979].

The rough analysis is about the investigation of body position and movement possibilities, and motion assignment. The fine analysis is about the investigation of gripping types (crush grip, pinch grip, support grip), coupling types (form and force closure) and hand posture (neutral or non-neutral). Design parameters will finally be determined by considering all these influence factors and with the help of guidelines about e. g. hand anthropometry [Strasser et al. 2008].

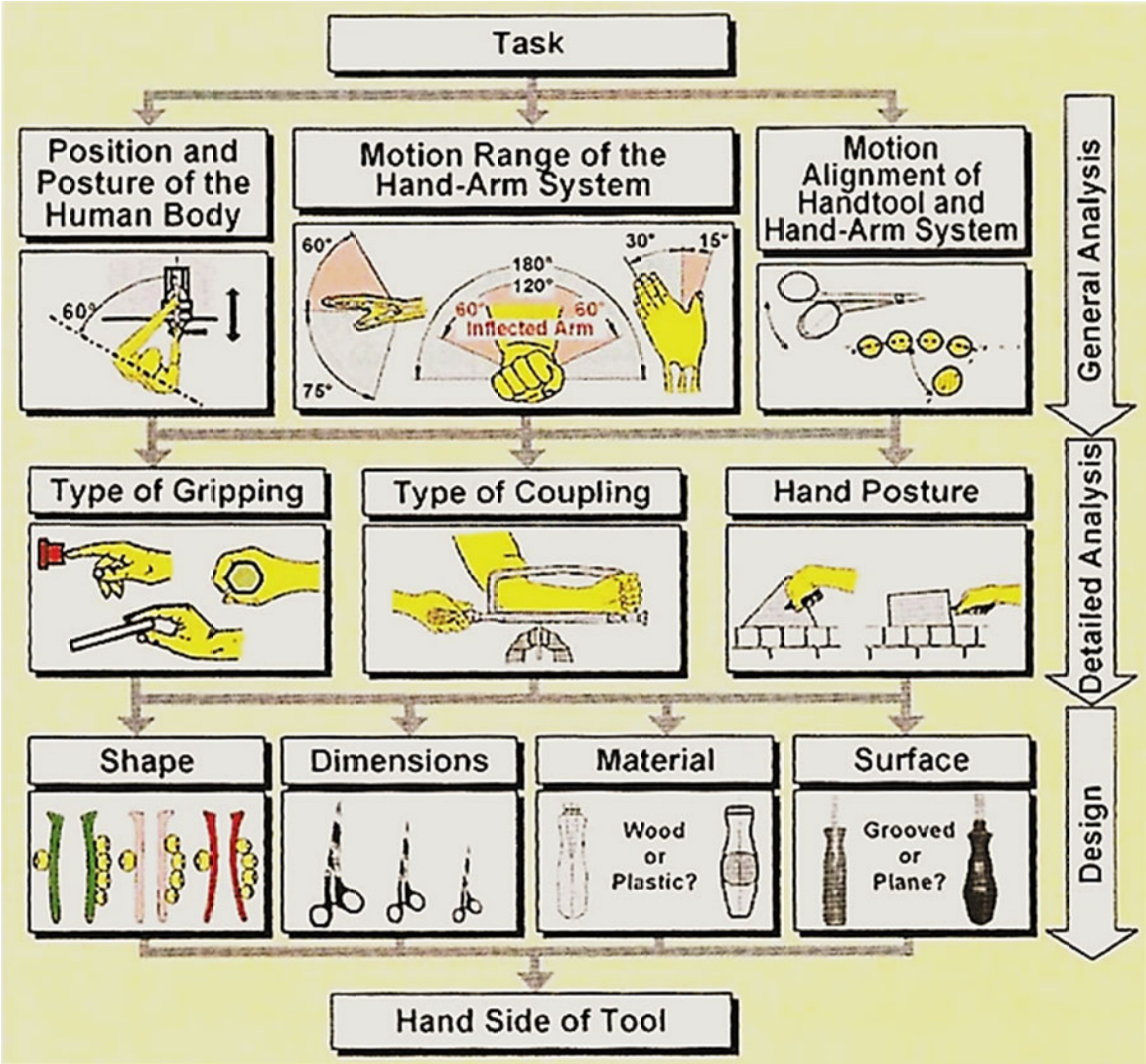


Figure 1. Ergonomic handle design [Strasser 2007]

2.2 Discomfort model

A discomfort model is derived from subjective ratings and objective pressure values [Hartung 2006, p. 22]. Pressure values are referred to as pressure discomfort thresholds (PDT) [Aldiena et al. 2005]. The term discomfort stands in a relation to biomechanical and fatigue factor [Zhang, et al. 1996]. Another key parameter is pressure pain thresholds (PPT). PPT describe the strength of pressure which is perceived by the subject as painful [Rodday et al. 2011].

Based on this pressure pain research Hall et al. [1993] examined the PPT of 64 skin areas and showed that the heel of the hand and the fold of skin between the thumb and index finger are sensitive to pressure. Figure 2 shows a section of the PPT of the palm. Using color subtractive printing films (Prescale) Hall also identified a PDT of 104 kPa for the entire palm.

More pressure pain investigations were carried out by Stevens et al. [1959] and Brennum et al. [1989]. Women generally had significantly lower PPTs than men. The PPTs were mostly performed with a pressure algometer. But PPTs vary considerably in different publications depending on the methodology, the anatomical region of the pressure surface and the pressure increase. In addition a dependency of pressure sensation in relation to the shape, size and material of the pressure stamp has been shown [Hall et al. 1993].

In the work of Johannson et al. [1999] PDT for three areas of the palm were determined by pressure stamp. The results shows that the index finger, the center of the hand area and the thumb have different sensations, and the thumb as opposed to the index finger and the center of the hand area is more sensitive to pressure. PDT for the middle finger is 188 kPa, for the center of the hand area is 200 kPa, and for the thumb is 100 kPa [Johannson et al. 1999].

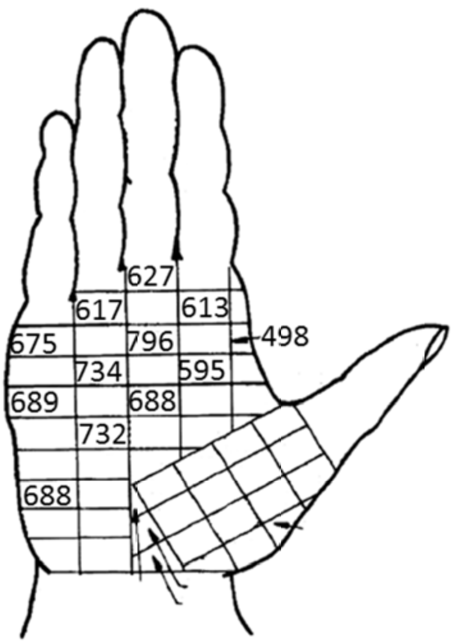


Figure 2. Model of the pressure pain thresholds (kPA) [Hall et al. 1993]

Since the development of pressure sensor mats, pressure measurements have been performed for hand-held work equipment, particularly in work science [Tofaute 2009]. Pressure sensation was often evaluated with a rating scale for individual sites or for the entire palm. For example, bicycle handlebar grips [Tofaute 2009], handsaw handles [Kuijt-Eversa 2007], and vacuum cleaner handles [Kamat et al. 2010] have all been tested and objectively compared for pressure distribution.

Hall et al. [1997] investigated pressure distribution with respect to handle diameter. He performed pressure measurement with 15 capacitive pressure sensors on 9 handles with diameters between 10 and 100 mm. The subjects transferred a force of 200N for 15-30 sec. to the handles. With increasing diameter, pressure distribution moved from fingers to thumb. Pressure distribution decreased with large palm areas. Maximum grip strength was on average 512 N for men and 352 N for women.

Fellows et al. [1991] examined pressure distribution in relation to handle stiffness. For this purpose the pressure distribution of wood and foam handles was identified with FSR sensors. Because of the deformation of foam grips, higher grip forces were necessary. In addition, foam handles could be controlled as well as wooden handles. However, most subjects preferred the foam grip due to its uniform pressure distribution.

Kong et al. [2005] analyzed pressure distribution from hook handles on the finger. The handles had different curvatures and diameters. Subjects pulled a weight and kept it for 3 sec. Measurements were made with an FSR sensor glove. Discomfort was assessed on a 7-step rating scale. Results showed that the highest force of about 34N mainly affects the proximal finger elements, especially the middle finger. Force distribution, and thus discomfort, grew as diameter was reduced and curvature increased.

3. Results

3.1 Method of evaluating handle comfort

Handle design lacks a method for measuring comfort in individual items of work equipment. The designer basically has to fall back on the PDTs of Hall et al. [1993] and Johansson et al. [1999]. However, these PDT were determined with a pressure stamp in the normal direction to the palm, so – due to the dependence of pressure sensations on shape, size and material –they are not directly transferable to work equipment handles, which produce different pressures on the palm depending on time. Thus the existing PDT, which lies between 100 kPa to 200 kPa, cannot be used to rate handle comfort. For example, handles that produce long-term pressures on the palm below 100 kPa will always be comfortable (e. g. vacuum cleaner handle), and handles that produce a short-term or pulsed pressure of about 200 kPa on the palm will always be uncomfortable (e. g. hammer handle). Also for handles that produce shear forces on the palm surface, such as the handle of a screwdriver, established PDT are irrelevant, because shear forces raise the pressure sensation [Bennet et al. 1979].

Hence the task addressed was to develop a standardized method for individual comfort grip evaluation of work equipment. The method used is based on work-equipment dependent pressure discomfort thresholds (PDT). The method begins with a comfort analysis, for which significant factors of the work equipment must first be defined. The next step is to measure pressure distribution between the handle and hand surface with various handle design parameters. The resultant pressure distributions and pressure pain thresholds (PPT) of the palm are then used to determine a work-equipment dependent multiplier. This enables the PPT to be transformed to PDT. For comfort optimization the PDT can be embedded in a discomfort model and used for assessing pressure distribution for gripping, so the designer can decide after a few minutes how the handle will feel after several hours.

3.2 Application example

The method was developed on an iron bender as application example. An iron bender is a hand tool for bending iron. When bending, the worker is physically stressed and feels pain on the palm after prolonged use. In the worst case, it can cause blisters and redness on the palm that harm the health of the worker. To bend iron, the worker (usually male) as a rule uses the right hand to press the lever and the left hand to hold the iron. Therefore, it is a closed kinematic chain (dual wielding). The working movement extends approximately 60° with respect to the frontal plane. The bending is usually performed in a standing position. The bending process takes about 3 seconds, and one iron is bent per minute. To transmit a high force, the bending handle is gripped with a crush grip. The grip presses against the palm in a form closure, with neutral hand posture. To bend an iron, an average bending force of 200N was determined with a load cell.

A pressure analysis was performed by means of a drill stand. Three different handles were attached to the handle of the drill stand. These handles were printed, and varied in relation to the mean radius (minimum R = 12 mm, medium R = 16 mm, maximum R = 18 mm). All handles had the same surface roughness and stiffness. The force transmissions of the drill stand were measured with a scale on the drill bit. According to the force balance, a force of 50 kg was required on the scale to transmit a force of about 200N on the palm and hence to the iron bender. Pressure distribution on the hand area was measured with 6 FSR (Force Sensing Resistors). Force-sensing resistors consist of a conductive polymer, which changes resistance following application of force to its surface. The hand areas were limited to the main hand zones that were under pressure during the iron bending process. The FSR were bonded to an elastic band and programmed with an Arduino (Nano) microcontroller. Their output voltages were recorded with PLX-DAQ (Data Acquisition Parallax tool). Pressure values were calculated from the output voltages by means of linear and two-exponential approximation functions.

To measure pressure distribution, the handles were attached to the drill stand and pushed with the determined factors in a vertical direction. The working height of the drill stand was set to the same level as the iron bender. The force transmission of 50 kg and the pressure force of about 200 N on the handle were checked with the measuring scale on the balance. The handles were pressed and held for approximately 3 seconds, during which time six pressure values for each of the three grips were recorded with the PLX-DAQ. Each of the three handles was measured three times.

The six pressure values for each handle yielded different pressure distributions. A comfort multiplier by 9.43 % for the palm was determined from the ratio between the average pressure values and the PPT of [Hall et al. 1993]. The difference between PPT and PDT gives the tolerance range of the upper and lower pain thresholds. The lower pain threshold is the so-called discomfort threshold, which is work-equipment dependent. The discomfort model for an iron bender is shown in Figure 3. This was determined from the PPT of Hall et al. [1993] and the work-equipment dependent comfort multiplier. It is possible to see the low pressure sensitivity of hand area 3 (74 kPa) compared to the rest of the hand areas.

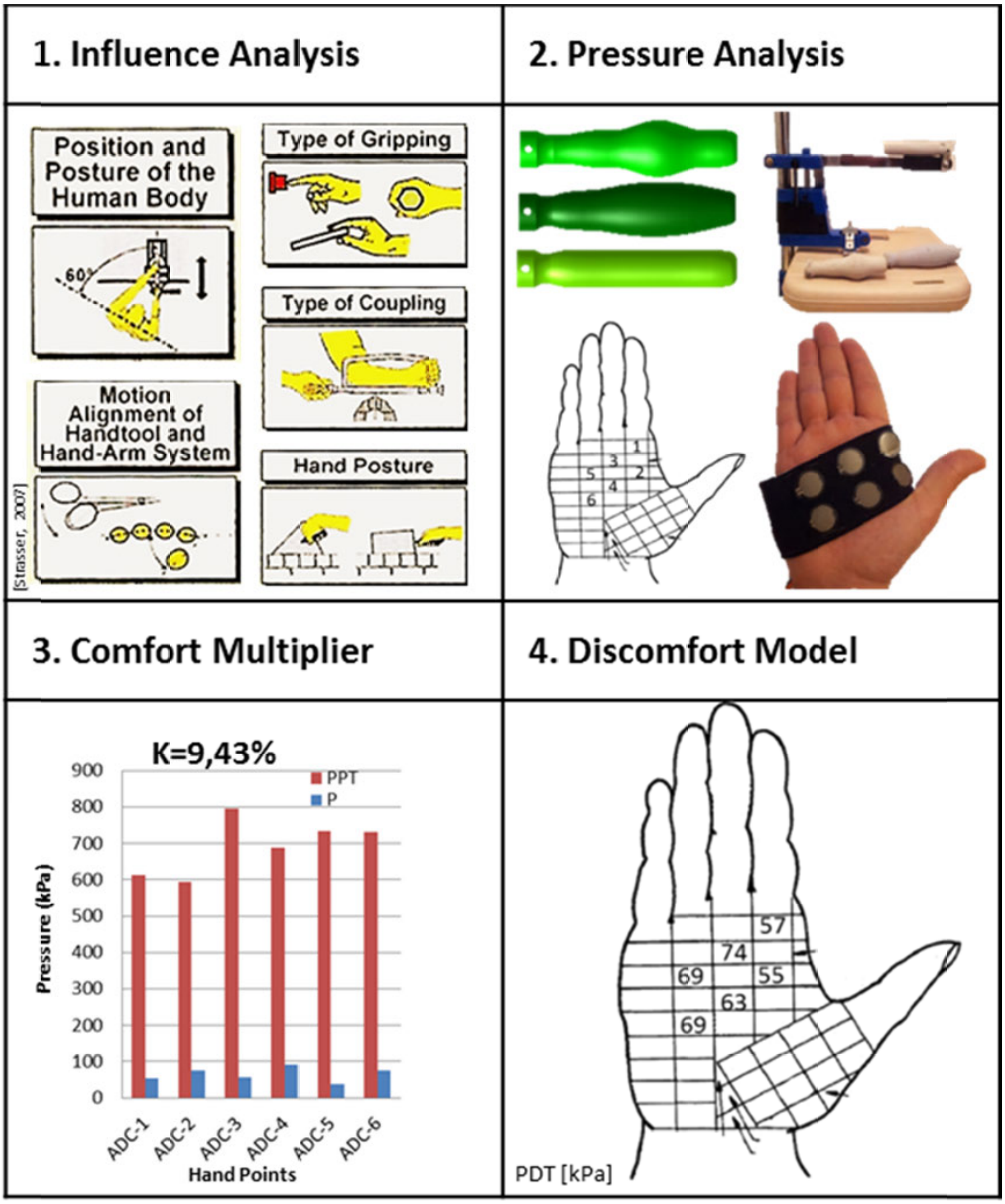


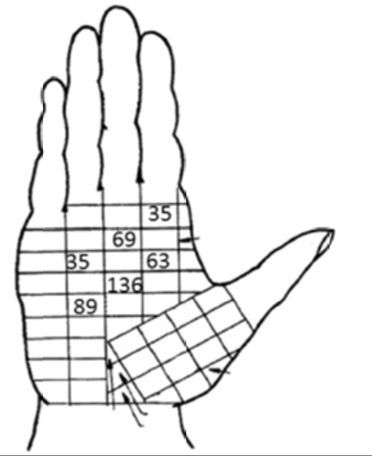
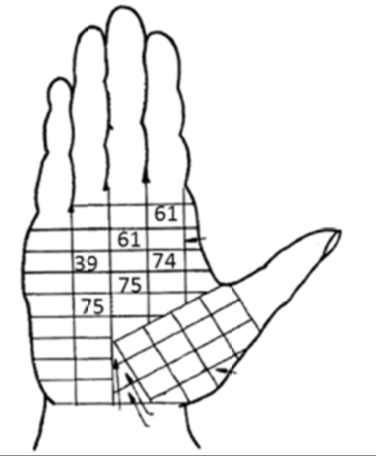
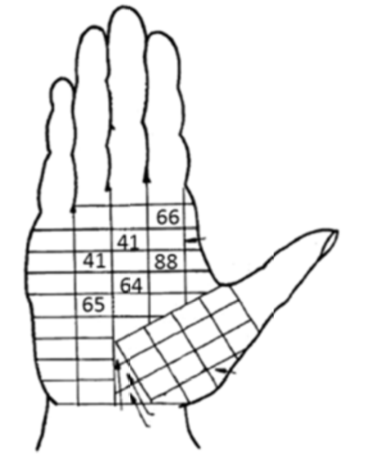
Figure 3. Method of evaluating handle comfort

4. Discussion

The work equipment dependent discomfort model (PDT) in Figure 3 was investigated for the first approach with four male subjects between 27-45 years of age. The subjects had an estimated same hand proportions. For this, the three handles were attached to the handle of the drill stand. The subjects had to press the handles for a total of 3 minutes. The handles were pressed approximately with 200 N and held for 3 sec., resulting in 12 pressure actuations per minute and a total of 36. The discomfort sensation was then evaluated for the six hand areas. The evaluation was conducted with a scale of 1 to 3 (3 = high, 2 = medium and 1 = small discomfort sensation). The subjects were previously instructed about the relevant factors and were obligated to comply with them. However, in the experiments the influence of variables such as body posture, grip type, hand posture and force transmission were also controlled.

Table 1 shows the measurement results for pressure distribution and discomfort evaluation for all three types of handle. Overall a high discomfort can be seen in relation to the hand areas, when pressure distribution lies above the PDT. High discomfort was created in handle shape 1 of hand area 4, as shown by the pressure measurement of 136 kPa, along with a significant excess of the PDT at 63 kPa. If the pressure distribution was below a PDT, the affected hand area was evaluated as experiencing little discomfort. It is also recognizable that at hand area 5 pressure distribution lay within the PDT values for all handles. At pressures with a slight deviation from the PDT, the affected hand area was evaluated as experiencing moderate discomfort. For example, a uniform distribution of pressure was felt in handle shape 2, where pressure distribution shows a slight deviation from the PDT.

Table 1. Discomfort evaluation in relation to the pressure distribution

<table>
<tr><th></th><th>Handle shape 1 " Sharp"</th><th>Handle shape 2 "Oval"</th><th>Handle shape 3 "Flat"</th></tr>
<tr><td>Pressure Distribution (kPa)</td><td>
</td><td>
</td><td>
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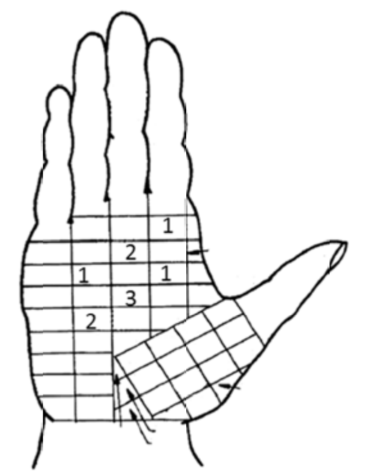
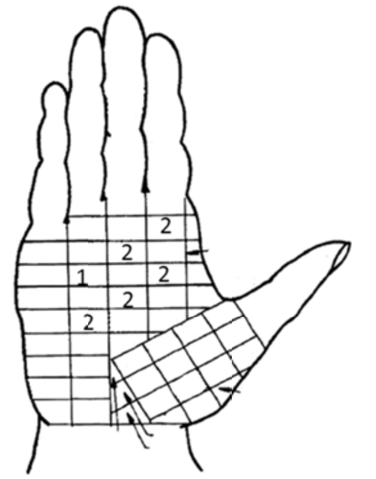
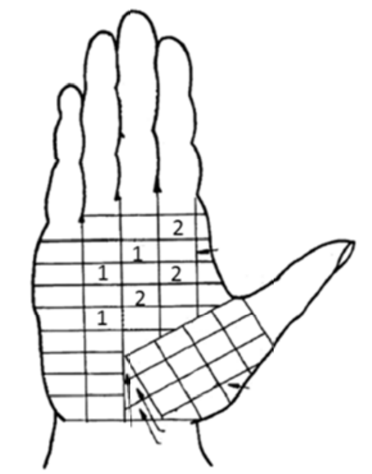
<tr><td>Discomfort</td><td>
</td><td>
</td><td>
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5. Conclusion

The comfort evaluation method developed in this research project by means of the work-equipment dependent discomfort model (PDT) is an effective tool for assessing handle shape. The method was applied using the example of an iron bender with three different handles. At first the influencing factors of the work equipment were analyzed and determined. Pressure distributions were then measured on the palm in relation to three handle shapes with the defined factors. From the average pressure distribution of the work equipment on the palm, and using the PPT from [Hall et al. 1993], a comfort multiplier and a discomfort model (PDT) were derived. The results show that exceeding the PDT produced high discomfort and falling below the PDT produced less discomfort in the subjects. Thus the discomfort model with defined factors can be used for evaluating comfort in using an iron

bender. Furthermore, handle shape can be designed by applying the discomfort model (PDT) to create a more comfortable grip for the iron bender.
The remaining handle design parameters – dimensions, material and surface – are still to be investigated in relation to the PDT. The impact of the variation of dimensions, material and surface on discomfort and pressure distribution remains to be clarified. It may turn out that the main determinant of pressure distribution, and thus discomfort, is variation of shape. In this case a PDT model will depend in practice on shape variation.
In addition, the shear forces that occur during the use of work equipment should be included in the comfort multiplier. For the iron bender the shear forces were neglected, since pressure distribution mostly arose in the use of the palm. But screwdrivers, for example, inevitably generate shear forces on the palm, which may affect the pressure sensation to a high degree [Bennet et al. 1979].
Further studies must be performed with respect to age-related factors among elderly people. Currently, there are no PPTs of elderly subjects over the age of 60 years. It has been found, that older people can perceive pressure difference less well, because of the lowering of sensitivity associated with aging [Zenk 2008]. Other age-related factors include the reduction of the friction coefficient of the hand surface and the reduction of muscle strength and fat. Further research is needed into the role these changes play for the PDT model, by investigating, for example, whether older people have a higher or lower PPT and PDT.

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