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The effects of tool handle shape on hand performance, usability and discomfort using masons' trowels

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ABSTRACT

The effects of five new different handle shapes on hand performance capabilities, usability and discomfort, and also the relationship between these variables were evaluated in the context of masonry work and using masons' trowels as an exemplar hand tool. The prototype handles were designed to provide different patterns of grip so that they could be suited to the hand/tool interaction in particular hand areas. The results showed significant effect of tool handle shape on the hand grip effort, usability, and hand and finger discomfort assessments, but not on the time to complete the masonry task. The hand grip effort and usability were negatively correlated with subjective assessment of hand and finger discomfort, so that a lower level of hand and finger discomfort corresponded to higher hand grip exertion and usability. These findings provide a better insight into the performance and usability issues when using hand tools which can be applied by tool manufacturers to improve industrial hand tool design.

Relevance to industry: These findings present a unique insight into the handle design for industrial hand tool use and support the general conclusion that objective measurements should be supplemented by qualitative subjective assessments to provide a more holistic approach where specific and additional details about the hand tool design characteristics are incorporated from the workers' perspective.

1. Introduction

Hand tools are widely used in many industrial tasks and most workers in manufacturing industry have to use them as a routine in their work activities (Kong et al., 2007; Dianat et al., 2012). Working with hand tools is associated with several health risks. Injuries caused by hand tools has been claimed to be costly, severe and frequent (Aghazadeh and Mital, 1987; Tanaka et al., 1997; Punnett and Wegman, 2004). According to Aghazadeh and Mital (1987), 9% of all work-related compensable injuries in the United States (e.g. an estimated 265,000 hand tool related injuries annually) were caused by hand tools, in which the most injured body parts were the upper extremities. With respect to the type of industry, construction, agriculture, manufacturing and mining industries had the greatest number of reported injuries (Myers and Trent, 1988; Aghazadeh and Mital, 1987).

The evidence also suggests that there is an association between the use of hand tools and onset of work-related musculoskeletal symptoms (Aghazadeh and Mital, 1987). A number of occupational factors such as forceful exertions, repetitive movements, awkward postures and localised mechanical stresses can lead to the development of musculoskeletal problems (Buckle and Devereux, 2002; Aldien et al., 2005; Nazari et al., 2012; Dianat and Salimi, 2014). Working with hand tools involves one or more of these factors (Myers and Trent, 1988; Aldien et al., 2005; Das, 2007). Using hand tools, particularly if the job requires supporting the tool's weight for a prolonged period of time, may also cause increased discomfort and fatigue (Fellows and Freivalds, 1991), which may be due to the existence of high stresses on the anatomical structures of the hand (Aldien et al., 2005).

Ergonomically designed hand tools can reduce user discomfort, biomechanical stresses, and risk factors for musculoskeletal symptoms and injuries (Freivalds, 1996; Li, 2003; Kuijt-Evers et al., 2007). Moreover, by improving the quality and usability of hand tools it is possible to improve efficiency and work productivity (Kuijt-Evers et al., 2007; Päivinen and Heinimaa, 2009). The design

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of tool handle, which interfaces with the human hand, is of major importance in this regard (Das, 2007).

It has been suggested that for reliable assessment of the ergonomic quality of a tool it is necessary to take into account both objective and subjective measurements (Strasser et al., 1996; Kuijt-Evers et al., 2007). Moreover, the combination of both objective and subjective evaluations enables the identification of new design factors in terms of the tool geometry parameters (Päivinen and Heinimaa, 2009). A number of hand tool evaluation studies have considered objective measurements (e.g. physiological or physical measurements) along with subjective assessments (e.g. comfort/discomfort, preference, satisfaction, usability, ease of manipulation, etc.) (Strasser et al., 1996; Freund et al., 2000; Groenesteijn et al., 2004; Li, 2003; Kuijt-Evers et al., 2007; Päivinen and Heinimaa, 2009). However, there are limited and contradictory findings about the relationship between objective and subjective measures in evaluating hand tools with some studies showing positive correlation (Strasser et al., 1996; Li, 2003; Päivinen and Heinimaa, 2009), while others show no correlation (Freund et al., 2000; Kuijt-Evers et al., 2007). This is, therefore, an area that requires further investigation.

A review of the literature shows that very few studies have proposed handle design parameters for masons' trowels. Strasser et al. (1996) evaluated an ergonomically designed handle of a mason's trowel in comparison with two standard types, both with a round cross-section of the handle. The ergonomically designed handle, which was based on the hypothesis that an ergonomically designed handle should enable a specific relief of the strain in the grip musculature and the ulnar deviation muscles, was shown to be better than the standard types in terms of both objective (e.g. electromyography measurements) and subjective measures. However, the improvement in hand grip performance evaluated by objective method was much less than that obtained from subjective assessments.

The aims of this study were to assist in introducing design alternatives for improving hand tool handles and to evaluate the relationships between objective and subjective measurements in evaluating hand tools. The effects of five prototype handles, which were designed to provide different patterns of grip with the aim of improving the hand/handle interface, on several hand performance capabilities and subjective assessments were studied.

2. Methodology

2.1. Participants

Eighteen male masons were recruited to participate in this study. Their ages ranged from 22 to 58 years (mean age = 34.8 years, SD = 11.3), and had been working in their current jobs between 5 and 35 years (mean = 14.5 years; SD = 9.4 years). They were all right-handed and healthy, with no history of upper limb injury or musculoskeletal disorders. Anthropometric data of the participants is presented in Table 1.

2.2. Prototype handles

To fulfil the objective of the study for evaluation of the design of hand tool handles, masons' trowels were selected as exemplars of one of the most common hand tools used in construction work. Working with a mason's trowel was considered to be a good choice to represent realistic conditions of work and to cover the range of different variables evaluated in the study. The prototype handles were constructed by modifying conventional masons' trowels frequently used by masons for construction work, with the modification being to the handles so that it could be suited to the hand/tool interaction in particular hand areas. The new prototype handles were developed in 3D modeling software packages (Rhinoceros and CATIA) and made of polyester and fibreglass using the hand lay up method, a well-known technique in engineering composites.

Table 1
Anthropometric data of participants in the study ($n = 18$).

Characteristics	Mean (SD)	Range
Age (years)	34.8 (11.3)	22–58
Stature (cm)	175.8 (8.8)	156.4–190.3
Weight (kg)	72.1 (12.1)	50.3–99.8
Hand length (mm)	192.7 (9.0)	180–209
Hand width (mm)	89.0 (7.4)	65–98
Hand thickness (mm)	33.7 (2.4)	30–41
Palm length (mm)	110.9 (6.8)	103–125

The handle shape should be designed to maximize task performance, usability and contact area between the hand and the handle to provide better pressure distribution, leading to reduced discomfort (Groenesteijn et al., 2004; Kong et al., 2007, 2012; Harih and Dolšak, 2013, 2014). The prototype handles in this study were constructed based on different design approaches, and therefore represented different patterns of hand grip. The first prototype handle allowed both horizontal and vertical grip axes as necessary. Handle design A, together with handle design D, was also slightly curved to accommodate the concave surface formed by the fingers and the convex surface formed by the heel of the palm during gripping. Handle design B was equipped with two protruding edges (slipguard) at both ends of the handle to prevent the hand slippage in the direction of the handle axis. Furthermore, several previous studies have shown that handles with variable diameters can influence hand performance and subjective discomfort (Welcome et al., 2004; Kong and Lowe, 2005; Harih and Dolšak, 2014). Therefore, another design possibility was to consider handle designs with variable diameters. Thus, handle design C had a larger diameter at the distal end of the handle, while handle design E was broader at its forward end. The structures of the prototype handles are shown in Fig. 1, and their characteristics are presented in Table 2.

2.3. Experimental task

For the evaluation trials, participants performed a simulated masonry task using different trowel designs. For this, a workstation for wall construction was simulated which required the participants to construct a wall on a working surface with the approximate dimensions of 1 m height and 3.5 m length. Wall construction consisted of mortar application, brick laying and finishing. The task required that each participant to construct a brick wall in three rows using conventional bricks (as frequently used in construction work). The number of bricks in the first, second and third rows were 13, 12 and 11, respectively, with a total of 36. The brick dimensions were 220 mm × 105 mm × 55 mm, with a weight of 2200 g. The brick laying task required that each participant pick up a brick from the supply stack with both hands and position it (from the right to the left side) on the wall. The finishing task required that each participant scrape off excess mortar or tap on a brick to maintain a level wall. A mortarboard with 0.8 m height was placed behind the bricklayer, and a stack of bricks was placed on both sides of the mortarboard on the same height. The participant was instructed to perform the task at his normal work pace and the time to construct the entire wall was measured. The mortar was made of lime mixed with aggregate. An experienced masonry worker maintained an adequate supply of mortar during the experimental trials.