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Objective classification of performance in the use of a piercing saw in jewellery making

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ABSTRACT

Data from 15 jewellery students, in their 1st and 3rd years of training, were analysed to show how data collected from work settings can be used to objectively evaluate performance in the use of tools. Participants were asked to use a piercing saw to cut 5 lines in a piece of metal. Performance was categorised in terms of functional dynamics. Data from strain gauges and a tri-axial accelerometer (built into the handle of the saw) were recorded and thirteen metrics derived from these data. The key question for this paper is which metrics could be used to distinguish levels of ability. Principal Components Analysis identified five components: sawing action; grasp of handle; task completion time; lateral deviation of strokes; and quality of lines cut. Using representative metrics for these components, participants could be ranked in terms of performance (low, medium, high) and statistical analysis showed significant differences between participants on key metrics.

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1. Introduction

This paper focuses on the question of how one distinguishes between different levels of performance in the use of tools in the workplace (rather than in laboratory settings). Ergonomics has a long history of researching hand tools (Dudley, 1968; Freivalds, 1987; Greenberg and Chaffin, 1977; Kuijt-Evers et al., 2004; Lewis and Narayan, 1993; Mital, 1991; Rubin et al., 1952; Salvendy and Seymour, 1973; Seymour, 1953, 1972). While the study of performance and expertise in tool use played a major role in ergonomics research in the 1960s and 1970s, it has received less attention in recent years (Baber, 2003, 2006). At an applied level, understanding what constitutes variability in tool use could inform the design of tools or the training of tool users, and at a theoretical level, such understanding can help in explaining how skill is acquired and why it varies across individuals. In order to define levels of performance in tool use, the paper follows the functional dynamics approach that has been developed by Bril and her colleagues (Biryukova and Bril, 2008; Bril et al., 2010; Parry et al., 2014).

1.1. The ergonomics of human tool use and functional dynamics

Much of the work into functional dynamics of tool use has focussed on flint-knapping. In this activity, a core of flint is worked using a hammer stone. When performing flint-knapping, experts (in comparison to novices) show a greater range of joint angle excursions in their movements (Biryukova and Bril, 2008), have significantly lower variability in kinetic energy (Bril et al., 2010) and are able to modify several parameters at the same time whereas novices tend focus on one parameter at a time (Vernooij et al., 2012). Thus, an activity which might appear quite mundane exhibits variability in terms of performance, such that it can take time and practice to become proficient. Roux et al. (1995) showed that expert craftsmen (using hammers to make beads from glass or stone) exhibit significantly less variation in performance than less experienced workers, suggesting that not only is there greater accuracy but also greater precision, or consistency, across the skilled tool users.

The work of Bril and her colleagues suggests that it is important to consider the type of action that is required to achieve a goal, and then determine the parameters which contribute to this action. Rather than seeing the goal in terms of the outcome of tool use, it makes more sense to regard the goal as one of several parameters which need to be managed. In this way, performance involves the definition of a dependent variable through the management of a set

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of independent variables. In studies of flint-knapping, the chosen dependent variable was the kinetic energy of the hammer as it strikes the stone (F_{kin} = ½mass × velocity).[1] This dependent variable, the functional parameter, defines the problem that the tool user is seeking to solve within the constraints imposed by the task. For flint-knapping, the problem is to remove pieces of flint from the core stone using an appropriate level of force (too much force could damage the core, too little could be ineffective). In order to manage this functional parameter, the tool user will modify velocity with which the hammer stone is moved. This represents the regulatory parameters (which the person can adjust) that result in the desired functional parameter. In the work of Bril and colleagues, regulatory parameters involve variation in potential energy, trajectory and distance travelled by the hammer as well as muscular effort. However, this set of regulatory parameters can lead to infinite ways in which actions can be performed, i.e., the well-known degrees of freedom problem in movement science (see below). Hence, the user will set limits on the selection of actions through the use of regulatory parameters, which can be further constrained by the control parameters, such as mass of the hammer stone used or other task demands.

In the field of biomechanics it is well known that muscle use and limb-segment movement shows inter- and intra-individual variation for the same movement execution (Scholz and Schöner, 1999; Riley and Turvey, 2002; Bergin et al., 2014). Examples are muscle activation patterns during human walking and running (e.g. Arsenault et al., 1986; Guidetti et al., 1996; Winter and Yack, 1987) or muscle recruitment in response to pain, such as lower back pain (Hides et al., 1996; Tucker et al., 2012; D'hooge et al., 2013). Similarly, EMG activity varies both with respect to muscle recruitment and activation intensity across participants when performing carpentry activities (Hammarskjöld et al., 1990). While the generation of a movement may vary within a bounded parameter space, visual inspection of the movements may lead one to conclude that they are identical. Quantification of this variability in movement may allow comparison of task performance across different people without the degree of freedom problem becoming a confounding factor. In the present study, we seek to quantify such parameters to investigate whether they indeed correlate with level of performance.

For this paper, we seek to define functional, control, and regulatory parameters for the use of a piercing saw. We can relate these parameters to Ergonomics notions of tool use through a quotation from Seymour (1972): *"First, the experienced worker usually employs 'smoother' and more consistent movements […]. Secondly, the experienced worker operates more rhythmically, indicating that a higher degree of temporal organization has been achieved. Thirdly, the experienced worker makes better use of the sensory data […]. Fourthly, the experienced worker reacts in an integrated way to groups of sensory signals, and makes organized, grouped responses to them".* The summary of relevant parameters from past work is as follows:

i. Control Parameters include the mass of the hammer stone and the velocity with which the hammer stone hits the core. Experts showed greater consistency in their behaviour when control parameters changed. The suggestion that there are differences in expert and novice hammering accords with the observation of Salazar and Knapp (1996) that using a hammer in the non-preferred (and, by implication, less skilled) hand is significantly inferior to use in the preferred hand;
ii. Regulatory parameters include the trajectory followed by the hammer stone and the potential energy applied. Regulatory parameters, to some extent, are under the control of the participant, but can lead to constraints on other aspects of task performance. Improved performance arises when the action become smoother and less variable because of the integration of actions into a seamless sequence. In Seymour's (1972) terms, this shows how experts are able to use a 'higher degree of temporal organization', i.e., demonstrating less variability in the timing of actions, and also to make 'better use of the sensory data', i.e., indicating a capability to pay attention to visual, tactile, auditory cues, in managing their actions (see also Dudley, 1968; Salvendy and Seymour, 1973; Seymour, 1953; Rubin et al., 1952);
iii. Movement Parameters – the kinematics of the task performance. As Seymour (1972) put it, the expert actions are performed in a 'smoother', 'more consistent', 'more rhythmical' manner;
iv. The Functional parameter, in the case of flint-knapping, is kinetic energy, which is not directly under the control of the participant but represents the dependent variable which defines performance. In the studies discussed above, Bril and colleagues show that expert activity when performing flint-knapping tasks results in constant kinetic energy, which is kept as low as possible without compromising performance between movement cycles. Presumably, kinetic energy relates to the manner in which a blow is made on the core stone. Using other tools for other purposes are likely to involve the definition of other Functional parameters, and it is a question for this paper as to what the Functional parameter might for people using piercing saws.

1.2. Measuring tool use in the field

In previous research, strain gauges have been fitted to tool handles in order to measure grip force (Fellows and Freivalds, 1991; Kilbom et al., 1993; McGorry et al., 2003; Murphy et al., 2000; Stoy and Aspen, 1999). In this paper, we follow the lead of McGorry (2001) who mounted strain gauges in a bespoke tool handle in order to measure grip force. The handle was made from a hexagonal bar, milled to produce three beams around a hollow centre, with the strain gauges mounted on top and underneath each beam. Our design (Fig. 1) is much the same (except we mount the strain gauges on to strips which are then screwed to hexagonal bolts at each end). The handles can then be fitted with different tool heads; in this paper, we attached a jeweller's piercing saw to the handle. In addition to measuring grip force, we were interested in the kinetics of tool use. This has received less attention in the recent ergonomics literature, although the previous section considered some of the research in the motor skills domain which looks at the relationship between tool-use and movement. In this study, we have fitted a tri-axial accelerometer in the tool's handle to derive kinematic parameters.

The handle consists of three strips of stainless steel (140 mm × 14 mm × 2 mm) attached to two hexagonal bolts (25 mm diameter); attachment is to alternate edges on the bolt. Each strip has a 120Ω strain gauge mounted on it, which is used to detect the bending force exerted on the bar. A tri-axial accelerometer (ADXL335), strain gauge amplification circuit, microcontroller, and battery are all contained within the space between the strips, while a Bluetooth wireless module is mounted on the end of the handle. The analogue signals from the strain gauge circuit and

[1] For example, out of the 15 participants, participant P01 is ranked 3rd for Resultant Velocity, 8th for Peak Grip Force, 5th for Time per Line, 15th for Line Quality and 3rd for SD x; arranging these ranks in gives 3 3 5 8 15; thus, the median value is 5. This estimation of median was repeated for all participants.

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