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Strategies in performing a manual assembly task

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ABSTRACT

A study of naïve participants' strategies in manual assembly is reported. Four groups of ten participants assembled hacksaws under varying conditions of the number of aids given to participants. The aids were provision of an assembly jig, instructions on use of the jig and components set up in an ergonomically-designed workplace. Assembly took place under four conditions: (a) with no jig or instructions (b) with a jig and with no instructions on its use (c) with a jig and with instructions and (d) with a jig, instructions and also an ergonomically designed workplace in which all parts were placed within the zone of convenient reach. Video recording was used to measure performance times and strategies in assembling the hacksaw. The 40 participants used a total of 32 models of liaison sequence and 152 patterns of assembly sequence. Participants used many different strategies in their early learning and generally settled down to a single pattern after the early trials. The common strategy of participants was to pick and assemble the longer and heavier components, followed by small and lighter components.

Relevance to industry: Participants showed many different patterns of assembly, even for a simple product. The data indicate a need for the industrial engineer to determine the ergonomically best layout of components for assembly and demonstrate the best assembly sequence to the operator.
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1. Introduction

In order to improve productivity and efficiency in industrial assembly tasks, many assembly lines have become automated to a degree dependent on the complexity of the task. Where production runs are small or where a high degree of manipulation of components is required, manual assembly is still an important part of production.

Manual assembly has been studied by various means:

(i) Time and motion studies (Maynard et al., 1948; Barnes, 1980)
(ii) Generation of assembly sequences (De Fazio and Whitney, 1987; Homem de Mello and Sanderson, 1989; Lui, 1988),
(iii) Cognitive modelling of assembly tasks (Baggett and Ehrenfeucht, 1988, 1991; Fish, 1993; Van Santen, 1970; Wilde, 1978; Shalin et al., 1996)
(iv) Measures of the subjective difficulty of the assembly task in terms of the component tasks (Richardson et al, 2004; Richardson and Jones, 2006)
(v) Studies of the effect of structure on manual assembly performance (Prabhu et al., 1995; Fish et al. 1997)
(vi) Study of how a worker would set up their own workplace (Lim and Hoffmann, 1997)
(vii) The effect of instructions on manual assembly performance (Verneau, 2014).

The one factor that has not been reported is how a worker goes about completing the assembly task if given the freedom to choose their own methods of doing so. This involves the learning of the process of picking and assembling parts and the way in which this strategy changes with practice (Crossman, 1959) in order to minimize assembly time.

Baggett and Ehrenfeucht (1991) investigated strategies in performing a manual assembly task and found that participants adopted a bottom-up approach when asked to build an 80-piece object made from the Fischer-Technik assembly kit. Baggett and Ehrenfeucht (1988) hypothesized that the resulting 'tree' can be viewed as the worker's mental model of the object and, when they build the object, the person "mentally breaks it down according to the tree structure and builds it up according to the conceptual division".

The task of putting together some components or parts, outwardly, seems to just involve the monotonous movements of

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two hands and eyes only. However, when a person is requested to build a more complex object with more components and repeat the task for say 20 trials, then there is no guarantee that the object is assembled in exactly the same sequence for every trial. Unlike robots which could be preprogrammed to do repetitive tasks exactly the same way at all times, human operators would be likely to attempt different sequences unless they are specifically instructed by the industrial engineer or supervisor to follow the same sequence for every trial (Crossman, 1959).

The person may use a variety of methods or sequences each time they build the same object since there may be more than one sequence for assembling an object. Questions could be raised as to why different methods or sequences were used to build the same object and what cognitive aspects of performance are involved in the task. The above queries are of much interest from the human factors point of view. Thus the assembly process involves not just manual work, but also has a large cognitive component (Karwowski et al., 1999). It is through a process of trying different methods of joining parts and joining and in different orders, that a person can develop a method that is best according to some personal criteria, such as minimization of time, bodily comfort/stress or mental/physical effort.

Bourjault (1984) presented a method which, using a set of rules derived from questions about the parts that are to be mated, will give all of the sequences that are practical for the assembly of an object. This method was simplified by De Fazio and Whitney (1987) to allow the method to be used for assemblies with many more components. This 'Liaison-sequence analysis' can be used for finding the best way to assemble components for a given assembly task as it gives a full description of the possible sequences for the assembly and can be represented in a simple graphical form (De Fazio and Whitney, 1987). De Fazio and Whitney claimed that their method of generating a complete set of assembly sequences and reducing this set by eliminating any awkward methods was more efficient than the standard industrial engineering methods that may lead to the same end result. Liaison-sequence analysis has the advantage that all possible assembly sequences are considered. Lui (1988) used graph theory to describe the network of assembly, called a liaison diagram, where a node represents a part, a subassembly, or a non-assembly task, and a liaison represents the relationship between two nodes, such as mating (Bourjault, 1984). Lui claimed his research findings would assist the engineer to examine all valid assembly sequences and reduce the large number of all possible sequences to a size useful for further analysis. As a result, an engineer can find a good assembly sequence with the confidence that no other sequence has skipped his/her attention. Such analyses have been carried out for the hacksaw assembly tasks in this paper.

The purpose of the present work was to investigate the strategies of participants in performing a relatively simple industrial assembly operation. The product used in the experiment was a common hacksaw. This research is an extension of that of Lim and Hoffmann (1997) where the effects of having participants design their own workplace layout was studied.

2. Method

2.1. Experimental design

The assembly task was performed under four different conditions, as summarized in Table 1. In the text, these conditions are coded as follows, representing the presence or absence of an assembly jig (NJ, YJ), presence or absence of instructions on how to use the jig (NI, YI) and the presence or absence of an ergonomically designed workplace (NE, YE) in which all of the components were arranged within the zone of convenient reach (ZCR, Pheasant, 1986).

Table 1
The four experimental conditions used in the assembly experiment.

Condition code	Jig used?	Participant instructed how to use jig?	All parts ergonomically arranged?
NJ,NI,NE	No	No	No
YJ,NI,NE	Yes	No	No
YJ,YI,NE	Yes	Yes	No
YJ,YI,YE	Yes	Yes	Yes

2.2. Participants

Forty right-handed participants took part in the experiments. These had a mean age of 24.5 years and ranged from 18 to 42 years. We selected only right-handed participants due to the design of the jig being specifically for right-handers. No participant had any industrial experience of assembly work, were all from non-engineering background and were not familiar with ergonomic principles. There were ten participants in each of the four experimental conditions. Mean arm characteristics related to reach envelopes are given in Table 2. Participants took part under the ethical guidelines of the University of Melbourne.

2.3. Apparatus

Participants sat at a work bench of height 660 mm that provided ample space for setting up the workplace (depth 750 mm and length 1220 mm). An adjustable chair was used for participants to have the seating posture recommended by Grandjean (1988) for light assembly work, with the elbow 50–100 mm above the table surface. Components of 20 hacksaws were placed in bins or stands (Fig. 1a) on the work bench. The arrangement of components in three of the four experimental conditions was made by the participant; a typical setup, where a jig was used for assembly, is shown in Fig. 1b.

2.4. Procedure

The task was explained to the participant at the start of the experiment, along with a set of written instructions. As learning was being studied, no practice trials were given and a different group of participants was used in each condition. Participants were required to work as fast as possible, while maintaining accuracy of assembly of the 20 hacksaws.

In the conditions where participants were allowed to design their own workspace (NJ,NI,NE; YJ,NI,NE and YJ,YI,NE), the

Table 2
Mean and standard deviation of arm lengths (mm) of the group of participants that determine the size of the reach envelopes (normal work area and zone of convenient reach).

	Female mean	Female SD	Male mean	Male SD
Right hand: center of palm to elbow	309.3	21.0	339.7	35.4
Right hand: elbow to shoulder	303.4	26.2	335.0	29.6
Right shoulder to left shoulder	394.1	31.1	445.6	27.3
Left hand: elbow to shoulder	303.4	26.2	335.0	29.6
Left hand: center of palm to elbow	309.3	21.0	339.7	35.4

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