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Maximum acceptable effort for connector assembly in automotive manufacturing

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ABSTRACT

The manual assembly of connectors has job risk factors associated with musculoskeletal disorders including force, posture and repetitiveness. A variety of laboratory simulated connector assembly tasks, based on pilot work conducted at an automotive manufacturing plant, were studied using adapted psychophysical methods. The maximum acceptable frequency of connector assembly for six grip types was determined for various combinations of force and distances. In studies with a three-day acclimation and trials scheduled for 8-h days, 4-h trial lengths are sufficient. Distance did not influence acceptable frequency for hand/arm motions between 7 and 16 mm. There might be differences in maximum acceptable frequency for grip type, and force might affect acceptable frequency. Force × Cycle Rate (FCR) or time-weighted average percent maximum acceptable effort (TWA-%MAE) for these short duration tasks can be used for guidance.

Relevance to industry: The current study addressed industrial tasks that require high finger exertions for very brief periods. The force and frequency may provide less reliable design guidance than using the force exertion as a percent of maximum voluntary effort adjusted for duty cycle or using a time-weighted average of %MAE.

1. Introduction

Cumulative trauma disorders (CTDs) are a major concern where repetitive tasks are performed. For upper extremity CTDs, it is generally accepted that applied force, awkward postures, static loads, mechanical stress, and vibration are job-related risk factors (Armstrong et al., 1982; Bernard, 1997; Kilbom, 1994; National Research Council and the Institute of Medicine, 2001; Silverstein et al., 1987). Because there is incomplete understanding of the risk factors, a common strategy of job design is to eliminate as many risk factors as possible.

Psychophysical techniques are well established for investigating job risk factors in manual work. Fox and Smith (2014) used frequency as a dependent variable for manual lifting of light loads. Their paper points out that in psychophysical studies frequency is usually controlled and that there are optimal frequencies for manual material handling. Marley and Fernandez (1995) used psychophysical techniques to establish maximum acceptable frequencies at varying wrist postures for drilling tasks with relatively long duty cycles. For repetitive wrist motion, Snook et al. (1995, 1997) used psychophysical methodology to develop tables of maximum acceptable.

Automotive manufacturing requires repetitive manual work involving the hands, often to connect two parts. For instance, electrical cables are connected together via a male and female plug; spark plug wires are connected to spark plugs; and hoses are connected to a metal tube. The closing or mating of these connectors often involves high forces and non-neutral postures over short duty cycles (Potvin et al., 2006; Silverstein et al.,, 1987). Potvin and associates (Potvin et al., 2006; Potvin et al., 2000) used psychophysical methods to assess acceptable work demands for manual closing of connectors at fixed frequencies. Recently, Potvin (2012) assembled data from his studies and others to develop a relationship between duty cycle and relative effort.

For connector assembly, interesting questions in the evaluation and design of those jobs are the degree to which the grip type, distance of travel and force would affect acceptable effort. In addition, the instructions in psychophysical studies include a duration that is a working day. For a study designed to be performed over consecutive workweeks, would a 4-h trial provide a similar outcome to an 8-h trial? The objective of this study was to examine the effects of grip, force, and travel distance on acceptable

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frequencies of connector assembly in automotive assembly using a modified psychophysical method. There were four hypotheses that were tested for the data reported in this paper.

- Null Hypothesis 1: There is no difference in acceptable frequencies associated with a 4-h and 8-h trial.
- Null Hypothesis 2: There is no difference in acceptable frequencies associated with distance.
- Null Hypothesis 3: There is no difference in acceptable frequencies associated with grip.
- Null Hypothesis 4: There is no difference in acceptable frequencies associated with force.

The results were then examined in terms of Force × Cycle Rate (FCR), duty cycle (DC), and time-weighted average (TWA) percent maximum acceptable effort (TWA-%MAE).

2. Methods

2.1. Scoping study

A scoping study was performed to determine grips used and to set realistic bounds on force and travel distance. Force–distance curves for 47 connectors found in seven engine plants and one final assembly plant were described. Engine plants have a range of electrical and mechanical connections that include small electric connectors with a few wires, larger connector blocks, spark plug wires, and vacuum and coolant hose connections. The final assembly plant had small and large electrical connectors. While there was not a random sampling of connectors, a range of type was sought. A linear displacement transducer and force gage were coupled and used to collect force–distance (displacement) curves by slowly closing the connector. There were three to ten trials, with new connectors for each trial. Typical curves had linear relationships between force and distance. The maximum force occurred at the maximum connector displacement with average and standard deviation of 112 ± 34 N over a range of 35–178 N. The distances from first contact to closure had an average and standard deviation of 11.2 ± 4.6 mm over a range of 4.5–25 mm.

For all jobs that involved the 47 connectors, task activities were videotaped for grip types used on that job, whether a force–distance profile was determined or not. To summarize grip types, 125 connectors were studied, where 63 were right hand only, 41 were left hand only, and 21 involved both hands. Because the right and left hands were considered independently, there were a total of 146 connector assembly postures considered in the scoping study. Six grips accounted for 95% of the observations: pulp pinch (tips of thumb and index finger) (31%), lateral pinch (tip of thumb to middle phalanx of index finger) (20%), thumb press (19%), finger press with tips of the index and middle fingers (10%), medial grasp with thumb wrapping over fingers (8%), and oblique grasp with thumb aligned along the axis of the connector (7%).

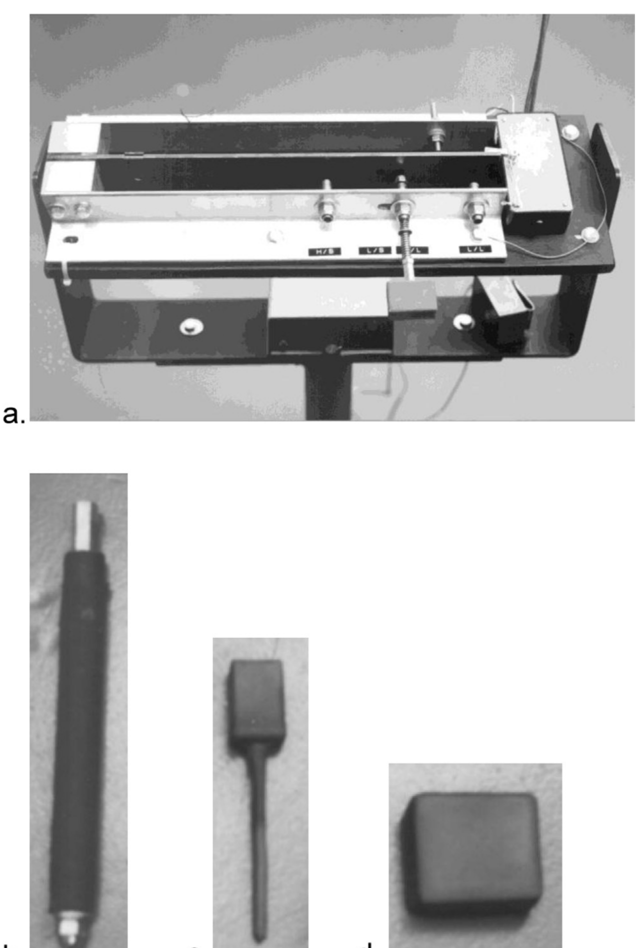
2.2. Experimental hardware

The test platform was designed to control force, distance, and grip. From the scoping study, two values for force and distance were selected; they were the mean plus and minus one standard deviation to represent the lower and upper halves of the distribution. The Low force was 78 N and the High force was 146 N. The Short distance was 7 mm and the Long distance was 16 mm. The grips were two pinches, two presses and two grasps. The dependent variable was the self-selected acceptable frequency.

Six identical connector platforms were built with sufficient adjustability to accommodate all experimental conditions and participant variability. The key feature of the connector platform was a cantilever beam that controlled the force and distance (see Fig. 1). By adjusting the load application point of the gripping fixture on the beam, the required closing force could be adjusted to either 78 N or 146 N. By adjusting a stop positioned behind the beam to control deflection, the closing distance could be adjusted to either 7 mm or 16 mm. The force–distance profiles had a linear relationship similar to the profiles found during the scoping study.

Three different gripping fixtures shown in Fig. 1 were built to accommodate the six experimental grips. The size of each fixture was representative of the connectors from the scoping study. Aluminum blocks, coated with a plastic dip compound, were used for the pinch and press grips. The lateral pinch gripping fixture ($W \times H \times L$) was 12 × 18 × 30 mm; the gripping fixture ($W \times H \times L$) for the pulp pinch, thumb press, and finger press were 20 × 45 × 40 mm. A steel shaft, cushioned with butyl rubber and covered with friction tape ($D \times L$) (15 × 155 mm), was used for the medial and oblique grasps.

A data acquisition system (100 Hz sampling rate) monitored the initiation and successful completion of an effort. An adjustable electronic timer, which operated between 0.65 and 30 pulses per minute, was built for each platform. The timing interval for each timer was controlled by the participant and monitored by the data



a. b. c. d.

Fig. 1. Photographs of a. test platform, b. medial and oblique grasp fixture ($D \times L$) (15 × 155 mm), c. lateral pinch gripping fixture ($W \times H \times L$) (12 × 18 × 30 mm) and d. gripping fixture for the pulp pinch, thumb press, and finger press was ($W \times H \times L$) (20 × 45 × 40 mm).