ACCEPTABLE PEAK FORCES AND IMPULSES DURING MANUAL HOSE INSERTIONS

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INTRODUCTION

Tasks including drilling [1], gripping [2], automobile trim installation [3], and the mating of electrical connectors [4], have been studied recently using psychophysical approaches. However, no study to date has determined the forces that workers find acceptable during manual engine hose installations, even though hose failure in automobiles can in part be attributed to incorrect assembly practices [5].

METHODS

Five women in each of 3 age groups (20 year olds (1.72 (0.07) m; 65.1 (7.9) kg), 30 year olds (1.66 (0.06) m; 72.9 (8.6) kg), and 40+ year olds (1.62 (0.08) m; 82.1 (12.7) kg)), had no previous upper limb injuries or experience with hose insertion tasks, and signed a consent form accepted by the University of Windsor Research Ethics Board.

A tri-axial load cell was mounted to a hose insertion jig supported by an angle iron frame. An ABS plastic hose (length 15.5 cm, diameter 3.8 cm) surrounded a hardwood dowel and base plate that was anchored to the load cell. The jig and load cell could swivel and be adjusted for height. The angle iron frame was mounted to the concrete floor of the lab.

Subjects in each age group were randomly assigned to 9 of 15 total conditions for posture (Lateral Push-Far (LPF), Lateral Push-Near (LPN), Midline Push (MPush), Midline Pull (MPull), and Push Down (PD)), and frequency (1, 3, and 5 insertions/minute. Each subject trained for a total of 24 hours (2.67 hours per posture/frequency condition), and was tested for 3 hours (0.33 hours per condition). Posture conditions were randomly presented. Subjects heard a signal at the set frequencies, via an earphone, after which they applied force to the hose using a power grip until the next signal was presented (750 ms). Subjects applied the maximum force that they found acceptable for 8 hours without feeling fatigued or discomfort. MVCs were executed in each posture.

Force data were A/D converted using a 12-bit card and sampled by computer at 1000 Hz using custom LabVIEW software. Signals were amplified and filtered with a dual pass Butterworth digital filter (f_c = 15 Hz). A total of 1250 samples (1.25 s) of data were collected for each trial: 500 pre-trigger samples, and then 750 samples following the trigger. Data from the last 20 minutes (0.33 hours) of testing in each condition were analyzed.

ANOVAs were performed on mean acceptable peak force (APF), %MVC force, and impulse, with posture and frequency as between subject factors. Tukey/Kramer post hocs were performed for all significant effects ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Significant main effects of posture and frequency were found ($p < 0.0001$ and $p < 0.03$, respectively) for APF. A significant main effect of posture only was found ($p < 0.0001$) for acceptable impulse. The MPull posture condition resulted in the greatest mean APF and impulse, with the lowest seen in the LPF condition. An average decrease of approximately 17% and 13.4% was shown in mean APF and impulse, respectively, as frequency increased from 1 to 5 insertions/min. Average within-subject coefficients of variation (CV) for APF and impulse ranged from 7.2% to 11.2%, and from 5.6% to 9.9%, with means across all conditions being 9.0% and 8.1%, respectively. There were no significant main effects or interactions of posture or frequency for %MVC values. At a frequency of 1/min, subjects selected acceptable forces that were in the range of 63% MVC for each posture, despite the variable physical demands in the different conditions. Fairly comparable levels of APF (as a %MVC) have also been seen in other psychophysical studies in our laboratory involving the hand [4,6].

The results of well-trained novice subjects have been shown in the past not to differ from actual workers using a psychophysical approach [3]. In the current study, each subject executed 4860 trials in training and testing on average. Mean within-subject CVs were low in general and comparable to those reported elsewhere [3,4], suggesting that subjects were consistent and that training was adequate.

Posture conditions used in this study reflected the orientation of the upper limb and not just the wrist or the grip type, as reported in previous work [1]. The LPF posture put increased load on the operators' shoulders, compared to other orientations, as they supported the mass of their extended upper extremity and also applied force to the hose. This likely factored into subjects' decisions to accept less insertion force in this condition. The MVC data support this, with average maximal forces for the LPF condition being the lowest of the postures at 87.0 (±19.2) N.

The decreasing trend in APF and impulse, as frequency increased, is similar to previous work [3]. Declines in maximum APF (and torque) as frequency increases, have been shown in the literature for other tasks that have utilized power grips in a variety of posture conditions [1].

CONCLUSIONS

This is the first study that has quantified APFs and impulses associated with engine hose insertions. Consistent %MVC forces seen across the variety of tested conditions compares favorably with other investigations of hand-intensive mating operations in automobile assembly, and will enable assessments of hose insertion tasks not explicitly tested in this study.

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