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Human-Robot Collaboration in a Sanding Task

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Abstract
Robots can help reduce physical stress in manual sanding, but implementation has been challenging due to the skill required, task variability, and robot limitations. In shared control (SC) a robot operates semi-autonomously while the human provides real-time corrections. A laboratory study tested the effectiveness of SC for removing paint using an orbital sander. A robot autonomously sanded the surface, and twenty participants sanded manually and in collaboration with a robot using SC. Subjective discomfort for manual sanding was greater than SC in the upper arm by 28.5%, the lower arm by 29%, the hand by 38%, and the shoulder by 42%. Muscle fatigue, measured using EMG, was 22.4% greater for the manual condition. Cognitive workload measured using the NASA TLX was 14.25% more for manual sanding. Digital imaging showed that SC outperformed the fully autonomous robot by 10.75% for uniformity, by 4.96% for quantity, and by 6.06% for average performance.

Keywords
Occupational Biomechanics, Human-Robot Collaboration, Industrial Robots, Physical Stress and Strain, Muscle Fatigue

Introduction

Manual sanding is a physically demanding task (Armstrong et al., 1987; Bernard, 1997; Mani & Gerr, 2000). The surface variability and manual skill required make it difficult to fully automate sanding (Kabir et al., 2018). Collaborative robots (cobots) have the potential to utilize the decision-making and skill of humans through human-robot collaboration (HRC). Shared control (SC) is a HRC method where the robot operates semi-autonomously while the human provides real-time corrections (Hagenow et al., 2021). The current study investigated how using SC in surface sanding affects performance, cognitive workload, and physical stress and strain.

Methods

The laboratory study consisted of a sanding task using a pneumatic random orbital sander to remove paint from a plastic surface. The surface had one layer of spray paint and additional layers in random regions of defects. Three control methods were tested: 1) manual, 2) SC, and 3) autonomous control. A Frankia Emika robot was pre-programmed to move autonomously across the surface but was unaware of the defects. Twenty university student volunteers were recruited, with informed consent under IRB approval. The goal of the sanding task was to uniformly remove as much paint as possible in ten minutes.

Results

A summary of the outcomes is shown in Figure 1. Separate linear mixed effect models with Type III Wald Ftests for the fixed effects were used to test statistical significance. Control was a within-subject predictor. Statistical significance was found for a p-value $<.05$. Pairwise comparison tests were used for post-hoc comparisons, with a Holm-Bonferroni correction. Control had a significant effect on localized discomfort of the shoulder, $F(1,19) = 29.76$, $p < .001$, $\eta_p^2 = .61$, hand, $F(1,19) = 45.27$, $p < .001$, $\eta_p^2 = .70$, lower arm, $F(1,19) = 17.97$, $p < .001$, $\eta_p^2 = .48$, and upper arm, $F(1,19) = 20.79$, $p < .001$, $\eta_p^2 = .52$. There was a significant increase in the medial deltoid EMG RMS amplitude, $F(1,19) = 6.73$, $p = .02$, $\eta_p^2 = .26$. There was a 22.4% increase in EMG RMS amplitude for the manual control versus the SC control. Control had a significant effect on the cognitive workload measured with NASA-TLX (Hart, 2006). The manual control significantly increased the cognitive workload, $F(1,19) = 22.85$, $p < .001$, $\eta_p^2 = .55$.

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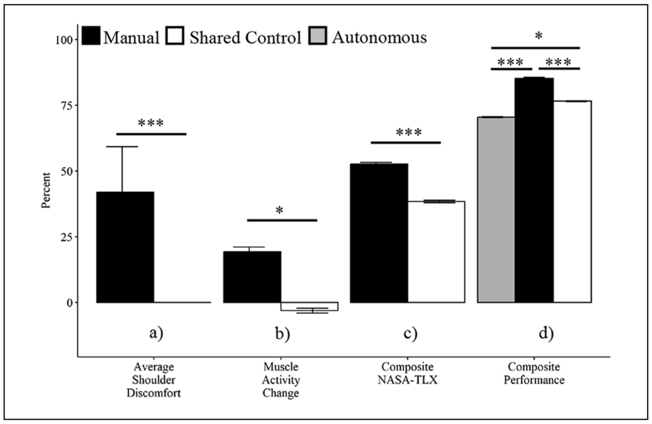

Figure 1. The graph above shows average values of subjective discomfort, EMG RMS amplitude, NASA-TLX, and performance. The bars are standard error (SE) bars. a) The average subjective discomfort for shoulder. b) The percent change in RMS amplitude from before and after the task. c) The composite score for NASA-TLX ratings calculated by the sum of the workload ratings divided by six. d) The average of the quantity of paint removed and uniformity (composite performance) of paint for each control type.

Control had a significant effect on composite performance, $F(2, 5.83) = 24.126$, $p = .001$, $\eta_p^2 = .89$. Manual performance was 14.76% greater than autonomous performance, $p < .001$. Manual performance was 8.7% greater than the SC performance, $p < .001$. SC performance was 6.06% greater than for autonomous control, $p = .02$. The control method was also significant for quantity removed, $F(2, 2.924) = 24.68$, $p = .01$, $\eta_p^2 = .94$. The manual control quantity was 11.61% greater than the autonomous control, $p < .001$ and 6.65% greater than the SC, $p < .001$. The SC quantity was 4.96% greater than autonomous control, $p = .002$. Control was also significant for uniformity, $F(2, 7.52) = 21.99$, $p < .001$, $\eta_p^2 = .85$. In manual control, uniformity was 17.91% greater than autonomous control, $p < .001$ and 10.75% greater than SC, $p < .001$. The SC uniformity was significantly greater than autonomous control, $b = 7.16$, $p = .042$.

Discussion

The results demonstrated that SC significantly improved performance for the sanding task, but with less fatigue and discomfort. These outcomes are for a short-term study. Future research should study longitudinal effects to ensure additional areas of the body do not experience discomfort with SC control, similar workload effects of new office technology (Ritchey et al., 2014). The cognitive workload was significantly greater in the manual task, which are similar to results from (Hagenow et al., 2021).

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