EFFICACY OF A DYNAMIC ARMREST FOR HEAVY JOYSTICK CONTROLLED HEAVY VECHICLES: COULD THE SAME APPROACH BE USED FOR JOYSTICK CONTROLLED WHEELCHAIRS?

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INTRODUCTION

Stationary armrests used in conjunction with joysticks typically do not provide adequate support of the user's forearm. They tend to provide insufficient support during forward motions, while during backward motions the shoulder is forced to rise. The vertical movements create postural requirements that, in both forward and backward instance, increase static loading in shoulder musculature. Muscle loading in the shoulder has been proven to exceed suggested static loading limits that can increase the risk of repetitive strain injuries (RSI) (Asikainen & Harstela, 1993; Attebrant et al., 1997; Nakata et al., 1993; Lindbeck, 1982; Murphy and Oliver, 2006).

Through the introduction of a dynamic and ergonomically correct armrest, one that replicates natural motion of the user's forearm in 3D space, the muscular load can be reduced. By increasing the amount external stabilization provided by the armrest the loading within the muscular can be regulated.

In addition to the reduction of muscle activation, an armrest that stabilizes the arm throughout the entire range of motion could potentially assist users to execute smooth joystick movements. Individuals with poor muscular control may be assisted by the armrest as it guides their arm in the forward and backward directions.

In light of the previous discussion, an armrest was developed that replicated the trajectories of an operator's forearm from unrestricted joystick manipulation (US Provisional Patent #: 60/827086). The objective of this study was to assess the efficacy of a newly designed dynamic armrest, in the forward and backward movement directions. It was expected that supporting the operator's arm by replicating movement throughout its natural motion range would lead to decreases in shoulder complex biomechanical loading, thereby decreasing the risk of musculoskeletal disorders. Design success will be based on the armrest's ability to decrease shoulder musculature loading (upper trapezius (UT), posterior deltoid (PD), and anterior deltoid (AD)) and selected psychophysical indicators determined by a questionnaire.

The purpose of this paper will be to discuss the process followed in assessing the efficacy of the heavy equipment armrest prototype and to consider the potential of implementing a dynamic armrest in joystick controlled wheelchairs.

METHODS

Twenty-one right-handed male subjects, without previous experience using hydraulic-actuation joysticks, between 19 and 28 years of age (mean and standard deviation: age 29±2.9 years; height 176±8.6 cm, mass 72±10 kg) completed the study. All subjects were seated in laboratory mock-up of a typical North American excavator cab fitted with a right-handed, semi-pronated joystick (Figure 1).

Subjects performed a series of forward and backward joystick movements under three randomized blocks of armrest conditions: no armrest, standard armrest, and new dynamic armrest (Figure 1). Each block of trials consisted of the three forward and backward trials, beginning with a directional command of *"forward"* or *"backward",* and concluded once the joystick was returned to the neutral position. Subjects were not given any indication of speed at which to execute the motion, but only to maintain a smooth motion within the trial, and consistent speed between trials.

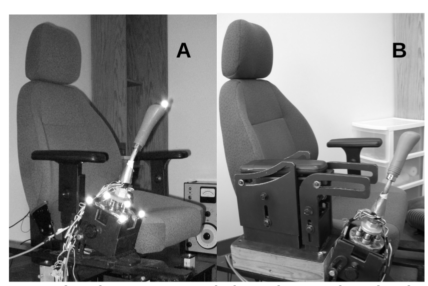

Figure 1: Standard armrest (A)and newly design dynamic armrest (B) shown in backward position.

Muscle activation from three shoulder muscles was analyzed: upper trapezius (UT), anterior deltoid (AD), and posterior deltoid (PD). These muscles were selected under the rationale that, the UT as previously discussed, is a main source of stabilization for the shoulder complex and exposed to static loading and therefore at risk of RSI's. Similarly, the AD and PD act as primary movers or common synergists of shoulder motion in the sagittal plane and provide important information about actuation force requirements.

Surface EMG signals were collected using bipolar surface electrodes (Delsys Inc, Boston, MA) attached centrally over the centre of the muscle and belly aligned in parallel with the muscle fibers. Electrodes were located as described by Cram (1998) and the reference electrode was placed over the medial epicondyle.

Kinematic data of the upper limb and joystick were captured by 6 Vicon® M2 cameras using a frame rate of 100Hz collecting a total of 21 retro-reflective markers placed on the upper body and joystick.

Immediately following the completion of testing, subjects were asked to complete a brief, anonymous questionnaire. The questionnaire allowed subjects to provide subjective responses to questions regarding comfort, effort, and the effectiveness of individual armrests, as well as their preference of armrest.

<u>Data Processing</u>

The EMG data were processed by first full wave rectifying the signal and then linear enveloping using a second order, 6Hz, dual pass Butterworth filter. Once data were linear enveloped each trial was clipped using the first derivative of joystick angle, thereby excluding data outside of the motion cycle. From the clipped EMG data, peak and mean values were recorded for each muscle. Trials were then normalized to a standard length, which gave an average motion cycle of approximately two seconds duration. Once length was normalized, a trapezoidal integration (iEMG) was applied to obtain the total muscle activation across the motion cycle.

Kinematic data were also processed in a similar manner, first by filtering the data using a low-pass, second order, 30Hz dual pass Butterworth filter, and then clipping data using joystick angles. Joint angles were calculated by defining rigid body segments, each with its own distinct coordinate system with the origin at the centre of the distal joint. Using the Euler Angle convention, the attitude of one segment to the next was determined for flexion/extension, abduction/adduction, and rotation.

<u>Statistical Analysis</u>

For the EMG results for each experimental condition (i.e., dynamic armrest, stationary armrest, and no armrest), three repetitions were performed by each subject for each of the two directions (i.e., forward and backward). An average of the three trials was used for statistical purposes. The goal of the experiment was to determine how the response variables (UT, PD, and AD) responded to the various armrest conditions. The EMG response variables included values for mean (mean EMG), peak (peak EMG) and integrated (iEMG) for each of the three muscles studied (UT, PD, and AD) resulting in a total of nine separate ANOVA's. The statistical model was as follows:

*EMG response variable = Mean (mean, Peak, or iEMG) + Armrest + Subject(Stature) + Stature + Movement + Armrest*Subject(Stature) + Armrest*Movement + Armrest*Stature + Movement*Subject(Stature) + Movement*Stature + Armrest*Movement*Stature + Error*

The questionnaire results were also analyzed by ANOVA's. The response variables in this case were perceived exertion, perceived comfort, and overall effectiveness. The model was as follows:

*Response Variable = mean + Subject(Stature) + Stature + Armrest + Armrest*Stature + Error*

When appropriate, differences between means were assessed using a Tukey's t-test post-hoc procedure. Since large numbers of statistical analyses were performed, the level required to declare a significant difference between means was set at $p \leq 0.01$ for the EMG model. The significance value was set to $p \leq 0.05$ for the questionnaire position of the analysis since fewer ANOVA procedures run. All statistical analyses were performed using Minitab™ 13.32 (Minitab, State College, PA, USA).

RESULTS

Muscle activation for all muscles was significantly lower when the dynamic armrest was implemented in comparison to the typical stationary armrest ($p \leq 0.01$). Similarly, muscle activation under the no armrest condition produced significantly lower activation levels than the stationary armrest condition. Lastly, lower muscle activation was observed while the dynamic armrest was employed in comparison to no armrest, but not at significant levels. The statistical model explained greater than 95% of the data variability for all the EMG ANOVA procedures indicating that the experiment was well controlled and most contributing factors were accounted for.

The subjective response to various armrest conditions as described by the questionnaire revealed that subjects significantly preferred the dynamic armrest design over all other types. One significant interaction was found for the perceived exertions response variable for armrest*stature interaction.

Ratings from the questionnaire showed that subjects felt that the dynamic armrest required less effort, was more comfortable, and was more effective than its counterparts. In agreement with these findings, subjects preferred the dynamic armrest over the other armrest options in 17 of 21 cases.

EMG results suggest that muscle activation in the shoulder is significantly affected by the type of arm support and direction of controller motion (i.e., armrest*movement interaction). Peak, mean, and iEMG variables indicated that muscle load was significantly lower for the dynamic armrest in comparison to the stationary armrest for the UT and AD (Figure 2). The dynamic armrest also demonstrated significantly lower EMG variables (peak, mean, and iEMG) for the AD when compared to the no armrest condition. Lastly, iEMG was lower for the no armrest condition in comparison to the stationary armrest for both UT and PD.

For almost all response variables there were significant interactions between armrest*subject(stature). This interaction is expected since individuals have unique characteristics and would react in different ways to the various armrest conditions. No significant differences were observed for operator upper limb kinematics.

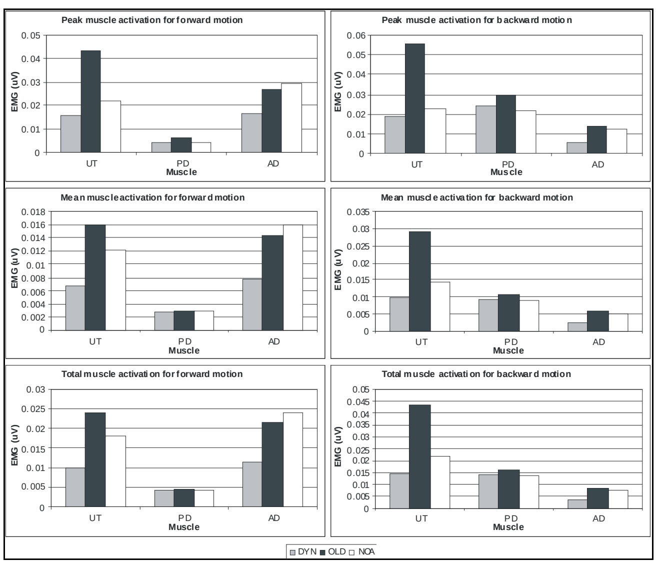

Figure 2: Peak, mean and total (iEMG) muscle activation (upper trapezius (UT), posterior deltoid (PD), and anterior deltoid (AD)) for forward and backward joystick motions using no armrest (NOA), Standard Armrest (OLD), and newly designed dynamic armrest (DYN).

DISCUSSION

Unlike the "moveable armrest" described by Attebrant et al. (1997), that translated only horizontally (forward and backward) the present design allowed for vertical movement as well. By incorporating the "natural motion" path trajectories of the forearm into the armrest the arm could be supported throughout the full range of motion, thereby significantly decreasing the UT loading in comparison to the stationary armrest. The effect of the armrest on the UT is demonstrated by the interaction plot of armrest*direction (Figure 3). It is clearly indicated by Figure 3 that the standard armrest has significantly greater muscle activation during backward motion in contrast to forward motion. Both the no armrest and dynamic armrest conditions produced lower and nearly equal muscle activation in both directions, indicating that the arm was likely unrestricted, and the motion path between the armrest and the arm's natural motion was closely matched for the dynamic armrest condition. It is unknown whether or not Attebrant et al. (1997) found similar results, since the motion was not divided into discrete tasks for forward and backward controller motions. Perhaps the decreases in the UT activation observed by Attebrant et al. (1997) are a result of increased support in the forward motion, while larger UT activation levels persist during backward motion since the arm was more constrained during this type of motion.

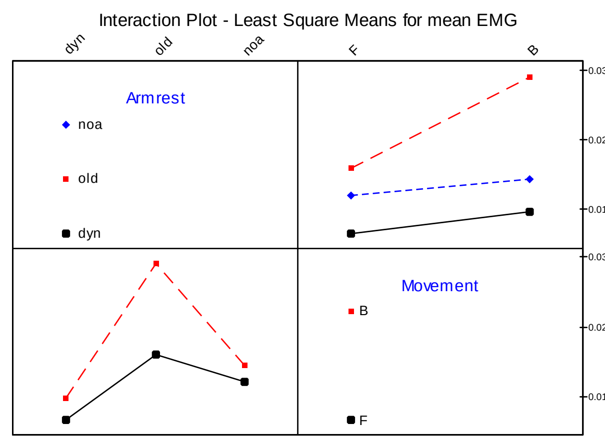

*Figure 3: Two way interaction for armrest (dyn=dynamic, old=stationary, noa=no armrest) and movement (F=forward and B=backward) (armrest*movement) for the upper trapezius (UT). The muscle activation response is plotted on the y-axis (uV). Interactions are present when the change in muscle activation resulting from one factor despends on a second factor (i.e., if the lines are parallel to one another, an interaction is not present).*

As previously mentioned, muscle load was consistently lower for the dynamic armrest in comparison to the no armrest condition, but not at a significant level (with the exception of the AD). Similar results have been found in ergonomic studies concerning desk work (Hedge & Powers, 1995). The inconclusive results indicate that a balance between the internal and external sources of joystick-arm-

armrest system stabilization may exist. In typical situations the standard armrest provides uncompromising external support to the point of fault, thereby constraining natural movement and increasing shoulder musculature loading (Northey, 2004). Alternatively, the complete lack of external forearm support, in the case when there is no armrest, requires the stabilization to come from elsewhere (eg. shoulder musculature). It is possible that decreased stabilization is compensated for by muscle load redistributed from the shoulder to the forearm by gripping the joystick more firmly, resulting in potentially larger activation levels within the forearm. Attebrant et al. (1997) also established, but failed to explain, the slight increases in forearm loading associated with the "moveable armrest". Therefore more research is necessary to determine if there are sequential increases in forearm activation may have been observed from stationary armrest, to dynamic armrest, and no armrest.

The subjective responses, or user preferences, are also important considerations. Seventeen of 21 subjects prefer the dynamic armrest while also indicating that users felt that the dynamic armrest required less effort, was more comfortable, and more effective than either no armrest or the stationary armrest. Individual's preferences can likely be attributed to various movement patterns between subjects. It has been noted in several instances that individuals differ in their utilization of armrests (Bendix & Jessen, 1986; Erdelyi et al., 1988), creating varying arm support needs between individuals.

Although intersubject kinematic data was quite variable, it nevertheless emphasizes that the dynamic armrest's design is forgiving to variances in posture and movements. This is an important finding since there will likely be differences in the way that each operator completes controller motions. The same is expected to hold true for the implementation of the dynamic armrest into a joystick controlled wheelchair where the movement patterns of users can be widely varying.

The decreases in muscular activation levels as well as the increased support offered by the dynamic armrest suggest that it may also be capable of providing increased comfort while concomitantly helping wheelchair users to execute smoother joystick motions. In such cases the dynamic armrest may act as guide for the forearm and prevent excessive muscle activation or unintended motions. The positive results obtained from the dynamic armrest prototype assessment suggest that this design approach and implementation should be investigated for joystick controlled powered wheelchairs.

CONCLUSIONS

The results of this study indicate that dynamic arm supports are an important consideration when discussing comfort and muscle activation in the shoulder during hydraulic-actuation controller use. All operators using the dynamic armrest, with the exception of one, experienced significant decreases in shoulder muscle activation in comparison to the standard armrest. Further strengthening the argument for implementation of dynamic armrests was the overwhelming user preference of the dynamic armrest over either the stationary or no armrest condition.

Research is ongoing to consider the potential of introducing the dynamic armrest to joystick controlled wheelchairs. Future work will also incorporate forearm trajectories of lateral joystick motions into the design that will allow for operator movements in all directions.

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