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The effect of two alternative arm supports on shoulder and upper back muscle loading during pipetting

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Abstract. *Objective*: Pipetting involves static upper arm positions with the pipette held away from the body for sustained periods of time, putting increased musculoskeletal load on the shoulder and upper back. This study explores the effect of using two alternative arm supports while pipetting on muscle loading in the shoulder/neck region.
Participants: 15 experienced pipette users participated in this study.
Methods: In a repeated-measures design, participants performed simulated pipetting in a laboratory setting under three arm support conditions: (1) a gel pad on the work surface, (2) a freely-moving counter-balanced forearm support, and (3) no support (control). Surface electromyography (EMG) of the anterior deltoid and upper trapezius muscles were recorded, as well as productivity and subjective usability.
Results: Both arm support conditions resulted in significantly lower mean muscle activity of the anterior deltoid and upper trapezius muscles ($p < 0.001$) and significantly higher subjective comfort ratings ($p < 0.001$) compared to the control condition. The freely moving forearm support resulted in significantly lower peak muscle activity in the anterior deltoid compared to the control condition ($p < 0.001$). Productivity was not affected by the arm supports. These findings suggest that arm support may be beneficial in reducing muscle loading and improving comfort in the shoulder and upper back during pipetting. Future studies are needed to measure the impact of these arm supports in the workplace.

Keywords: Electromyography (EMG), musculoskeletal disorders (MSD), ergonomics

1. Introduction

Extended use of a mechanical pipette has been recognized as a risk factor for musculoskeletal disorders. Bjorksten et al. [1] found that those who pipette for more than 300 hours a year are at an elevated risk of musculoskeletal disorders (MSD) and injuries compared to those who pipette less than 300 hours a year (odds ratio of 2.4 for shoulder problems). Previous research has shown that during pipetting the upper limb, shoulder, and upper back muscles have high musculoskeletal load [1,2].

In order to eliminate or reduce the shoulder and upper back stressors during pipetting, one recommendation has been to not elevate the arm for lengthy periods without support [2]. Previous research on wrist and forearm support for hand intensive tasks, particularly computer users, has found biomechanical benefit such

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as decreased muscle loading in the trapezius, deltoid, and supraspinatus muscles [3–5]. However, since these supports only offer a small range of motion [3] and/or may interfere with existing workstation furniture [4], they may not meet all of the task and mobility requirements for pipetting.

Pipetting involves repetitive hand movements and static upper arm positions with the pipette held away from the body for sustained periods of time, putting increased musculoskeletal load on the shoulder and upper back [6,7]. This combination of distal mobility with proximal stability is a common requirement in tasks calling for a high level of precision, and the resulting static muscle exertions and postures of the neck and shoulder are associated with fatigue and musculoskeletal disorders in those areas of the body [8,9]. One potential arm support strategy to reduce shoulder and upper back loading during pipetting is to rest the elbow on the work surface. Another potential arm support strategy would be to provide arm support in all axes (X, Y, and Z). This study tested a custom-engineered freely moving arm support which offers support throughout the dynamic range of motion in all 3 axes required for pipetting.

The purpose of this study was to examine the effect of arm support on shoulder and upper back muscle loading during pipetting. We hypothesized that shoulder and upper back muscle loading would both be reduced through both forms of arm support compared to having no arm support during pipetting. In addition, the usability for each support strategy was tested.

Fig. 1. Gel pad support. This figure depicts the gel pad support as used in the gel pad support condition.

Fig. 2. Freely moving arm support. This figure depicts the freely moving arm support as used in the freely moving arm support condition.

2. Methods

2.1. Participants

A total of 15 subjects volunteered and participated in this study (9 females and 6 males). Inclusion criteria were that subjects had to have more than 60 hours of total pipetting experience and no recent or recurring discomfort in the upper extremities. There was no compensation given for the subject's time. All subjects pipetted with their right hand, which were their preferred hand for pipetting. Approval for the study was given by the Institutional Review Board at the Lawrence Berkeley National Laboratory.

2.2. Support strategies

2.2.1. Gel pad

The gel pad was a large gel-filled pad (AliMed, AliEdge Gel Edge Protector, 792307G) that measured 24 inches long and 4.5 inches wide (Fig. 1).

2.2.2. Freely moving arm support

The freely moving arm support was a custom fabricated prototype arm support (Flexible Scientific, San Diego, CA) with two pivots allowing horizontal mobility in the X-Y plane and a vertical rail to move in the Z direction (Fig. 2). Motion in the Z direction was assisted by an adjustable mechanical spring balance that exerted a constant vertical force regardless of arm position. The device provides support directly on the forearm or elbow. The freely moving arm support could operate between 3 and 7 inches above the surface of the table.

2.3. Experimental setup

The experiments took place in various office settings to minimize travel time for the subjects. A simulation of a laboratory work area was provided, with the work surface set at standard lab bench height (36"), using a small portable table (Resolve table, Herman Miller, Zeeland, MI). A micro centrifuge-tube rack, loaded with 8 tubes, was located in the center of the table approximately 8 inches from the near edge of the table. Each tube had 3 mm of sand at the bottom of the tube, representing a gel, and 400 μl of water. The water trough and the waste trough were placed directly behind the tube rack, and the tip container and tip disposal bin were placed directly behind the troughs.

When testing the gel pad condition, a gel pad was placed next to the edge of the table slightly to the right of the center of the table. The freely moving arm support was clamped to the table 16 inches to the right from the centerline of the table. Subjects sat in a laboratory chair (Soma Hybrid, Soma Ergonomics, Berkeley, CA) and they were invited to use a separate adjustable footrest. Subjects were then told that they could adjust their workstation setup.

2.4. Testing protocol

Subjects were instructed to change into a tank top to allow for access to the upper trapezius and anterior deltoid. Surface electromyography (EMG) electrodes were then attached oven the anterior deltoid and the upper trapezius muscles.

After palpating and locating the muscle bellies, surface electrodes were attached over the anterior deltoid and the upper trapezius muscles after the areas were shaved and cleaned with isopropyl alcohol. The electrodes were connected to the Noraxon Telemyo 2400T V2 wireless transmitter (Noraxon USA Inc., Scottsdale, AZ). All EMG readings were sampled at 1000Hz. The EMG data was smoothed with a moving 100 ms root-mean-square (RMS) window, and the amplitude was normalized to the subject's maximum voluntary contraction (MVC). Maneuvers were performed to elicit the maximum voluntary contraction for 5 seconds for each muscle 3 times, with a rest period in between. The maneuvers were as follows: subjects performed shoulder flexion and shoulder elevation, for the anterior deltoid and upper trapezius respectively, as hard as they could while the researcher applied an equal and opposite force to stop the motion during the half way point of the range of motion. Subsequent EMG data was normalized to the 95th percentile of the MVC value.

Subjects practiced pipetting on their optimized work surface to acclimate themselves to the three arm support setup conditions: 1) no arm support, with the arm always elevated off the table (control), 2) gel pad support with a large gel pad placed on the table, and 3) freely moving arm support with the freely moving arm support. Subjects were given three minutes to familiarize themselves with the interventions, the workstation setup, and the pipette used in this study (Rainin model LTS L-200, Rainin, Oakland, CA). Many subjects chose to take extra time to adjust to the freely moving arm support in order to improve task control and to learn how to use the intervention without "fighting" against it.

After practicing, each subject was randomly assigned to the sequence they would perform each of the three conditions. They were then able to re-optimize their workspace and were then told to complete a repetitive pipetting task for a 15-minute duration for each condition for a total of 45 minutes of pipetting while attempting to match their usual productivity. Rest breaks of five minutes were provided between each condition. The total number of task cycles was counted for each condition. A subjective usability questionnaire on comfort, ease of use, productivity, aesthetics, and a pre/post usefulness rating was given after each condition.

2.5. Task

Participants took the pipette in their dominant hand and acquired a tip. They then removed a 2ml micro-centrifuge tube out of a tube rack and aspirated 75 micro-liters of water from the tube while avoiding contact with sand placed at the bottom of the tube (representing a gel or a high concentration of cells). They dispensed and all of the water in the pipette tip and repeated the above process, extracting water from a total of 10 micro-centrifuge tubes. They then ejected the pipette tip, acquired a new tip, and added 75 micro-liters of water from a water trough into all 10 micro-centrifuge tubes. Subjects then ejected the current pipette tip, acquired a new tip and repeated the above task until 15 minutes had elapsed.

2.6. Statistical analysis

Summary statistics for the EMG, productivity, and subjective ratings were analyzed using SAS software (SAS Institute, Cary, NC). A repeated-measures ANOVA was conducted to examine for significant differences between the 3 conditions (gel pad support, freely moving arm support, no support (control)) for the mean and peak (100th percentile) values for the anterior deltoid and upper trapezius muscle activities, as well as the

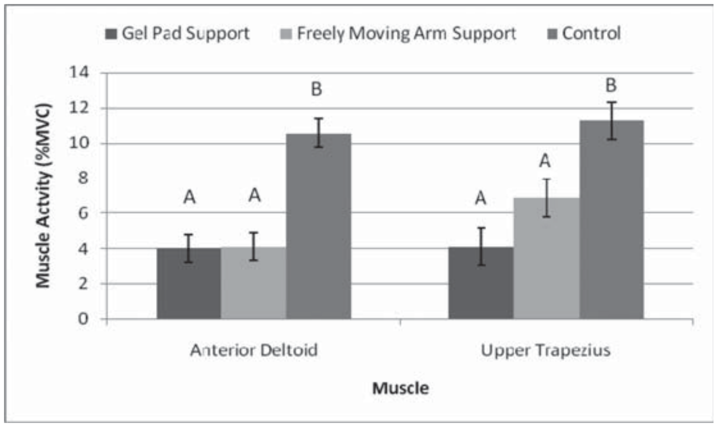

Fig. 3. Mean (± SE) muscle activity across conditions ($n = 15$). The figure depicts the result of the mean muscle activity across support conditions. Significant differences between groups are denoted by different letters.

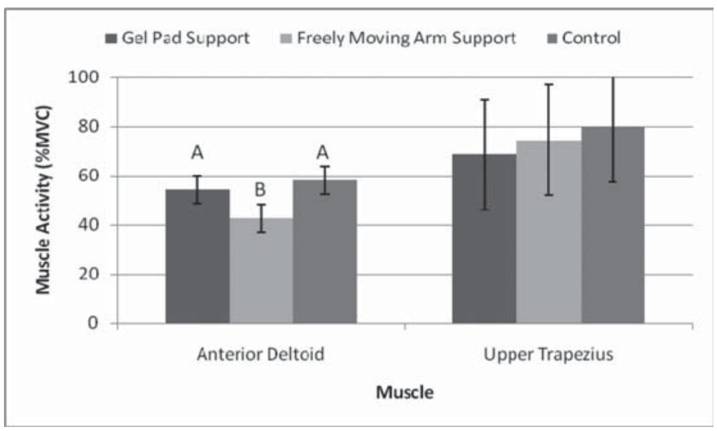

Fig. 4. Peak (± SE) muscle activity across conditions ($n = 15$). The figure depicts the result of the peak muscle activity across support conditions. Significant differences between groups are denoted by different letters.

number of cycles completed across conditions (productivity). A follow-up Tukey test for pair wise comparisons determined which groups were significantly different from each other. Subjective rating data was analyzed with the Kruskal-Wallis test. An alpha level of 0.05 was selected as the minimum level of significance.

3. Results

Figure 3 shows that mean muscle activity were significantly reduced in both interventions for the anterior deltoid and the upper trapezius ($p < 0.001$ for both muscles) compared to the control condition. The mean muscle activity of the gel pad condition was reduced to 38.2% of the control condition for the anterior deltoid, and to 36.7% of the control condition for the upper trapezius. The mean muscle activity of the anterior deltoid for the freely moving arm support was reduced to 39.2% of the control condition, and to 60.8% of the control condition for the upper trapezius.

Figure 4 shows that peak muscle activity was significantly reduced for the freely moving arm support for the anterior deltoid compared to the control condition ($p = 0.003$). The peak muscle activity for the anterior deltoid was lowered to 26.8% of the control condition. There was no significant difference across conditions for the peak muscle activity for the upper trapezius ($p = 0.64$).

Table 1 shows the productivity for each condition. There were no significant differences in the number of cycles completed across conditions ($p = 0.83$). A

Table 1
Mean and standard deviation of work cycles completed across conditions (= 15)

Condition	Mean	Standard deviation	p-value
Gel Pad Support	27.80	6.64	0.83
Freely Moving Arm Support	28.36	6.66	
Control (no support)	28.00	6.64	

post-hoc statistical analysis on EMG and productivity outcome variables was completed to test for potential order effect and potential interaction between order and intervention condition. The post-hot analysis did not reveal any statistically significant order effect or interaction between order and intervention condition.

Table 2 shows that there were significant differences across conditions for both the comfort of the arm and the comfort of the shoulder/upper back ($p < 0.05$). For arm comfort the arm support and the gel pad were rated higher in comfort (3.79, and 3.71 respectively) than the control condition (2.64). For the comfort in the shoulder/upper back area, the gel pad was rated highest (3.80) followed by the freely moving arm support (3.20) and the control condition (2.80). The other comfort and usability ratings were not significantly different across conditions.

4. Discussion

The purpose of this laboratory study was to explore the potential benefit of arm support during pipetting on shoulder and upper back muscle loading. Both the gel pad and the freely moving arm support led to significantly lower mean muscle activity for the anterior deltoid and upper trapezius while pipetting. This suggests that both interventions may be effective in reducing the muscle loading in the shoulder and upper back during pipetting. This finding was supported by the improved subjective comfort of the arm and of the shoulder/upper back regions for both support conditions.

Given the recommendations from previous research to use support for reducing shoulder and upper back ergonomic stressors [2] as well as the design of the intervention on the biomechanics of the shoulder and upper back, we expected the decrease in muscle activity. While pipetting, the dominant arm is often extended directly in front of the body. The weight of the arm exerts a moment about the shoulder, which is resisted by the contractions of the anterior deltoid and other muscles, while the upper trapezius and rotator cuff muscles act to support and stabilize the shoulder girdle. By providing a supporting force at the elbow the moment about the shoulder is reduced and the muscle activity of the anterior deltoid was decreased. Because the arm supports relieved some of the weight of the arm, the upper trapezius could exert less force in its role of assisting the shoulder to maintain a static position.

However, this study did find some differences between the gel pad and the freely moving arm support. Only the freely moving arm support lowered the peak muscle activity, and only for the anterior deltoid. Further analysis of the EMG data in conjunction with the timing of the pipetting activity suggests that the peak muscle activity for both the anterior deltoid and the upper trapezius occurs during tip ejection and tip acquisition. For both of these tasks the subject had to hold the pipette far away from their body, and at least 10 inches above the surface of the table. As a result, subjects using the gel pad were forced to lift their elbow off the support to acquire and to eject a tip, while subjects using the freely moving arm support were able to change tips while receiving arm support throughout the range of motion of the task.

Using the interventions may cause inadvertent problems in other body areas. It was observed during the study that many of the participants compromised their wrist posture when using the gel pad. Because the subjects had their elbow “planted” on the pad, they would flex their wrist in order to reach tubes closer to their elbow. Furthermore, for the freely moving arm support subjects may have compensated for the limited range of motion of the device through awkward upper arm postures (e.g., increased shoulder elevation or abduction) or increased use of surrounding shoulder muscles. The lower comfort ratings may be due to these awkward postures and use of surrounding muscles when using the freely moving arm device.

There were several limitations to this study. The study was limited to recording muscle activity from just one shoulder and one upper back muscle. It may be worthwhile to also monitor other shoulder muscles and record shoulder and wrist posture. Also, since this study examined the effect of arm support in a simulated lab environment it would be worthwhile to verify the study findings among subjects performing their usual work in the workplace.

In addition, initial observations showed that subjects did not take the time to adjust the tension on the freely moving arm support. Therefore, during the experiment, subjects were required to try several spring tension settings in order to identify the optimal adjustment. If users do not properly set up their arm support, or if they

Table 2
Subjective Ratings (Mean (SD)) Across Conditions ($n = 15$)

Variables	Condition			
	Gel pad support	Freely moving arm support	Control	p-value
Comfort in hand/wrist	3.13 (1.06)	3.07 (1.22)	3.00 (1.13)	0.95
Comfort in arm	**3.71 (0.99)**	**3.79 (0.97)**	**2.64 (1.21)**	**0.02**
Comfort in Shoulder/Upper Back	**3.80 (0.68)**	**3.20 (1.15)**	**2.80 (1.01)**	**0.02**
Ease of Use	3.93 (1.03)	3.27 (1.03)	3.67 (1.50)	0.21
Range of Motion	3.07 (1.27)	3.79 (1.31)	3.93 (1.07)	0.12
Control	3.87 (0.99)	3.40 (1.30)	3.73 (1.16)	0.55
Visibility of work surface	4.36 (0.84)	4.07 (1.00)	4.57 (0.65)	0.37
Aesthetics	3.45 (1.04)	3.15 (1.21)	4.4 (0.89)	0.11
Productivity (objective)	4.00 (0.76)	3.73 (1.16)	3.87 (0.74)	0.87
Ease of Adjusting to condition from standing	4.00 (0.88)	3.36 (1.08)	4.23 (0.93)	0.07

Subjects rated variables on a scale from 0–5, where 0 is poor and 5 is excellent. Bolded values indicate statistical significance across conditions ($p < 0.05$).

share an arm support with others and do not change the setting from person to person, there is a chance that the users will be resisting the device and using muscle groups that would not otherwise be heavily used for pipetting. It was observed that although the freely moving arm device allows support to either the forearm or elbow, most subjects preferred the support under their elbow. It may be worthwhile to also monitor the differences if subjects supported only their forearms.

5. Conclusion

Mean muscle activity in the shoulder and upper back were reduced when subjects used both dynamic and static arm supports. The freely moving arm support also lowered peak muscle activity for the shoulder. Shoulder and upper back subjective comfort were also improved with the arm supports. These initial positive findings should be confirmed in subjects performing their usual pipetting tasks in the workplace, and wrist posture should be monitored.

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