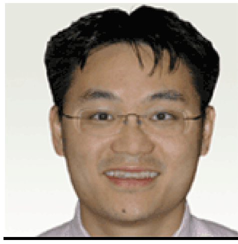
Effectiveness of a drywall sanding machine (DSM) in reducing forceful exertions and repetitive motion



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ABSTRACT

The purpose of this study was to verify the effectiveness of the drywall sanding machine (DSM) in reducing musculoskeletal exertion and repetitive motion in actual field condition. Fourteen drywall-finishing workers participated. They were divided into 1) a control group to perform the sanding task using a pole sanding tool; and 2) an intervention group to use the DSM. Electromyography (EMG) signals were collected on the bilateral middle deltoid muscles. Two Xsens sensors were used to quantify continuous trunk and upper arm postures. Significantly ($p<0.05$) higher levels of trunk and upper arm acceleration and higher middle deltoid muscle activities were found when participants used the sanding pole versus the DSM.

Keywords
Drywall sanding, construction, intervention, force, repetition

INTRODUCTION

Currently, typical working procedures for drywall sanding require workers to sand the compound manually using a hand-held block or a long-handle pole with a piece of sandpaper on the end of a swivel plate (see Figure 1). To achieve a smooth finish, the sander moves the sandpaper up and down (or back and forth for horizontal joints) along the unfinished/rough area. This work procedure places stress on the back, arms, and wrist because pressure has to be applied to the paper to create the friction for sanding. Using a DSM such as Porter Cables' Drywall Sanders (see Figure 1), may reduce the force required to perform the task. This can in turn decrease the risk of work-related musculoskeletal disorders.

The mechanical sanding machine used in this study (Porter Cable Drywall Sander, Models #7800 and #7814) each consist of a small motor attached to the head of a swivel plate (See Figure 1). The attached motor, when turned on, allows the swivel plate to rotate at a high frequency in order to sand the joint area without gouging the drywall. Attached to the motor is a long-handled pole and a vacuum system which decreases exposure to drywall dust. Using the drywall sanding machine can also reduce repetitive and forceful exertion of the upper limbs. The total weight of the motorized sanding machine and the attached pole is 8 lbs. The weight of the long-handle pole with a swivel plate is approximately 2 lbs.

The purpose of this study was to evaluate the potential reduction in repetitive and forceful exertion of the upper limbs when using the DSM for drywall sanding in the field setting. The hypothesis was that using the DSM for drywall sanding will required less repetitive motion and forceful exertion of the upper extremity and trunk when comparing to manual sanding with a sanding pole.

Figure 1: Sanding skimmed drywall using a mechanical sanding-vacuum machine (left), and a sanding pole (right).

Methods

2.1 Participants

Twelve (12) drywall-finishing workers were asked to participate in this experiment. They were divided into 1) a control group to perform the sanding task using a pole sanding tool; and 2) an intervention group to use the DSM. All participants were chosen from Local 1891 of the Painters Union.

2.2 Dependant Variables

2.2.1 Electromyography (EMG)

To investigate the physical load on the musculoskeletal system while performing drywall sanding tasks, electromyography (EMG) was used. For each data collection period, muscle activity was measured using surface EMG. EMG signals were recorded by attaching surface electrodes (Ag/AgCI - electrode distance of 20 mm) on the skin surface above the following two muscles: (1) left and (2) right middle deltoid to estimate muscle loads on the shoulders. Positions of the electrodes for the respective muscles can be found in other references (Basmajian and Blumenstein, 1980). After all the electrodes were secure on the skin, the participants were asked to relax their muscles for 5 – 10 seconds to obtain baseline resting EMG signals. After collecting the resting baseline EMG, a series of maximal voluntary contractions (MVC) were performed in order to obtain EMG signals representing each muscle's MVC. These MVC EMG signals were used to normalize (expressed as %MVC) the collected experimental trial EMG signals. Two-repeat MVC, with two minutes rest between each MVC were. The EMG signals were record by a Biometric DataLog EMG system (Biometrics Ltd, Gwent, UK). Muscle activity signals picked up by the electrodes were stored by the DataLog and were downloaded after the data collection period. A sampling frequency of 1000 Hz used in this study to transfer the analog signal to digital units for computer processing. After downloading the data, the EMG signals were subtracted by the DC levels (system noise), RMS converted, and low-pass Butterworth filter at cut-off frequency of 4 Hz. Working EMG signals was obtained by subtracting the experimental trial EMG with the mean resting EMG levels. The work EMG signals were normalized by the signals obtained during the maximal voluntary contractions (MVC). The normalized signals were analyzed in the amplitude domain using the amplitude probability distribution functions (APDF) technique described by Jonsson (1982). Three muscle load levels (i.e. static, median and peak levels) was obtained from the 10, 50 and 90 percentiles of the distribution according to Jonsson's definitions (1982).

2.2.2 Gyroscope

The Xsens MTx (Xsens Motion Technologies, The Netherlands) was used in this study to quantify real-time continuous trunk and upper arm postures. The Xsens MTx was attached to the Xbus Master for data collection. Two MTx were utilized in this study. One of the MTx was used to collect the posture of the trunk and the other was used to collect the upper arm posture on the dominant hand side. In this study, all participants were right handed. For the trunk, the MTx was attached on the mid-section of the posterior scapula. For the upper arm, the MTx was attached above the elbow joint on the posterior side of the upper arm. The MTx sampled at 100 Hz, and low-pass filter at 4 Hz to reduce the high frequency noise. Second order differentiation was also performed on the posture data to calculate the angular acceleration (degree/s^2). Absolute values of the angular acceleration were used in this study to compare the two sanding methods.

2.3 Data Collection Procedure

Selection of participants was obtained from a list of experienced plasterers currently members of Local 1891. Twelve (12) plasterers were asked to participate in this study. Six workers were asked to use the drywall sanding machine (intervention group) while performing their rough sanding task. The participants in the intervention group were allowed a half hour practice with the sanding machine before data collection was commenced. For the control group, six workers using the traditional pole-sanding techniques were selected. Before conducting the study, all participants' employers were contacted to explain the purpose of the study and obtain their signed consent. While the participants were performing their work tasks, a videotape of all sanding task was recorded. Information on muscle activities (EMG), and trunk and arm repetitive motion (MTx sensors) were also collected at the same time. Data collection time for each participant varies between 45 minutes and 2 hours.

2.4 Data Analysis

SPSS (version 12) was used to analyze the collected data. Statistical tests with $p<0.05$ was considered significant. Univariate analysis using between groups T-test was used to determine the differences between the control and intervention group.

Results

3.1 Kinematics results during sanding task:

Comparing with the drywall sanding machine, the control group had a significantly ($p<0.05$) higher level of mean and peak trunk acceleration in the flexion/extension (f/e) plane (Figure 2). The median acceleration of the trunk in the f/e plane for the pole sanding was found to be 120 $^{o}/s^2$. Using the DSM, the median acceleration of the dominate arm was 77.9 $^{o}/s^2$, which is significantly lower than the pole sanding condition ($P<0.05$, Figure 2). Also the peak trunk acceleration in the f/e plane of the trunk was found to be significantly higher in the pole sanding condition (pole: 361 $^{o}/s^2$ vs. DSM: 231 $^{o}/s^2$, $P<0.05$, Figure 2).

The same result was also found in the dominate upper arm acceleration for both of the f/e and abduction/ adduction (ab/ad) plane. The median acceleration of the upper arm in the f/e plane for the pole sanding was found to be 367 $^{o}/s^2$. Using the DSM, the median acceleration of the dominate upper arm was 197 $^o/s^2$, which is significantly lower than the pole sanding condition (P<0.05, Figure 3). Also, the peak acceleration in the f/e plane of the upper arm was found to be significantly higher in pole sanding condition (pole: 1558 $^o/s^2$ versus DSM: 759 $^o/s^2$, P<0.05, Figure 2). Moreover, it was found that the amount of median and peak acceleration of the arm ab/ad were greater in pole sanding when compared to the DSM (median acceleration pole: 371 $^o/s^2$ versus DSM: 171 $^o/s^2$, P<0.05; peak acceleration pole: 1284 $^o/s^2$ versus DSM: 475 $^o/s^2$, P<0.05, Figure 4).

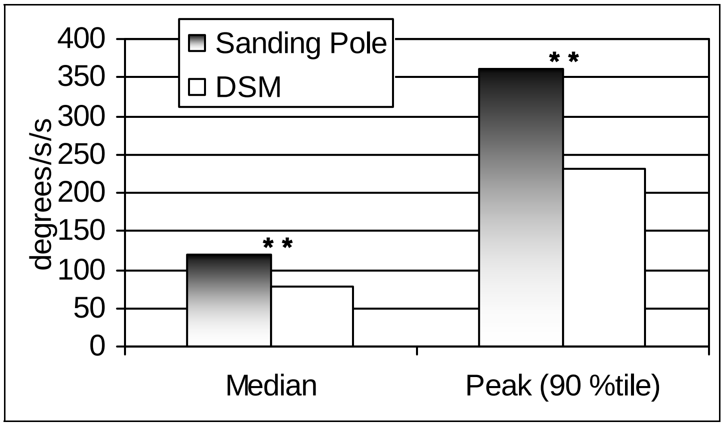

Figure 2: Median and peak (at the 90th percentile) ***trunk*** acceleration in the ***flexion/extension*** plane for sanding pole and drywall sanding machine (DSM). **p<0.05.

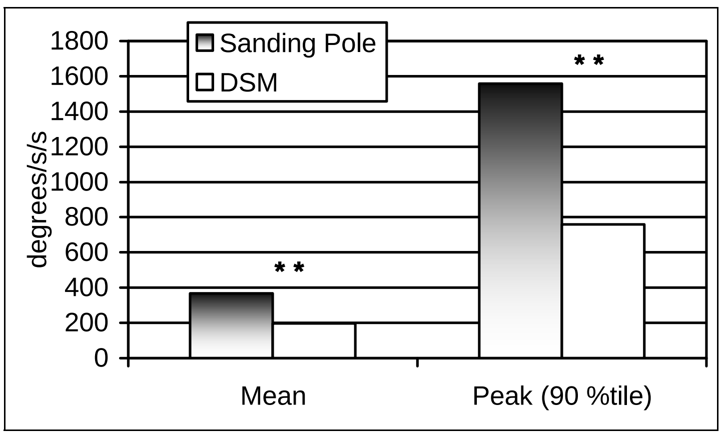

Figure 3: Median and peak (at the 90th percentile) ***upper arm*** acceleration in the ***flexion/extension*** plane for sanding pole and DSM. **p<0.05.

3.2 Electromyography data during sanding task:
The result of EMG analysis showed that sanding with the pole required a significantly higher activity of the shoulder muscles comparing to sanding with the DSM. On the right hand side, the APDF of the middle deltoid was observed to be higher at both of the median and peak load level when participants used the sanding pole (median APDF level for pole: 9.1 %MVC versus DSM: 3.0 %MVC, P<0.05; peak APDF level pole: 36.9 %MVC versus DSM: 14.3 %MVC, P<0.05, Figure 5). The peak APDF value of the deltoid on the left side was also observed to be significantly higher in pole sanding work condition (pole: 22.74 %MVC versus DSM: 15.72 %MVC, P<0.05, Figure 6).

In this study all participants were right handed. Comparing between the left and right hand while performing pole sanding, all three APDF load levels (static, median, and peak) were significantly (p<0.05) higher on the right middle deltoid muscles (see Figure 7). For the DSM group, no significant difference was found between the right and left middle deltoid muscles for all APDF load levels (see Figure 8).

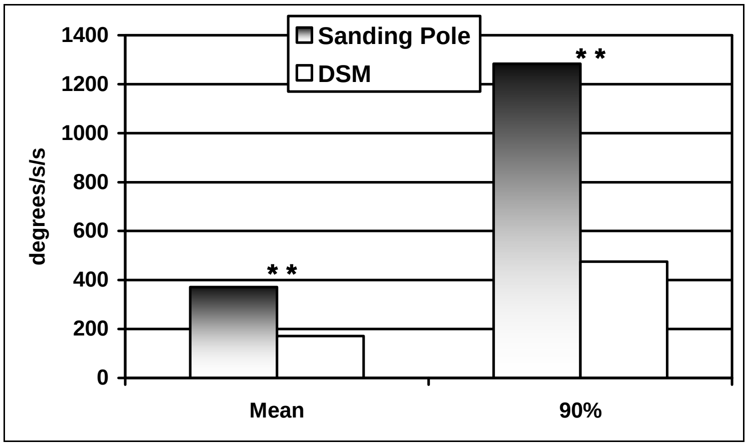

Figure 4: Median and peak (at the 90th percentile) ***upper arm*** acceleration in the ***adduction/abduction*** plane for sanding pole and drywall sanding machine (DSM). **p<0.05.

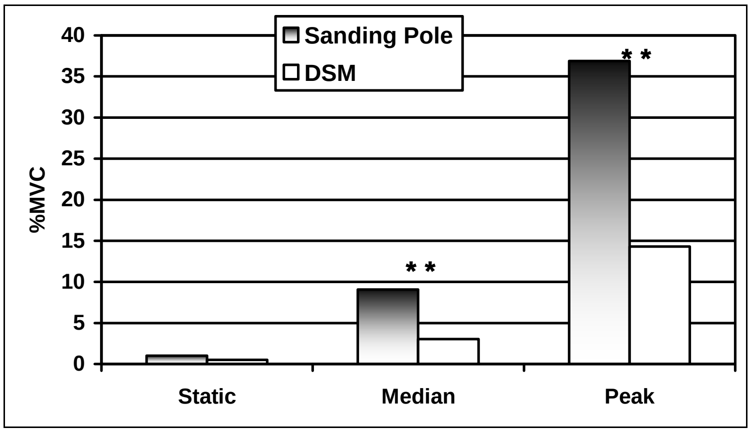

Figure 5: Static (10th percentile), median (50th percentile), and peak (90th percentile) level of the ***right deltoid muscles*** for the sanding pole and drywall sanding machine condition. **p<0.05.

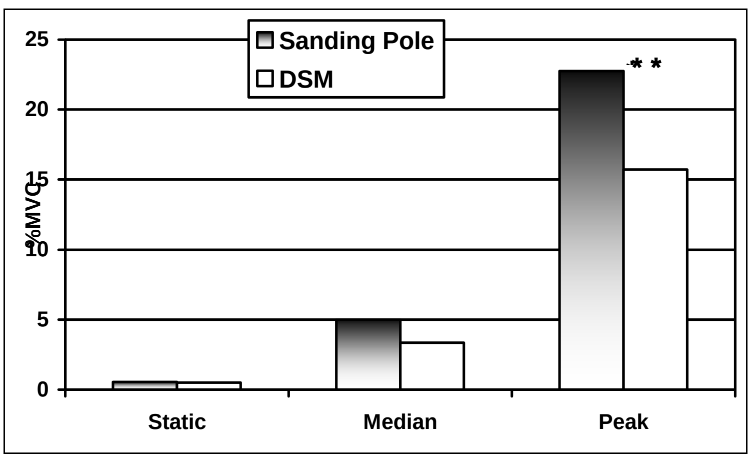

Figure 6: Static, median, and peak level of the ***left deltoid muscles*** for the sanding pole and drywall sanding machine condition. **p<0.05.

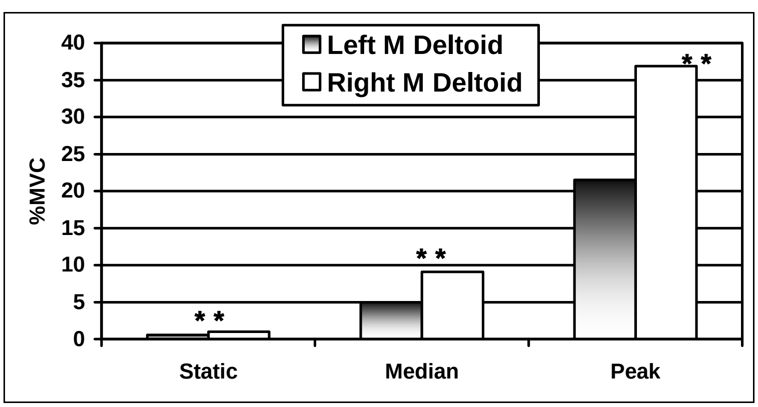

Figure 7: Static, median, and peak level of the left and right deltoid muscles for the ***sanding pole*** work condition. **p<0.05.

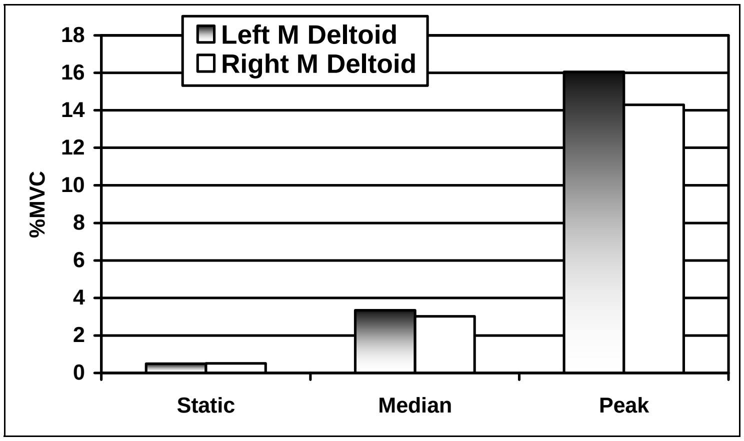

Figure 8: Static, median, and peak level of the left and right deltoid muscles for the ***DSM*** work condition. **p<0.05.

Discussion

According to Newton's second law, the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object. In terms of an equation, the net force (F) is equated to the product of the mass (m) times the acceleration (a) or F = m * a. Despite the large difference in total weight between the DSM (8 lbs) and the pole sanding tool (2 lbs), working with the DSM generally required less muscle forces, as measured by the bilateral middle deltoid (see Figure 5 and 6). Significant ($p<0.05$) reduction in the median and peak load level was observed for the right middle deltoid muscle, and for the peak load level in the left middle deltoid when participants used the DSM. The high muscular effort in manual pole sanding was a result of the high repetitive movement of the upper extremity in order to create a high friction force between the sandpaper and the wall. As noted in the result section of this report, a significantly ($p<0.05$) higher upper arm acceleration rate was found when workers used the sanding pole (see Figure 3 and 4). Such action needs a great amount of shoulder muscle activities. That is, an increase in acceleration of the upper arm will result in an increase in force generated by the upper arm muscles (i.e., $Force = mass \times acceleration$).

Using the DSM, workers used significantly ($p<0.05$) less shoulder muscle activities and lower acceleration of the upper arms. Due to the mechanical design of the DSM, the workers do not have to perform highly physical work activities as the worker only needs to grip and direct the DSM handle along the walls with minimal repetitive flexion/extension and abduction/ adduction of the shoulder joint. The small amount of repetitive action of the upper extremities resulted in smaller amount of muscular effort because the majority of the sanding force was generated by the sanding machine. The muscular effort generated by the upper extremity while working with the DSM was mainly used to support and move the sanding machine along the compound walls.

Another reason for the reduction in the shoulder muscular efforts when using the DSM was the even distribution of forces between the right and left upper extremities. Results of this study indicated that there was no significant ($p>0.05$) difference in the shoulder muscle activities between the left and right shoulder when participants used the DSM. For the pole sanding, however, significantly ($p<0.05$) higher shoulder muscular exertions were observed in the right middle deltoid muscles. In this study, all participants were right handed. Thus, more muscular forces were applied by the right arm when participants performed the pole sanding tasks. When using the DSM, however, participants equally used their left and right arms to support the sanding machine. This in turn reduced over loading on one particular muscle group.

The reduction in shoulder muscular effort when using the DSM in the field setting concurred with the findings by Sahai and Vi (2004). Sahai and Vi (2004) conducted a controlled experiment to assess the feasibility of using the DSM as an alternative work method for drywall sanding. Using a simulated drywall-finishing task using pole sanding and the DSM, Sahai and Vi (2004) found significantly ($p<0.05$) less muscular activity in the shoulder muscles when workers used the DSM. In addition to the reduction in muscular effort, Sahai and Vi (2004) also found the DSM reduced drywall dust by an average of 96%.

From the trunk kinematics data, there was significantly higher trunk acceleration in the flexion/extension plane when workers worked with the sanding pole (see Figure 2). The increase in trunk acceleration was due to the pushing of the sanding pole and at the same time moving the entire tool across the vertical and horizontal walls in order to generate friction force. Based on the trunk kinematics results, using the pole sanding tool may required higher amount of spinal muscle activities; which in turn can create higher loading on the lower back. Sanding with the DSM, however, required significantly less trunk movement as the worker just needs to support the weight of the tool and do the job while maintaining a neutral posture. Consequently, the amount of forces generated by the lower back may be lower when using the DSM for drywall sanding task (i.e., $Force = mass \times acceleration$). This study did not measure the trunk load and therefore further study should be conducted in order to confirm this finding.

There were few limitations in this study which should be considered when generalizing the results to other work settings. One of the limitations was the small sample size. Power analyses indicated that the sample size for the upper arm kinematics and EMG data were adequate for a study power of 80%. The trunk kinematics data, however, indicated that the sample size was inadequate for a study power of 80%. Therefore, more study should be conducted to further verify the findings in this study.

Another limitation in this study was the small amount of time given to each participant in learning and using the DSM. Past research conducted by Chaffin et al. (1999) has demonstrated that learning a new task can be very slow. Using EMG, Chaffin et al (1999) demonstrated no differences in muscle activities between manual lifting and lifting using a material handling assisted device. Some of the participants have demonstrated that working with the lifting assisted device actually increased the level of torso muscle co-contraction activities (2-4 times), despite having 40 practice trials and no twisting or lateral bending of the trunk. The increase in muscle activities was attributed to the unaccustomed use of the material handling device. Given the findings from Chaffin et al. (1999) study, the EMG measured in this study may not be reflective of the true muscle activities if participants were to use the DSM for a longer duration. It should be noted that all participants were given the opportunity to use the DSM for a longer period (up to three months). However, all participants were reluctant to borrow the DSM for the three month study duration. The main reasons for the resistance to use the DSM long term were:

1) The vacuum and sanding head was too big and participants did not have the vehicle space to transport the machine. It should be noted that recently Porter Cable have implement a vacuum that is half the size being used in the current study.
2) Participants felt that they do not want to try the machine for a short duration if they were not planning to invest in the machine.
3) Participants expressed the practicality of the DSM for drywall sanding, such as reduction of dust exposure and reduction in work load. However, participants were reluctant to adopt the intervention due to the inability of the sanding machine to sand the upper corners which the participants were still required to use the sanding

pole. Another resistance to invest in the DSM was the cost of the equipment (approximately $1000 CAD) and the higher costs for the sanding papers.

4) Some participants expressed concerns of setting up the DSM which required approximately 5 to 10 minutes, and the requirement for high electrical power (minimum 15 amps or there will be a power surge). For the sanding pole, however, set up is quick, ease of mobility, and no external electrical source is required.
5) The power cords and vacuum tube can be tripping hazards.

It should be noted that even though the data collection period for all dependent variables were short duration (varies between 45 minutes and 2 hours), the data collected for the pole sanding and DSM were realistic exposure values for the respective sanding task methods. Drywall sanding is a repetitive task which does not varies from one drywall to the next. To test the variability of the exposure values, separate duration analyses comparing the first half and last half of all dependent variables were performed. The results of the analyses revealed no significant ($p>0.05$) differences between the two isolated duration. Therefore, despite the short duration of measurement, all dependent variables were reflective of the true exposure values for the sanding pole and DSM sanding methods.

As stated earlier, there are numerous limitations of the DSM for sanding drywall compound. Despite these limitations, there are numerous benefits in adopting the mechanical tool. These benefits include:

1) Reduction in drywall dust exposure which can result in reducing numerous respiratory health risks.
2) Pole sanding required high repetitive motion and forceful exertion of the upper arms and trunk in order to generate friction force between the sanding paper and drywalls. Working with the DSM can reducing forceful exertion and repetitive motion and thereby decrease muscular work load and fatigue.
3) Renovating existing residences, hospitals or businesses that required minimal dust level will benefit from the vacuum features of the DSM.
4) Less cleanup of drywall dust when working with the DSM.

ACKNOWLEDGMENTS

This project was funded by a research grant provided by the Workplace Safety and Insurance Board (Ontario). The author would also like to acknowledge the Interior Finishing Systems Training Center (IFTC), and Local 1891 of the Painters Union.

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