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An ergonomic comparison of industrial spray paint guns

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Abstract

Two spray guns were used by 10 subjects in a laboratory. One gun was a 'traditional' spray gun. The other was the OMX gun which had 'ergonomic' features including reduced gun and hose weight and two triggers (one for horizontal surfaces and one for vertical). The 10 subjects (5 experienced industrial spray painters and 5 inexperienced students) used each gun for 4 h. The criteria used to evaluate the two guns were: (1) Wrist deviation in all three axes, (2) EMG frequency shift of 3 shoulder muscles over the test period, (3) integrated EMG activity of the forearm flexors, and (4) body discomfort ratings.

It was found that the OMX gun resulted in significantly less radial/ulnar deviation in the wrist, and moderately increased flexion/extension and pronation/supination deviations from neutral. During the painting period, up to 50% less fatigue in the shoulder muscles was found for the OMX gun. Additionally, the triggering activation levels for sustained grip contractions were found to be acceptable for the OMX gun when using the short trigger. Finally, the amount of discomfort reported by the subjects was statistically lower in the shoulder, upper back, arm, elbow, forearm, wrist, and hand with the OMX gun design. Collectively, these results indicate that the OMX gun would be expected to reduce exposure to occupational risk factors for workers. This study demonstrated how the incorporation of ergonomic design principles can be used to minimize occupationally-related risk.

Relevance to industry

Cumulative trauma disorders (CTDs) are soft tissue disorders resulting from repeated exertions and excessive movements of the body. Industrial spray painting fits the profile of a highly repetitive task. Improving spray paint gun design could potentially reduce the risk of CTDs in industrial spray painting tasks.

Keywords: Spray paint guns; Risk factors; Cumulative trauma disorders

1. Introduction

Cumulative trauma disorders (CTDs) are soft tissue disorders of the tendons and nerves resulting from repeated exertions and excessive movements of the body (Armstrong, 1986). The reported incidence of CTDs has grown dramatically over the past several decades. The Bureau of Labor Statistics (BLS) reported that in 1981, 18% of occupational illnesses were due to cumulative trauma (Bureau of Labor Statistics Press Release, 1992). As of 1992, this figure has grown to 62%. Concern over CTDs has been intensified due to the cost of the disorders. Pinkham (1988) estimated the actual cost of each hand/wrist CTD case ranges from $15,000 to $25,000. Furthermore, this cost has continued to increase at an rate given the rising cost of health care in the United States.

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A common part of the body affected by CTDs in industrial work is the wrist. Injuries to the wrist accounted for 48% of the worker compensation claims filed for CTDs (Tanaka et al., 1988). One of the primary risk factors for CTDs is repetition (Silverstein et al., 1986; Silverstein et al., 1987). As companies have become more competitive in the industrial market place, highly repetitive job cycles are becoming common place. Industrial spray painting fits the profile of a highly repetitive task. Typically, an industrial spray painting job requires a painter, paced by the assembly line speed, to spray paint eight hours a day. Therefore, it is reasonable to assume that spray painting may place a worker at risk of CTDs. One potential means of minimizing this risk would be to provide workers with an ergonomically designed spray gun. Characteristics of the paint gun (such as the weight of the gun, maneuverability, and required triggering force to activate paint) can all contribute to the level of exposure of CTDs to the workers. One spray paint gun, the OMX™ (DeVilbiss), has considered many of these features into the design of the spray gun. The objective of this study was to quantitatively compare risk factors associated with traditional spray gun designs against an ergonomically designed spray paint gun.

There are several factors that may contribute to the risk of CTDs during spray painting. These include: wrist deviation, finger flexor activity when gripping a tool, and muscle fatigue. Past literature can provide quantitative 'benchmarks' for these risk factors. Wrist deviation from neutral position can contribute to the cause of CTDs of the wrist (Armstrong and Chaffin, 1979). Phalen (1966) reported the median nerve is compressed by the extrinsic finger flexor tendons when the wrist is in a flexed position. Armstrong and Chaffin (1979) reported that the resultant contact force between the flexor tendons and adjacent structures increases directly with tendon tension (increases with pinch or grip force) and inversely with radius of tendon curvature (increases with extreme wrist deviation). Marras and Schoenmarklin (1993) found high levels of wrist deviation were common in industry.

Sato et al. (1984) suggested that a sustained isometric contraction may contribute to CTD risk at contractions as low as 4% of maximum voluntary contraction (MVC). Bystrom and Fransson-Hall (1994) suggested that "intermittent hand grip contractions at (or higher than) a mean contraction intensity of 17% MVC and continuous handgrip contractions at (or higher than) 10% MVC were considered unacceptable". Because painting requires not only holding the tool, but intermittently activating it, we studied the finger flexor muscle activity required to operate the guns.

Muscular fatigue has been reported to be a contributor to musculoskeletal disorder (Chaffin, 1973). Under fatigue conditions, reduction in control of muscular exertion and joint stability are evident in movements (Parnianour et al., 1988), thus increasing the exposure of injury. There is a significant correlation between EMG median frequency reduction and muscle fatigue (Petrofsky and Lind, 1980; Petrofsky et al., 1982; Chaffin, 1973; Lippold et al., 1960; NIOSH, 1992). Based on interviews with the five experienced painters, three major muscles within the shoulder complex (the anterior deltoid, the middle deltoid, and the trapezius) were identified as areas likely to suffer from muscle fatigue during spray painting.

Psychophysical indices have been used to indicate the level of discomfort and perceived stress associated with the particular job and the above risk factors. Discomfort surveys are psychophysical measures by which data can be collected about a worker's perceived comfort level while painting. Pain and discomfort are the bodies' natural indicators to the onset of injury (Stuart-Buttle, 1994). A positive correlation has been demonstrated between discomfort reporting and biomechanical risk factors (Boussenna et al., 1982; Bonney et al., 1990). Snook et al. (1978) demonstrated the utilization of a psychophysical methodology which correlated a reduction in low back injuries with proper workplace design. Consequently, a discomfort survey was used to evaluate which local discomforts the painters were experiencing when using the two guns.

2. Methods

2.1. Approach

The objective for this study was to compare the musculoskeletal risk factors associated with two industrial spray paint guns. One gun was a spray paint gun commonly found in industry, and the other was an ergonomically designed OMX spray paint gun. Ergonomic principles were designed into the gun by reducing the weight, adding a top trigger, and permanently affixing a section of hose to the base of the gun. Wrist deviation, muscle fatigue, triggering activation levels, and discomfort, were quantitatively evaluated and statistically tested for differences between the guns.

2.2. Subjects

The 10 subjects (8 males and 2 females) ranged in age from 22 to 55 years (mean 34). Subjects' mean (±SD) height and body weight were 177 (±5.2) cm and 84.5 (±18.4) kg, respectively. Five of the subjects were currently employed by an automobile manufacturer as painters, and five had no industrial spray painting experience.

2.3. Experimental design

The study used a three-way mixed-factorial repeated measures design with two within-subject factors and one between-subject factor. The first within-subject factor, gun type, had two levels: the traditional and the OMX spray paint guns. The second within-subject factor, painting time, had five levels: corresponding to the time marked at the start of the work period and at time 1, 2, 3, and 4 h. The between-subject factor, experience, had two levels: experienced and inexperienced. Half of the subjects were randomly assigned to use the traditional gun first while the other half used the OMX gun first. Test procedures were carried out at least 48 h apart to minimize the possibility of fatigue carry-over. The dependent variables were: (1) Average wrist position (measured in 3 axes), (2) EMG frequency shift for the shoulder muscles throughout the test period, (3) trigger exertion level (integrated EMG for the forearm flexors), and (4) perceived body part discomfort.

2.4. Apparatus

2.4.1. Spray paint guns

The two guns used in this study are shown in Fig. 1. The traditional spray paint gun, which represents a large number of guns currently used in industry, was employed as the control gun for this study. The control gun weighed 0.6 kg (1.4 lb). The other gun was an ergonomically designed gun, the OMX gun, which weighed 0.4 kg (0.8 lb), and has a 114 cm (45 in.) long supply hoses permanently attached at the base of the grip. This length of hose weighs 0.3 kg

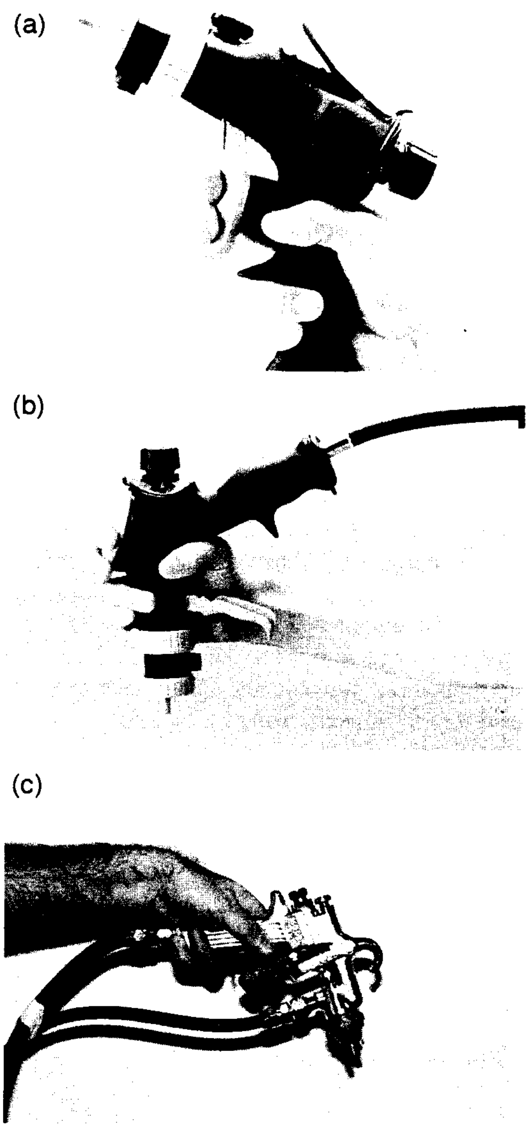

Fig. 1. The guns used in the experiment, and how they were used: (a) Ergonomic gun, conventional trigger, painting the vertical surface. (b) Ergonomic gun, top trigger, painting the horizontal surface. (c) Traditional gun, painting the horizontal surface.

(0.6 lb), compared to 0.6 kg (1.3 lb) of similar length hoses used for the control gun. This is a weight reduction of 0.3 kg (0.7 lb) for the supply hoses alone. The OMX gun has two triggers, a top trigger, for use when painting the top of a horizontal surface, and a conventional trigger. The conventional trigger has two modes of operation. In one mode, the trigger is in a shortened position that allows no control of the paint flow (on/off only). In the other mode, the trigger travels through a long path, and allows the painter to vary the paint flow rate. This trigger mode was the same as the control gun's trigger, therefore, it was not tested here.

2.4.2. *Wrist monitors*

Wrist position data were collected from the subjects' forearm and wrist via three independent electronic goniometers (Marras and Schoenmarklin, 1993). One monitor measured radial/ulnar movements, one monitor measured flexion/extension movements, and a third monitor measured pronation/supination movements. The monitors were placed on the subject's painting forearm.

2.4.3. *EMG system*

All EMG data were collected using the Myosystem 2000 (™Noraxon, Phoenix, AZ) via bipolar silver–silver chloride surface electrodes. Data filtering occurred within the Myosystem's software. The EMG collection system was connected to a 486 based PC where the data were stored for later analysis.

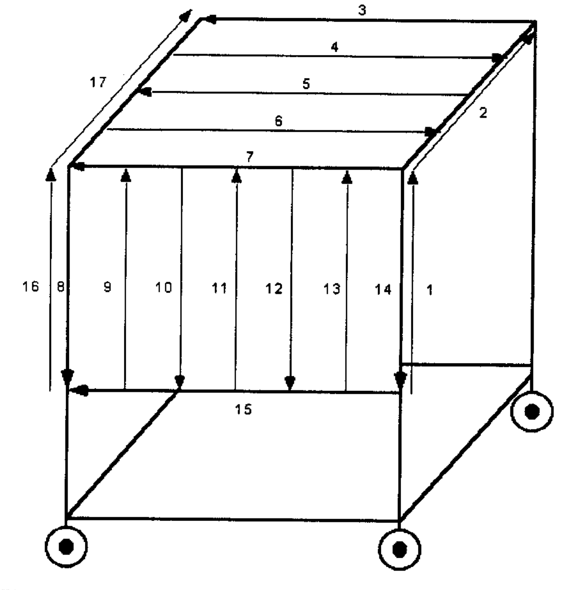

Fig. 2. Direction and order of paint strokes followed by the subjects for both guns.

2.4.4. *Painting target*

The target and the paint path were intended to resemble a repetitive painting task found in industry. The front and top surfaces of the target were 91 cm (36 in.) in width, 61 cm (24 in.) in height, and 61 cm (24 in.) in depth. The top horizontal surface was 124 cm (49 in.) from the floor. A path, composed of 17 separate strokes, was drawn on the target for all of the painters to follow (see Fig. 2). The first two strokes were used to 'cut-in' the leading edge of the target. Strokes 3 through 7 covered the top surface of the target. Strokes 8 through 15 were to paint the vertical front surface. Finally, strokes 16 and 17 painted the trailing edge.

2.5. *Procedure*

After receiving subject consent, the subjects were shown an introductory video about the study to ensure all subjects received identical instruction. Following the video, the subjects practiced with the gun and the target used in the experiment. Next, the EMG electrodes were applied to the shoulder complex, over the anterior deltoid, the middle deltoid, and the trapezius, and to the finger flexor muscle group. The electrodes were placed with approximately 3 cm distance between each pair of the electrodes. Each pair of the electrodes was placed at the center of the belly of the selected muscle and the direction of the electrodes was parallel to the muscle fibers. Finally, the goniometers were placed on the subject's wrist. The goniometers were calibrated for each individual subject.

The subjects were instructed to completely depress the trigger at the beginning of the each stroke and to release it at the end of each stroke. In addition, the subjects were instructed to keep the gun nozzle perpendicular to the surface. While no paint was used in this study, air pressure was provided to the guns so they realistically resembled a painting task 'feel'. The subjects were told that when the gun was held straight up and down, the paint would be fanning out vertically from the gun. Therefore, when painting the top surface, the gun was held straight up and down; when painting the front surface, the gun was rotated 90° so the paint was fanning out horizontally. When the subjects painted with the OMX gun, they were told to use the top trigger when painting the horizontal surface.

A computer generated tone was used to control the rate at which the painter was painting the target. Subjects were given 42 s to go through the path twice, followed by 6 s of rest. The length of 42 s was selected based on the total linear distance traveled while painting the target and a gun travel velocity of 5 cm/s. This work cycle was intended to resemble those observed in industry. The subjects were asked to pace themselves so they would be finishing their second pass over the target when the computer tone signaled the beginning of the rest period.

Data for wrist position were collected at five minute intervals during the experimental session. Data were collected in trials, defined as the wrist motions needed to paint the target one time. The subjects completed the discomfort survey at the start and on every half hour thereafter of the four hour work period. At each half-hour mark, subjects took one cycle time to complete the survey. For fatigue evaluation, the subject performed a controlled 'standard' exertion. For the shoulder muscles, this was accomplished by having the subject exert a force against a load cell, while strapped in a seated position. The load cell was chained between the base of the subject's chair and a strap looped around the subject's upper arm just proximal to the elbow joint. This restricted the subject's shoulder to a position of approximately 45° of flexion and 45° of abduction. The subjects were constrained in this position for all sub-MVC exertions so the median frequency of raw EMG could be compared across exertions. To identify the subject's sub-MVC level (standard test level), the subject performed a MVC exertion at the constrained position. The force from the load cell was measured for subject's MVC; 60% of this MVC was the standard test. Feedback about the exertion magnitude was provided with an oscilloscope to the subject so the desired 60% MVC could be controlled. The 60% MVCs were collected five times: at time 0, 1, 2, 3, and 4 h. To minimize muscle recovery, minimal time was used for the subject to be seated and perform the exertion.

Integrated EMG signal from the extrinsic finger flexor muscles was collected to represent the triggering activation level for each gun. The integrated EMG signal for each gun was normalized with integrated EMG collected during a maximum voluntary exertion. This exertion was performed with a grip dynamometer. The subjects pointed both guns and the grip dynamometer at the same point on the target so the two guns could be compared. At each triggering condition, subjects activated the trigger to a full stop and held for 5 s. This was repeated twice with 5 s of rest in between each exertion.

2.6. Data conditioning

All four channels of wrist data (three monitors and one time marker) were fed into a 12-bit A/D board sampling at 300 Hz. The digitized data were stored for later analysis. The average deviation per plane from the neutral position was normalized with respect to the maximal dynamic capability of the wrist reported by Schoenmarklin and Marras (1993). The maximal dynamic capability of the wrist was reported to be 57° in the flexion/extension plane, 29° in the radial/ulnar plane, and 101° in the pronation/supination plane. All position results to follow will be shown both as a percent of these maximum values and as angular deviation with direction.

The raw EMG signal of 60% MVC was collected at a sampling rate of 1000 Hz and fast fourier transformed to yield median frequency information for the analysis of muscle fatigue. The median frequency collected at the start of the experiment for each subject was used to normalize the exertions collected in the subsequent hours. Each normalized value was subtracted from one to get the percent of change in median frequency for the given hour and muscle.

The integrated EMG activity from the finger flexor muscles while the subject 'triggered' the different paint guns were collected at 100 Hz. To compare the short trigger of the OMX gun against the control gun, integrated EMG from a maximum voluntary exertion was used to normalized the signals.

For both guns, the subjects rated different upper extremity sites for discomfort by completing a discomfort survey developed by the Biodynamics Laboratory (Fig. 3). The survey uses a rating scale from one to nine with one being comfortable and nine being uncomfortable. The ratings for all subjects were averaged together over the entire four hour session for each gun type.

2.7. Statistical analysis

Univariate analysis of variance (ANOVA) was performed on each of the dependent variables to detect significant differences between the levels of the independent variables at $\alpha = 0.05$. The significance level for the trigger exertion levels were set a priori at $\alpha = 0.1$ since the variability of EMG has been found to be high (Mirka, 1991; Knutson et al., 1994). In addition, Tukey tests were used as the post hoc analysis to further evaluate the significant results.

3. Results

The significant results are summarized for all criteria measures in Table 1. This summary indicates the gun design significantly influenced wrist position, shoulder fatigue, perceived discomfort, and triggering EMG.

3.1. Wrist positions

The statistically significant differences between the two paint guns for each of the three planes of wrist motion are summarized in top portion of Table 1.

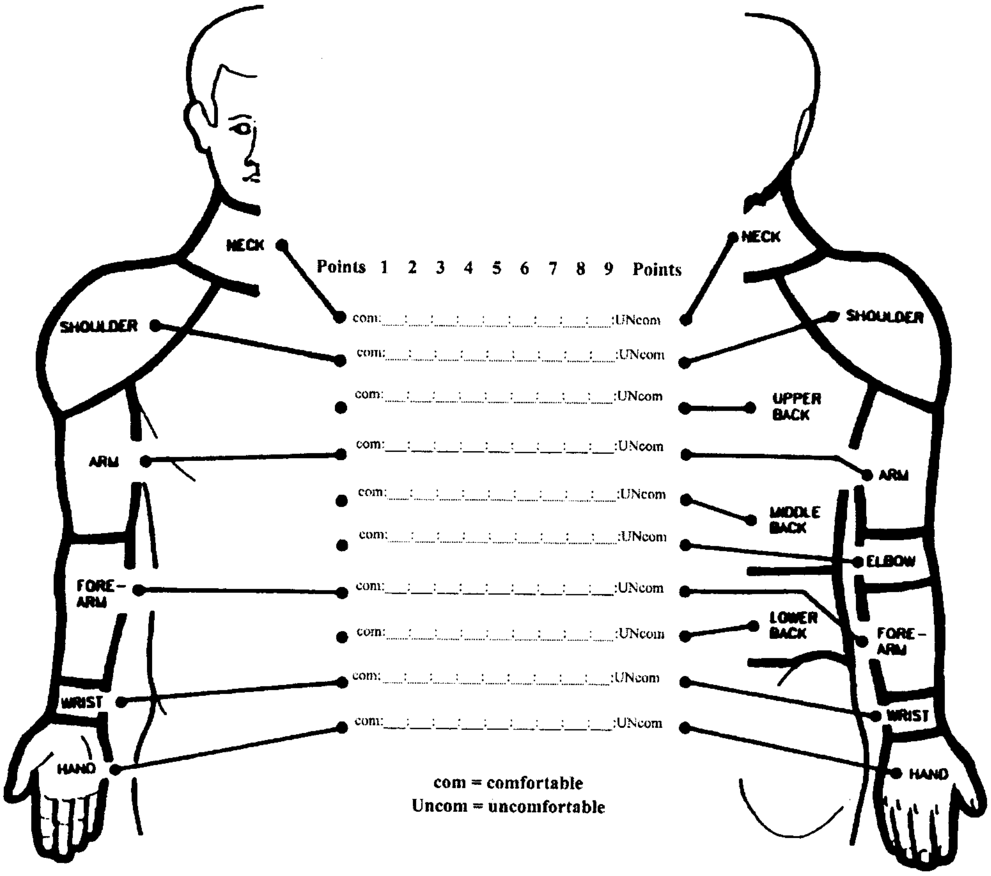

Fig. 3. Discomfort survey given to the subjects every half hour for both the OMX and the control guns.

3.1.1. Radial / ulnar

Fig. 4 indicates that there is substantially less deviation from neutral in the radial/ulnar plane when using the OMX gun, compared to the control gun.

The average deviation when using the OMX gun was 17% of maximum deviation, while with the control gun, the deviation was 40% of maximum. In terms of angular deviation, the average deviation when using the OMX gun was 0° in the ulnar direction, and 12° deviation when the control gun was used (Fig. 5).

3.1.2. Flexion / extension

Figs. 4 and 5 indicate about 6° less wrist deviation in the flexion/extension plane with the control gun. Subjects' wrist motion averaged 21° extension (37% of maximum) for the control gun and 27° extension (47% of maximum) for the OMX gun.

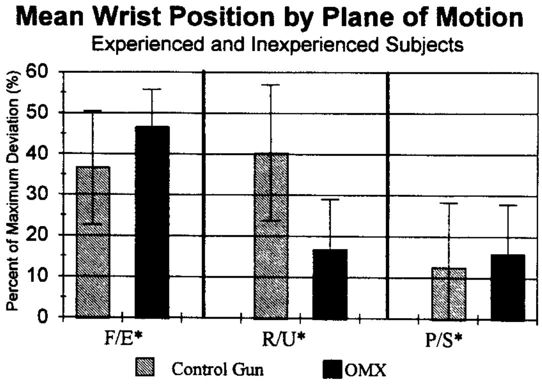

Fig. 4. Percent of maximum deviation for the three planes of wrist motion (F/E = flexion/extension, R/U = radial/ulnar, P/S = pronation/supination). See Fig. 5 for absolute degrees. The OMX gun and the control gun are significantly different at an $\alpha = 0.05$ (noted by *). The wrist deviations were averaged over all subjects across all four hours. The wrist deviations were divided by the maximum position for each respective plane.

Table 1
Summary of significance from the ANOVA analysis

	Gun (G)	Time (T)	Experience (E)	G∗E	G∗T
Wrist positions					
Avg. flex/ext	**			**	**
Avg. rad/ulnar	**		**	**	**
Avg. pron/sup	**			**	**
Median frequency shift					
Anterior	**				
Deltoid					
Middle					
Deltoid					
Trapezius	**				
Discomfort surveys					
Neck		**	**		
Shoulder	**	**	**		
Upper back	**	**	**		
Arm	**	**			
Middle back		**			
Elbow	**	**			
Forearm	**	**		**	
Lower back		**	**		
Wrist	**	**			
Hand	**	**		**	

	Trigger (T)	Exertion	Experience	T∗Exp	T∗Exert
Trigger level			*		
% of max.	*				

** indicates significant at $p < 0.05$. * indicates significant at $p < 0.10$.

3.1.3. Pronation / supination

Similar to the flexion/extension motion, the analysis revealed that subjects' forearm deviated 6° further away from neutral in the pronation/supination plane when using the OMX gun (Figs. 4 and 5) compared to the control gun. The average deviation when using the OMX gun was 8° pronation (16% of maximum), versus a 3° supination (13% of maximum) for the control gun. Additionally, with the exception of the radial/ulnar plane of motion, there was no statistical difference detected between experience levels. The experienced subjects had an average deviation from maximum of 29% for the control gun and 17% for the OMX gun in the radial/ulnar plane, while the inexperienced subjects had deviations of 52% for control and 16% for the OMX gun. This two-way interaction was significantly affected by the experience levels at the control gun condition. No significant difference was found in the wrist deviations as a function of time.

3.2. Upper extremity muscle fatigue

The anterior deltoid and the trapezius muscles showed significantly less change in median frequency over the four hours of painting while using the OMX gun ($p < 0.05$). This indicates the subjects experienced less muscle fatigue when using the OMX gun. As shown in Fig. 6, when the subjects used the OMX gun, the average reduction in median frequency over the four hours was below 5% for each of the three shoulder muscles. With the control gun, the reduction in median frequency ranged from 6 to 10%. Thus, the OMX gun resulted in up to a 50% reduction in the shift of median frequency in the muscles of the shoulder complex. Both experienced and inexperienced subjects demonstrated a similar reduction rate in median frequency over the four hours of the experiment.

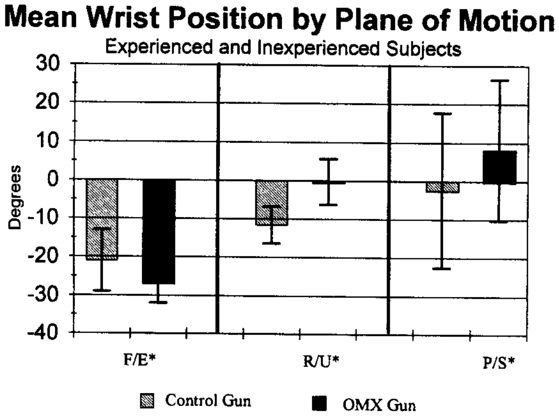

Fig. 5. Average wrist deviation across four hours of experiment. The wrist deviations were averaged over all subjects across all four hours. The OMX gun and the control gun are significantly different at an $\alpha = 0.05$ (noted by *).

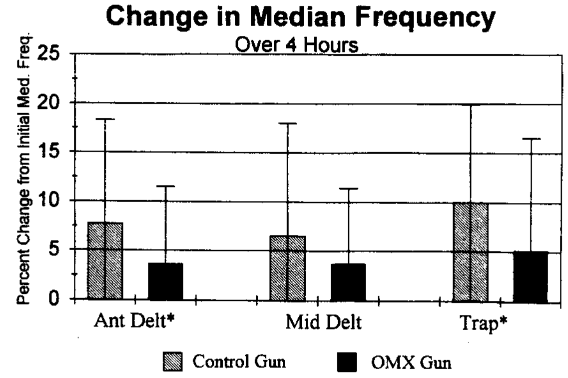

Fig. 6. Change in median frequency for the anterior deltoid, middle deltoid, and trapezius muscles. For all subjects, the OMX and traditional guns were significantly different for the muscles indicated by an * at an $\alpha = 0.05$.

3.3. Trigger exertions

Post hoc analysis revealed there was a significantly lower ($p < 0.1$) exertion level when using the short trigger of the OMX gun, when compared to control gun. Averaged across all subjects, the short trigger of the OMX gun significantly reduced the activation force to 9% of maximum, compared to 14% when using the control gun (see Fig. 7). For both triggers, there was a large variability in exertion levels among the experienced subjects. The variance in the inexperienced subjects' exertion levels was smaller, with all but one of the subjects exerting below 20% of the maximum exertion. Furthermore, the inexperienced subjects had lower exertion levels ($p < 0.1$) than the experienced subjects for both types of triggers.

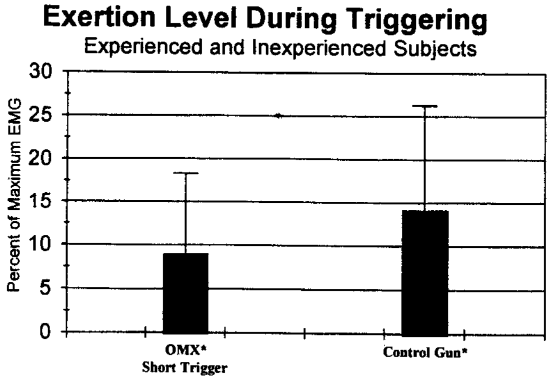

Fig. 7. Trigger exertion levels for the OMX and control guns. Triggers indicated by an * are significantly different at an $\alpha = 0.10$.

3.4. Discomfort survey

Discomfort ratings for each body part increased over the four hours of painting for both guns, with the highest ratings in the final hour. There was a significant difference ($p < 0.05$) between the control gun and OMX gun for the shoulder, upper back, arm elbow, forearm, wrist, and hand (see Table 1). In all significant cases, subjects reported a lower average discomfort rating when using the OMX gun (see Fig. 8). The experienced subjects reported significantly lower discomfort ratings than the inexperienced subjects for the neck, shoulder, upper back, and lower back.

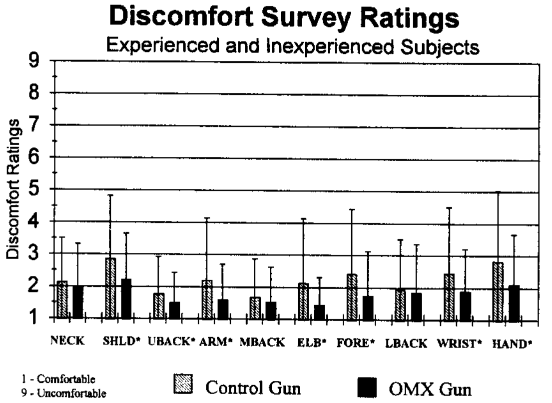

Fig. 8. Body part average discomfort rating for both the OMX and traditional guns. The ratings ranged from 1 (comfortable) to 9 (uncomfortable). The discomfort ratings were averaged over all subjects and all hours of painting. The guns were significantly different for the body parts indicated by * at an $\alpha = 0.05$. SHLD = shoulder, UBACK = upper back, MBACK = middle back, ELB = elbow, FORE = forearm, LBACK = lower back.

4. Discussion

4.1. Wrist deviation

This study was able to quantitatively document the benefit of the OMX's top trigger. The largest difference between the two guns occurred in the radial/ulnar plane of motion. Unlike the control gun, where subjects adapted an extreme ulnar deviation (11.3° of deviation) to keep the gun nozzle perpendicular to the horizontal surface of the target, the subjects were able to maintain a neutral posture (0.3° of deviation) in the radial/ulnar plane when using the top trigger of OMX gun. Pryce (1980) reported that maximum static grip strength reduces with an increase of wrist ulnar deviation. Since the OMX's top trigger allowed the subjects to paint with a neutral posture in the radial/ulnar plane, it should allow the subjects to activate the gun trigger at a lower percentage of their maximum static grip strength.

The analysis revealed subjects exhibited a slightly higher wrist deviation (a 6° difference) in the flexion/extension plane when using the OMX gun. Traditional ergonomics recommends minimization of wrist deviation from neutral. The OMX gun included the top trigger to minimize radial/ulnar deviation, but had no significant changes to minimize flexion/extension. Since Loslevert and Ranaivosoa (1993) suggested the resting position of the wrist is around 5° extension and there is a lack of literature to assess the magnitude of risk incurred by additional deviation, the additional five degrees of extension to 27° is not as severe as it might appear when compared to neutral posture, but it should be noted.

The analysis also revealed subjects exhibited slightly higher forearm rotation (a 5° difference) when using the OMX gun. Recall the OMX gun and attached hose weighed 0.6 kg (52%) less than the control gun plus supply hose. Also, some hand/wrist manipulation is required to switch from using the regular trigger to the top trigger and back. The authors suspect the combination of reduced inertia (due to reduction in gun/hose weight) and the required hand/wrist manipulation to be responsible for the higher deviation reported for the OMX gun in pronation/supination planes.

The five experienced subjects were employed as painters and had a working knowledge of the control gun. Neither the experienced nor the inexperienced subjects were familiar with the OMX gun prior to the experiment. Therefore, the experience level is different only for the control gun. This was confirmed by the significant difference in wrist deviation found in the radial/ulnar plane between the experience levels, but only under the control gun condition.

4.2. Upper extremity muscle fatigue

The effect of the OMX gun's weight reduction was evident from the observed EMG change in two of the three shoulder complex muscles. The permanent hose attachment also allowed the subjects to maneuver the paint gun with less effort. The weight reduction of the OMX gun reduces the cumulative weight the painters have to hold in a day. The reduced muscular fatigue associated with the use of the OMX gun will allow the painters to work at a lower percentage of his/her work capacity. This permits control of muscular exertion and joint stability throughout the work cycles.

4.3. Trigger exertions

A continuous contraction is defined as a sustained contraction with no rest. Depending on the requirements of the job and the painters' work habits, the industrial spray painting job has a combination of continuous hand grip and intermittent hand grip tasks. Such differences in work habits were reflected by the large variance in the trigger exertions among experienced subjects. The short trigger reduced the trigger force needed to activate the paint which would result in a reduction in the amount of finger flexor tendon travel through the carpal tunnel. These modifications will reduce risk of upper extremity cumulative trauma disorders by reducing wear and tear on the soft tissues inside the wrist. The activation force required by the OMX gun short trigger was found to be at an acceptable force level, as defined by Bystrom and Fransson-Hall (1994) for a continuous hand grip.

4.4. Discomfort survey

The biomechanical risk factors measured for this study were physical measures, while the discomfort surveys were used to measure perception of pain. The subjects were given a discomfort survey to quantify their perception and tolerance of discomfort. The results indicated there was a significant reduction in discomfort in the subject's upper extremities and upper back when using the OMX gun. The authors expect the light weight design and easy maneuverability of the OMX gun to be the major factors in reducing the discomfort associated with the use of the OMX gun. Since the discomfort survey is a measure of perception of pain, the results from the survey could be affected by the lab environment and the subjects' perception of the OMX gun. Since the OMX gun was introduced to the subjects as an ergonomically designed gun, it is possible the subjects favored the OMX gun based on its introduction.

5. Conclusion

This study demonstrated how an ergonomically designed spray paint gun can reduce the risk factors associated with CTDs. Ergonomic design can significantly affect the biomechanical behavior of the worker during the painting task. As we have just discussed, the largest difference between the two guns with respect to wrist deviation occurred in the radial/ulnar plane of motion. This reduction in radial/ulnar deviation can reduce the risk of tenosynovitis. The control gun produced less deviation in the other two wrist planes, however, the magnitude of these differences were smaller. The use of the top trigger permitted the workers to paint with a more neutral posture. The lightweight construction and flexible hose attachment of the OMX gun made it easier to maneuver, resulting in reduced muscular fatigue. The short trigger on the OMX gun also allowed the subjects to activate the gun while remaining within the limits of the safe trigger exertion level. Finally, the analysis of the discomfort surveys showed the subjects experienced less discomfort with the OMX gun. This study demonstrated the usefulness of quantitative ergonomic approach in assessing the benefit of an ergonomic tool design. The same approach can be incorporated into the prototyping phase of tools to detect any unexpected interactions. It should be noted that since the experiment was performed in a laboratory, the experimenters could not account for any additional factors, physiological or psychophysical, which might alter the subjects' performance. Future studies should verify that OMX gun is also effective in reducing these risk factors under actual working environments.

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References

Armstrong, T.J. and Chaffin, D.B., 1979. Some biomechanical aspects of the carpal tunnel. Journal of Biomechanics, 12: 567–570.

Armstrong, T.J., 1986. Ergonomics and cumulative trauma disorders. Hand Clinics, 2(3): 553–565.

Bonney, R., Weisman, G., Haugh, L. and Finkelstein, J., 1990. Assessment of postural discomfort. Proc. Human Factors Society 34th Annual Meeting, pp. 684–687.

Boussenna, M., Corlett, E.N. and Pheasant, S.T., 1982. The relation between discomfort and postural loading at the joints. Ergonomics, 25: 315–322.

Bureau of Labor Statistics Press Release, April, 1992. Occupational Injuries and Illnesses in the United States by Industry, 1990. United States Department of Labor Bureau of Labor-Statistics, Washington, DC.

Bystrom, S. and Fransson-Hall, C., 1994. Acceptability of intermittent handgrip contractions based on physiological response. Human Factors, 36(1): 158–171.

Chaffin, D.B., 1973. Localized muscle fatigue – definition and measurement. Journal of Occupational Medicine, 15(4): 346–354.

Knutson, L.M., Soderberg, G.L., Ballantyne, B.T. and Clarke, W.R., 1994. A study of various normalization procedures for within day electromyographic data. Journal of Electromyographic and Kinesiology, 4(1): 47–59.

Lippold, O.C.J., Redfern, J.W.T. and Vuco, J., 1960. The electromyography of fatigue. Ergonomics, 3: 121–131.

Loslevert, P. and Ranaivosoa, A., 1993. Biomechanical and epidemiological investigation of Carpal Tunnel syndrome at workplace with high risk factors. Ergonomics, (36)5: 537–554.

Marras, S.W. and Schoenmarklin, R.W., 1993. Wrist motion in industry. Ergonomics, (36)4: 341–351.

Mirka, G.A., 1991. The quantification of EMG normalization error. Ergonomics, 34(3): 343–352.

NIOSH, 1992. Selected Topics in Surface Electromyography for Use in the Occupational Setting: Expert Perspectives. U.S. Department of Health and Human Services.

Parnianour, M., Nordin, M., Kahanovitz, N. and Frankel, V., 1988. The triaxial coupling of torque generation of trunk muscles during isometric exertions and the effect of fatiguing isoinertial movements on the motor output and movement patterns. Spine, 13(9): 982–992.

Petrofsky, J.S. and Lind, A.R., 1980. Frequency analysis of the surface electromyography during sustained isometric contractions. European Journal of Applied Physiology, 43: 173–182.

Petrofsky, J.S., Glaser, R.M., Phillips, C.A., Lind, A.R. and Williams, C., 1982. Evaluation of amplitude and frequency components of the surface EMG as an index of muscle fatigue. Ergonomics, 25(3): 213–223.

Phalen, G., 1966. The Carpal Tunnel syndrome. Journal of Bone and Joint Surgery A, 48(2): 211–228.

Pinkham, 1988. CTD impacts thousands and costs are skyrocketing. Occupational Health and Safety, 52–53.

Pryce, J., 1980. The wrist position between neutral and ulnar deviation that facilitates the maximum power grip strength. Journal of Biomechanics, 13: 505–511.

Sato, H., Ohoshi, J. and Iwanaga, K. 1984. Endurance time and fatigue in static contractions. Journal of Human Ergology, 13: 147–154.

Schoenmarklin, R.W. and Marras, W.S., 1993. Dynamic capabilities of the wrist joint in industrial workers. International Journal of Industrial Ergonomics, 11: 207–224.

Silverstein, B.A., Fine, L.J. and Armstrong, T.J., 1987. Occupational factors and Carpal Tunnel syndrome. American Journal of Industrial Medicine, 11: 343–358.

Silverstein, B.A., Fine, L.J. and Armstrong, T.J., 1986. Hand wrist cummulitive trauma disorders in industry. British Journal of Industrial Medicine, 43: 779–784.

Snook, S.H., Campanelli, R.A. and Hart, J.W., 1978. A study of three preventive approaches to low back injury. Journal of Orthopeadic Medicine, 20(7): 478–481.

Stuart-Buttle, C., 1994. A discomfort survey in a poultry-processing plant. Applied Ergonomics, 25(1): 47–52.

Tanaka, S., Seligman, P., Halperin, W., Thun, M., Timbrook, C.L. and Wasil, J.J., 1988. Use of workers' compensation claims data for surveillance of cumulative trauma disorders (CTDs). Journal of Occupational Medicine, 30(6): 488–492.