Journal of Electromyography and Kinesiology 20 (2010) 191–198

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Effects of posture, movement and hand load on shoulder muscle activity

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ARTICLE INFO

Article history:
Received 28 May 2008
Received in revised form 22 April 2009
Accepted 22 April 2009

Keywords:
EMG
Flexion
Abduction
Hand load
Grip force
Shoulder
Joint

ABSTRACT

The influence of external factors such as arm posture, hand loading and dynamic exertion on shoulder muscle activity is needed to provide insight into the relationship between internal and external loading of the shoulder joint. Surface electromyography was collected from 8 upper extremity muscles on 16 participants who performed isometric and dynamic shoulder exertions in three shoulder planes (flexion, mid-abduction and abduction) covering four shoulder elevation angles (30°, 60°, 90° and 120°). Shoulder exertions were performed under three hand load conditions: no load, holding a 0.5 kg load and 30% grip. It was found that adding a 0.5 kg load to the hand increased shoulder muscle activity by 4% maximum voluntary excitation (MVE), across all postures and velocities. Performing a simultaneous shoulder exertion and hand grip led to posture specific redistribution of shoulder muscle activity that was consistent for both isometric and dynamic exertions. When gripping, anterior and middle deltoid activity decreased by 2% MVE, while posterior deltoid, infraspinatus and trapezius activity increased by 2% MVE and biceps brachii activity increased by 6% MVE. Increased biceps brachii activity with gripping may be an initiating factor for the changes in shoulder muscle activity. The finding that hand gripping altered muscle activation, and thus the internal loading, of the shoulder may play an important role in shoulder injury development and rehabilitation.

1. Introduction

Work-related musculoskeletal disorders (WMSD) of the upper extremity currently rank second to the lumbar spine as the most documented workplace injury claim in Ontario (WSIB, 2008). External factors, such as shoulder posture and the magnitude of an applied load, have been shown to influence the relative activation of shoulder muscles (Laursen et al., 1998; de Groot et al., 2004; MacDonell and Keir, 2005). While external load and posture dictate the well accepted inverse dynamics solution, they do not always offer an accurate indication of the internal loads on specific elements of the shoulder complex (Laursen et al., 1998). For example, dynamic shoulder exertions with precise hand movement have been shown to increase shoulder muscle activity (Sporrong et al., 1998; Laursen et al., 1998), while hand gripping has been shown to increase the activity of some shoulder muscles and decrease the activity of others (Sporrong et al., 1995, 1996; Au and Keir, 2007). Electromyographic changes due to these intervening variables may be considered relatively small (<10%) but when one considers the cumulative effect over the course of a worker's day, week or year, the effect may be considerable, and the difference between a worker developing a disorder or not (Kumar, 1990). The interactions between these factors and their effect on shoulder muscle activity have yet to be fully examined.

When raising the arm, the external shoulder moment increases to a maximum at 90° and muscle activity must increase to support the increased external moment. However, shoulder muscle activity has also been shown to increase with both abduction and flexion angle even if the external moment is experimentally maintained at a near constant magnitude (Sigholm et al., 1984; MacDonell and Keir, 2005). As the shoulder angle increases above 90°, the combination of decreasing muscle length and moment arm acts to reduce the moment generating potential, thus requiring greater muscle activity despite a decrease in external shoulder moment. Even without an additional load in the hand, Palmerud et al. (2000) found that intramuscular pressures of infraspinatus and supraspinatus rose above 40 mmHg with elevated flexion and abduction angles – a pressure above which muscular blood flow may be significantly impaired and muscle injury may follow (Jarvholm et al., 1991).

The nature of hand use is also known to increase shoulder muscle activity. Sporrong et al. (1998) found that a light movement task performed with the hand at raised shoulder positions elevated trapezius and anterior deltoid activity by 20% over maintaining the same posture without the light hand task. Holding a 1 or 2 kg load during either shoulder flexion or abduction increased the activity of the deltoids, trapezius, and to a larger extent, supraspinatus and infraspinatus (Sigholm et al., 1984). Also, the addition of a

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doi:10.1016/j.jelekin.2009.04.010

hand grip during shoulder exertions has also been shown to influence shoulder muscle activity, even though it had no effect on the external shoulder moment (Sporrong et al., 1995, 1996; MacDonell and Keir, 2005; Visser et al., 2006). Hand grip forces of 30% and 50% maximum increased supraspinatus and infraspinatus activity by nearly 10% of maximum voluntary excitation (MVE), while middle deltoid activity decreased (Sporrong et al., 1995, 1996). Under similar conditions, Au and Keir (2007) found that applying a 30% grip force while maintaining a 40% shoulder abductor moment, reduced both anterior and middle deltoid activity by about 2% MVE. Thus, gripping appears to redistribute muscle activity from the deltoid muscle group to the rotator cuff. This may partially explain why the rotator cuff is the most commonly injured site of the shoulder complex in the workplace (Zakaria, 2004).

Speed of arm movement also plays a role in internal loading (Laursen et al., 1998; Sporrong et al., 1998; Komi et al., 2000). For dynamic biceps contractions using an isokinetic dynamometer, Laursen et al. (1998) reported that when task speed was increased from the lowest to highest, the EMG of the three deltoids, rotator cuff, pectoralis major and trapezius increased by 55–110% depending on the precision required. Since the activity of both agonist and antagonistic muscle groups increased in response to dynamic exertions, it was suggested that shoulder muscle activity increased due to a demand for co-contraction to stabilize the shoulder joint, allow for smooth control of the hand and prevent jerky movement.

While changes in arm posture, hand loading and shoulder angular velocity have all been shown to affect shoulder muscle activity, they have done so under constrained conditions. Elucidating the relationships between these external factors and their combined effects on shoulder muscle activity during free motions will provide insight into the mechanisms of shoulder disorders, especially to those due to cumulative loading. The purpose of this study was to evaluate the effects of arm posture and hand loading on shoulder muscle activity during both isometric and dynamic conditions. It was hypothesized that the addition of a grip force would decrease deltoid activity and that muscle activity would be proportional to the speed of movement.

2. Methods

2.1. Participants

Sixteen healthy right-handed volunteers (8 males, 8 females; mean age 25.3 ± 1.4 years), who reported no history of shoulder pain or injury, participated in the study after providing informed consent. Body mass, height, maximum grip strength, and arm length were recorded for each participant (Table 1). The study protocol was approved by the University Human Participant Research Committee.

Table 1
Mean participant anthropometrics and grip strength (standard deviation).

	Males	Females	Both
Height (m)	1.78 (0.07)	1.64 (0.08)	1.71 (0.10)
Mass (kg)	80.0 (12.7)	64.0 (9.0)	72.0 (13.5)
Age (years)	25.1 (1.5)	25.4 (1.5)	25.3 (1.4)
Arm length (cm)	66.8 (3.5)	56.7 (8.0)	61.7 (7.9)
Max grip (N)	526.9 (99.0)	328.6 (42.5)	427.8 (126.1)

2.2. Experimental protocol

Participants performed isometric and dynamic shoulder exertions with their right arm, elbow extended, and a neutral wrist posture while standing. These were repeated in three shoulder elevation planes: (i) 0° (flexion, Fig. 1a), (ii) 45° (mid-abduction, Fig. 1b) and (iii) 90° (abduction, Fig. 1c). Shoulder exertions were repeated in three different hand loading conditions: (i) no load in the hand, (ii) holding a 0.5 kg grip dynamometer (MIE Medical Research Ltd., Leeds UK) and (iii) holding the grip dynamometer and exerting a grip force of 30 ± 3% of maximum. Grip force was maintained via visual feedback from a computer monitor facing the participant (Fig. 1a). The monitor displayed a column of three lights, indicating when the exerted grip force was above or below (red),[1] or within (green) the target force range. To maintain a neutral humeral position and forearm posture (at 0° shoulder angle) in all planes, the grip dynamometer was oriented vertically in the flexion and mid-abduction planes and horizontally in the abduction plane. These hand orientations were maintained for trials completed with and without a hand load.

Isometric shoulder exertions were maintained for 10 s at four different shoulder angles (30°, 60°, 90° and 120° of abduction) in each of the three planes (Fig. 1a–c). All 12 postures were repeated with each of the three loads for a total 36 isometric conditions. Each condition was performed twice for a total of 72 trials (Fig. 2a). Participants also performed dynamic exertions at both "slow" and "fast" speeds through the same range of motion as the isometric trials in each of the three shoulder planes. One full movement required the participant the arm to move from a 0° shoulder angle to maximum elevation above 120°, then return to the start position. "Slow" and "fast" motions corresponded to cycle times of 8 and 4 s, respectively. Two trials of two cycles, with each of the three load conditions, were completed for a total of 18 conditions and 36 dynamic trials (Fig. 2b). At least one minute rest was given between each trial. Participants practiced moving while maintaining the grip force prior to collection.

2.3. Data collection

Surface electromyography (EMG) was collected from eight muscles of the right upper extremity: anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), pectoralis major (PM), infraspinatus (INF), latissimus dorsi (LD), biceps brachii (BB) and superior trapezius (TR). Sites were scrubbed with alcohol (and shaved if necessary) prior to applying disposable Ag–AgCl surface electrodes (MediTrace 130, MA, USA) over the muscle belly, parallel to the muscle fibre orientation with a centre-to-centre distance of 3 cm using standard electrode placements. Electrode placements were confirmed using muscle specific contractions, including manually resisted shoulder flexion (AD), abduction (MD), extension (PD), horizontal adduction (PM), external rotation (INF), resisted elbow flexion (BB) and shoulder shrugs (TR). EMG signals were differentially amplified (CMRR > 115 dB at 60 Hz) and band pass filtered from 10 to 1000 Hz (AMT-8, Bortec Biomedical Ltd., AB, Canada). Signals were then analog linear enveloped at 3 Hz (hardware full-wave rectified followed by a 3 Hz critically damped low pass filter) and A/D converted at 100 Hz (12 bit, Model PCI-MIO-16E-4, National Instruments, TX, USA). Maximal voluntary excitation (MVE) was determined for each muscle using the procedures used to confirm electrode placement. Maximal exertion trials were collected for 10 s during which the participant increased to maximum and maintained it for a minimum of 3 s, with at least one minute rest between trials. The MVE for each muscle was calculated from the linear enveloped EMG signal using a 500 ms window centered about the peak. Bias was determined from a quiet trial and removed from all EMG data prior to analysis. Maximal grip force was determined with the arm at the side and the forearm in a neutral position. The participant squeezed the dynamometer to

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[1] For interpretation of the references in colour in this figure legend, the reader is referred to the web version of this article.

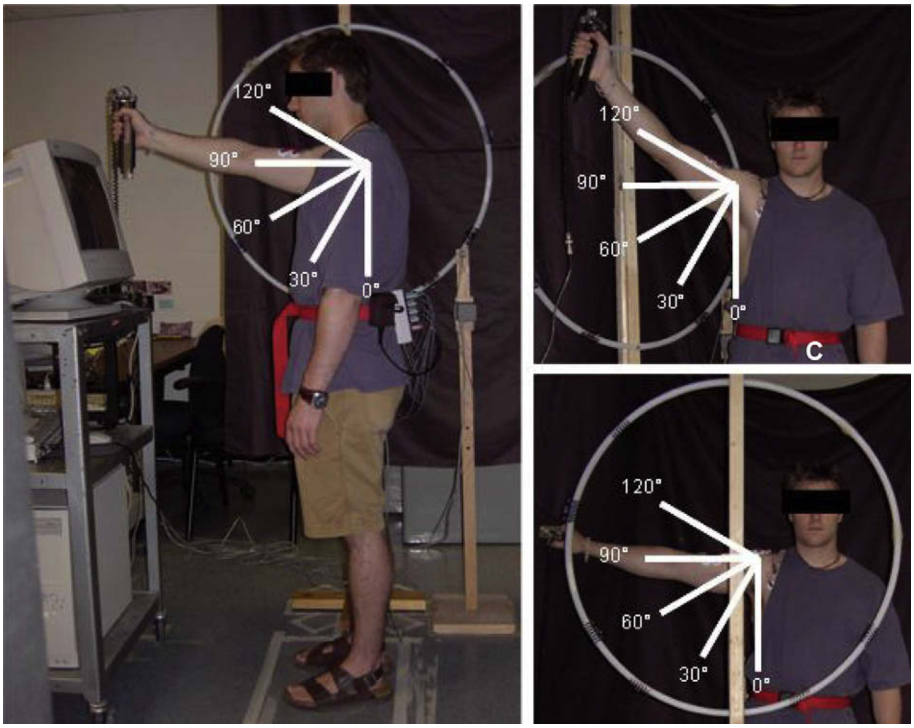

Fig. 1. Shoulder angle apparatus placement in the (A) flexion, (B) 45° and (C) abduction planes with shoulder angles of 0°, 30°, 60°, 90° and 120° superimposed.

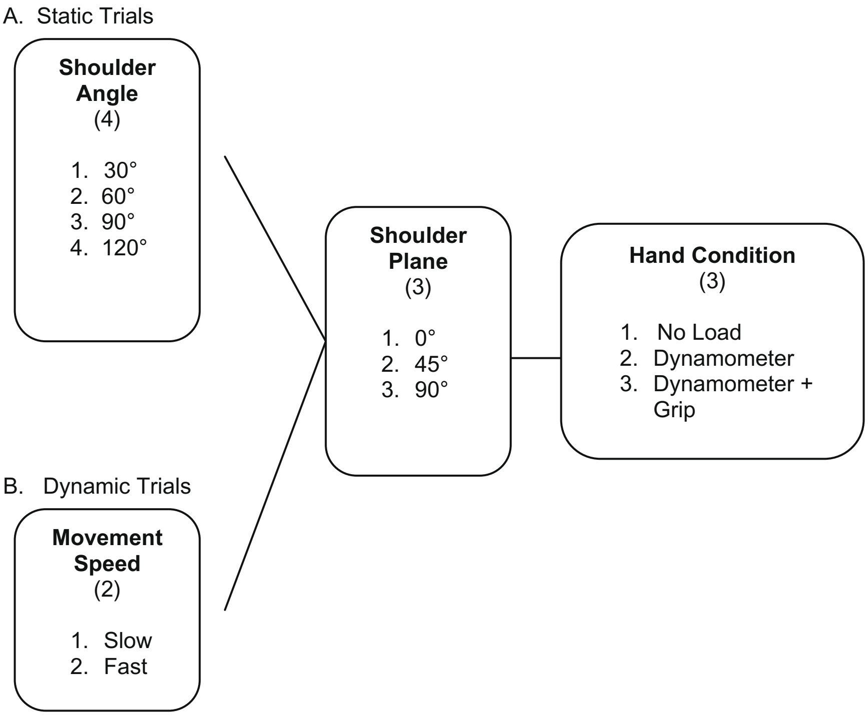

Fig. 2. Experimental conditions for (A) isometric trials and (B) dynamic trials to be performed randomly during each of two blocks consisting of 36 and 18 conditions (72 and 36 trials), respectively.

maximum in a 10 s collection period, the maximum grip was determined as the peak force seen during the trial. Two trials were completed. If the maximums were within 5%, the higher value was used, if not, an additional trial was collected.

Muscle activity during isometric exertions was analyzed by averaging a 3 s window when EMG and posture were in steady state as noted from the angle display and observation of the participant. Muscle activity from dynamic exertions was analyzed by calculating the mean of a 120 ms window centered about the angles of 30°, 60°, 90° and 120°. This allowed dynamic and isometric average EMG (AEMG) to be compared at each angle and speed. Arm posture, relative to vertical, was collected throughout the study using an electromagnetic motion tracking system (FASTRAK®, Polhemus Ltd., Colchester, VT, USA). A receiver was attached to the

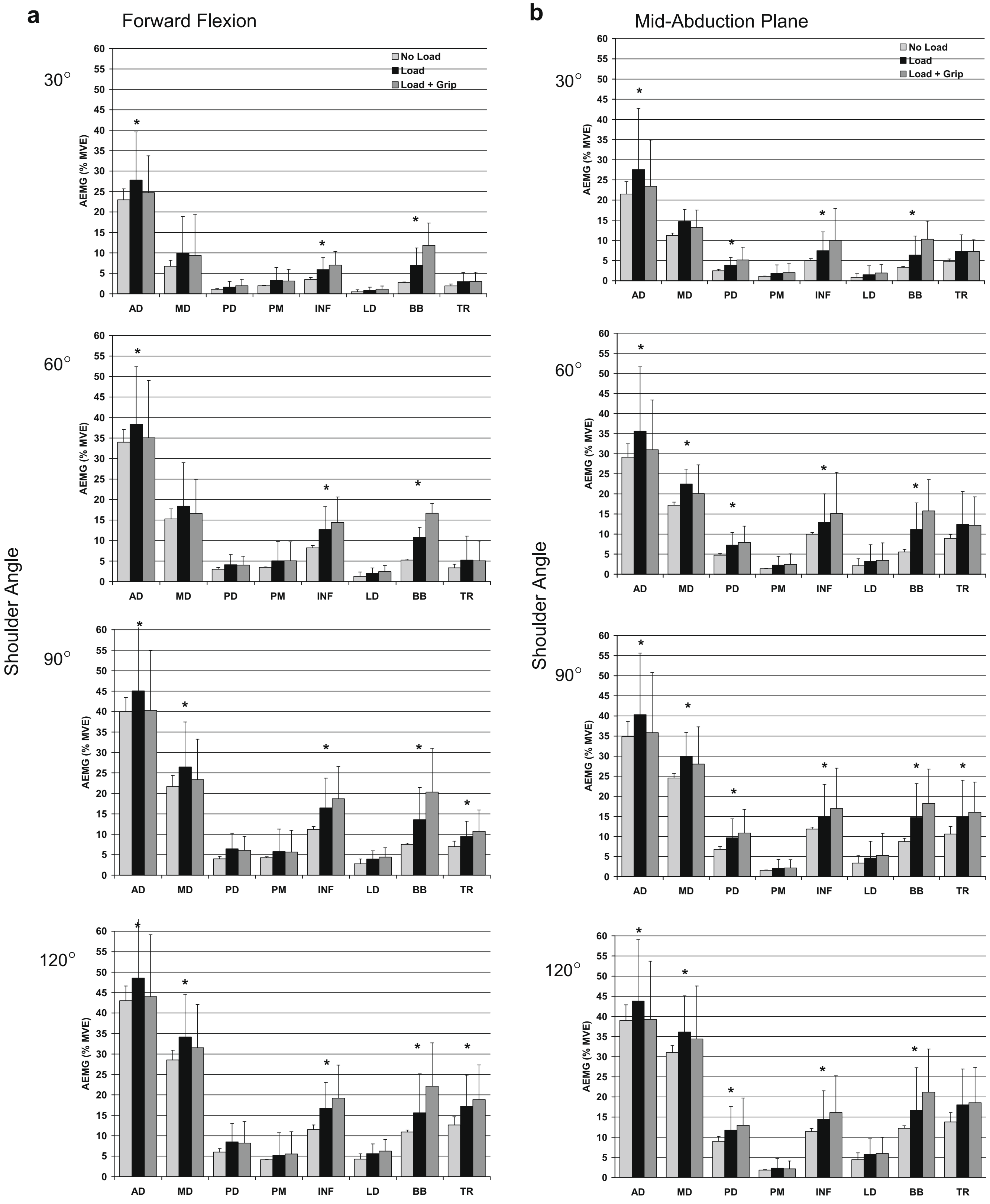

Fig. 3. Mean muscle activity (% MVE with standard deviation) during isometric shoulder exertions in (a) flexion, (b) mid-abduction and (c) abduction planes (see text for muscle abbreviations). Four shoulder angles (30°, 60°, 90° and 120°) and three hand conditions (no load, load, load + grip) are shown ($n = 16$). For a given muscle, * indicates a significant difference ($P < 0.002$) between load and load + grip conditions. Note in all conditions and all muscles, the no load and load only conditions were always significantly different and thus not marked.

lateral aspect of the right distal humerus using double sided tape, with the transmitter attached to a stationary post. Posture data was sampled at 33 Hz and was synchronized with EMG. Angular velocity of the shoulder was calculated digitally using the five point finite difference technique (Winter, 2005). The 120 ms window used to calculate dynamic EMG represented the time interval

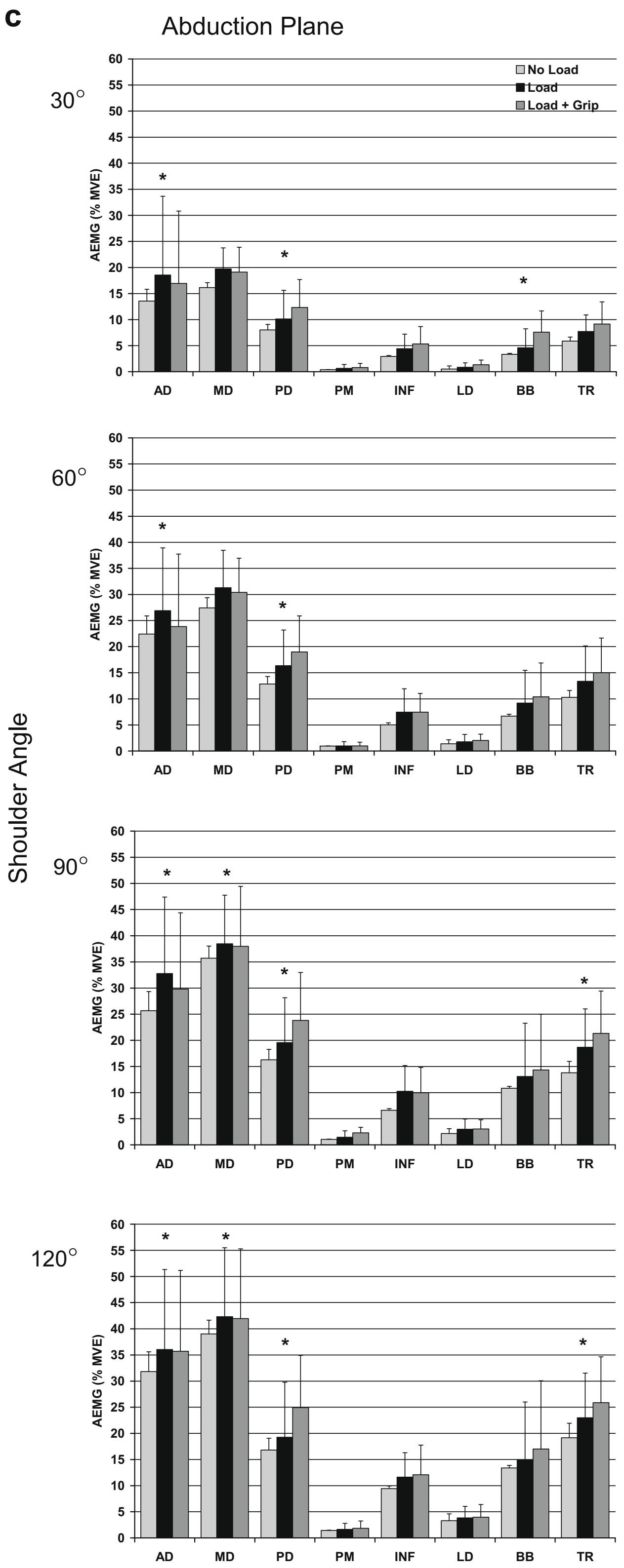

Fig. 3 *(continued)*

between five successive posture data points. During the trials, grip force was used for feedback but was not collected. To test that participants maintained grip force through all conditions, an additional session was conducted in which 12 of the 16 participants repeated all trials while collecting only posture and grip force using the grip force feedback system.

2.4. Statistical analysis

The mean AEMG from the two repetitions for each trial was analyzed. Muscle activity for dynamic exertions was separated into the concentric (arm ascending) and eccentric (arm descending) actions. This produced five contraction velocities: fast concentric, slow concentric, isometric, slow eccentric and fast eccentric. For each muscle, a repeated measures analysis of variance (ANOVA) was performed to determine the effects of contraction velocity (5), shoulder plane (3), angle (4) and hand load condition (2) on muscle activity (STATISTICA Version 6.0, StatSoft Inc., OK, USA). For the grip force data collected in a second session on 12 participants, the same velocity x plane x angle repeated measures ANOVA was repeated on the grip force as a check on consistency. Also as a check for data quality, shoulder angular velocity was tested for each movement speed using a 4 way ANOVA (plane (3) × load (2) × angle (4) × direction (2)). Alpha was set to 0.01 and significant findings were further decomposed using contrasts ($P < 0.002$ after Bonferroni correction).

3. Results

The mean shoulder angular velocities for slow and fast trials were 45.4°/s (SD 11.7°/s) and 94.9°/s (SD 27.4°/s), respectively. This was consistent regardless of plane, hand load, direction, or angle, except at 120° for the fast concentric condition. Analysis of the additional grip force data demonstrated that grip force did not change with shoulder exertion angle, plane or contraction velocity. Although, no four-way interactions were found, three-way interactions were found between various factors, with interactions between plane and angle reflecting differences in muscle function.

PD demonstrated a three way plane × angle × load interaction ($F_{12,180} = 3.77$, $P < 0.001$). Interactions between angle and load were found for MD and TR (both $F_{6,90} > 5.44$, both $P < 0.001$), while interactions between plane and load were found for INF and BB (both $F_{4,60} > 8.21$, both $P < 0.001$). Fig. 3 illustrates the interactions of shoulder angle, plane and hand load on isometric muscle activity (a. flexion, b. mid-abduction, c. abduction). AD and PM activity were highest in the flexion plane (Fig. 3a) and decreased progressively as exertions were performed in the mid-abduction (Fig. 3b) and abduction planes (Fig. 3c). Conversely, MD, PD and TR activity were highest with isometric exertions in the abduction plane (Fig. 3c) and decreased progressively from mid-abduction (Fig. 3b) to flexion (Fig. 3a). INF activity was lowest in the abduction plane (Fig. 3c vs. Fig. 3a and b). For all muscles except INF, AEMG increased progressively as shoulder angle increased from 30° to 120° in all three planes. INF activity increased from 30° to 60° and from 60° to 90° in all planes, but increased only from 90° to 120° in the abduction plane (Fig. 3c). The effects of plane and angle found in isometric contractions held true for the dynamic exertions.

Hand load had a significant main affect on the activity of all muscles under all conditions (all $F_{2,30} > 12.03$, all $P < 0.001$), resulting in a mean increase in AEMG of 4.0–4.4% MVE in AD, MD, BB and TR activity, 3.3% MVE in INF activity and 0.2–1.4% MVE for LD and PM. PD activity increased by 1.9% MVE in the flexion (Fig. 3a) and mid-abduction planes (Fig. 3b) and by 4.3% MVE in the abduction plane (Fig. 3c). These relationships held true for dynamic contractions as well. The 30% grip force altered shoulder muscle activity. Compared to holding the dynamometer (without gripping), gripping decreased AD activity by a mean of 2.4% MVE (SD 6.1) ($P < 0.002$) across all postures, while MD activity decreased by 2.2% MVE (SD 5.9) at shoulder angles of 90° and 120° ($P < 0.002$) (Fig. 3). Conversely, INF activity increased by 1.7% MVE (SD 4.7) ($P < 0.002$) and BB activity by 6.0% (SD 10.8) MVE ($P < 0.002$), respectively, when gripping in the flexion (Fig. 3a) and mid-abduction planes (Fig. 3b). Also, TR activity increased by 1.6% MVE (SD 3.1) when gripping at shoulder angles of 90° and 120° ($P < 0.002$) (Fig. 3a–c), while PD activity increased by 1.9% MVE (SD 4.1) when gripping in the mid-abduction (Fig. 3b) and abduction planes (Fig. 3c) ($P < 0.002$).

Three-way interactions (plane × angle × velocity) were found for the activity of all muscles (all $F_{24.360} > 2.21$, all $P < 0.003$), except latissimus dorsi (LD). Two factors were responsible for this interaction. AEMG amplitude was similar between the two eccentric speeds and, while AEMG increased significantly from 30° to 60° to 90° ($P < 0.002$), the AEMG of some muscles did not change as shoulder angle increased above 90° during fast concentric contractions. Part of this latter effect may have been due to a reduction in mean shoulder angular velocity by 24.0°/s as the shoulder angle increased from 90° to 120° in fast concentric contractions. For all muscles, AEMG was highest during fast concentric exertions, followed by slow concentric, isometric contractions and then both slow and fast eccentric contractions (which were not significantly different from each other). The relationship was similar for each muscle (Fig. 4 – pooled across angle and loading condition). On average, fast concentric AEMG was 105% (range: 73–145%) higher and slow concentric EMG was 66% (range: 43–98%) higher than isometric AEMG, while eccentric activity was 29% (range: 19–48%) lower than isometric activity.

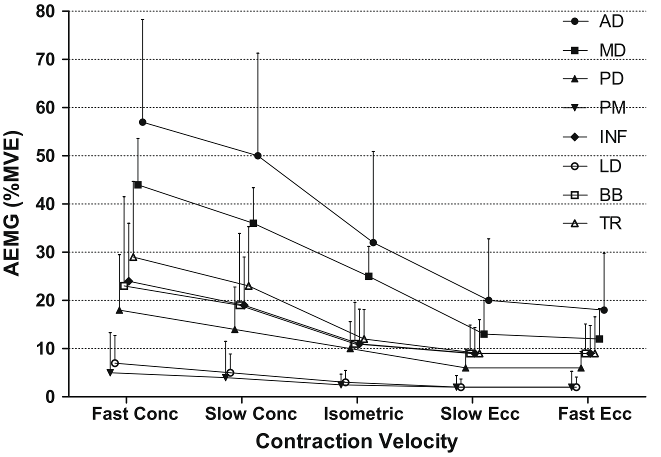

Fig. 4. Velocity effects on mean muscle activity (% MVE ± standard deviation) for five contraction velocities (fast concentric, slow concentric, isometric, slow eccentric and fast eccentric) collapsed across loads and postures (see text for muscle abbreviations).

4. Discussion

This study demonstrated that performing shoulder exertions simultaneously with a hand load versus the same load plus a grip resulted in a differential distribution of shoulder muscle activity that was evident in both isometric (Fig. 3) and dynamic conditions. Unlike other studies, postures were not constrained by mechanical devices that could alter the natural motion of the shoulder complex. Under these conditions, biceps brachii demonstrated the greatest effect and likely plays a significant role when gripping. The relative effects of grip and load on shoulder muscle activity were similar in dynamic and isometric contractions, being related through an EMG-to-contraction velocity effect (Fig. 4). The overall effect of gripping during a shoulder exertion was a reduction in the activity of the larger deltoid muscles while increasing the effort required of the smaller infraspinatus (a rotator cuff muscle). These findings have important implications for the development of shoulder injuries in repetitive or prolonged workplace tasks and their rehabilitation.

We found that a simultaneous static shoulder exertion and 30% MVC hand grip reduced both anterior and middle deltoid activity by 2% MVE and increased posterior deltoid, infraspinatus and trapezius activity by about the same value which is similar to previous work (MacDonell and Keir, 2005; Au and Keir, 2007). Previous work has shown that similar hand grip forces (30% and 50% MVC) acted to increase supraspinatus activity by nearly 10% MVE (Sporrong et al., 1995, 1996). Thus, there is strong evidence that hand gripping increases the activity of shoulder muscles that are commonly injured, such as infraspinatus, supraspinatus and trapezius (Sommerich et al., 1993).

While this study did not determine the precise mechanism by which grip influences shoulder muscle activity, it did provide many insights. Biceps brachii increased by 6.0% MVE when performing a simultaneous shoulder exertion and hand grip, likely contributing to shoulder moment as suggested previously (Armfield et al., 2003). This increase in activity only occurred in the shoulder flexion and mid-abduction planes, likely demonstrating the effect of the subtle difference in forearm/dynamometer orientation on the function of the biceps. This finding would suggest that the redistribution of shoulder muscle activity when gripping may be dependant on forearm posture, and should be investigated further. The small but significant effects of gripping on shoulder muscle activity appear to be dependent on function as DiDomizio (2006) found no changes in anterior or posterior deltoid activity when applying a 15% MVC hand grip in combination with a push or pull to a fixed transducer. Also, Visser et al. (2003, 2006) demonstrated that trapezius activity decreased when applying a pinch force of 10% MVC or higher to a hanging transducer. In both of those studies, participants did not support the transducer, which may have reduced the need to stabilize the arm compared to the current study.

As expected, the plane of exertion had a significant effect on EMG that was dependent the muscle's primary function. The obvious examples are the anterior deltoid (forward flexion) and middle deltoid (abduction) (Fig. 3). Infraspinatus activity was similar in flexion and mid-abduction but was significantly lower in the abduction plane, as found previously with hand weights (Sigholm et al., 1984). This is likely due to a relatively constant moment arm between flexion and mid-abduction (Hughes and An, 1996). It has also been suggested that the hand-load dependence is greater for infraspinatus, than for other muscles of the shoulder (Sigholm et al., 1984; Sporrong et al., 1995, 1996). In addition, rotator cuff muscles, such as infraspinatus, serve the dual roles of humeral movement and directing the humeral head into the glenoid fossa for joint stability (Hughes and An, 1996) and thus the activities found here may indicate differing functions depending on shoulder posture.

For all muscles, EMG increased as shoulder angle increased, as found previously (Sigholm et al., 1984; Mathiassen and Winkel, 1990; Jarvholm et al., 1991). In addition, the relationships between plane of movement and muscle activity were observed at all angles (Fig. 3). Using the participant arm anthropometrics, we determined that raising the arm from 30° to 90° doubled the mean static shoulder moment and elicited a mean increase in activity of 84% (range 69–109%) or 10% MVE in the three deltoid heads, infraspinatus and trapezius. In contrast, MacDonell and Keir (2005) reported that infraspinatus and posterior deltoid activity did not increase with angle in either shoulder flexion or abduction. However, in that study participants performed maximal shoulder exertions against a fixed sensor, which could have elicited a more constant activation of these muscles to stabilize the arm against the device, regardless of shoulder angle (Kronberg et al., 1990).

All muscles had similar activity patterns with respect to velocity of motion (Fig. 4). Similar to previous research, fast concentric contractions required the highest muscle activity, followed by slow concentric, isometric and the eccentric contractions (Kellis and Baltzopoulos, 1998; Komi et al., 2000). Muscle activity associated with slow and fast eccentric exertions were essentially the same, which may reflect the plateau on the eccentric portion of the force-velocity curve (Komi and Buskirk, 1972). However, it is not clear if the slow lengthening velocities in the current study would be associated with the plateau on the eccentric side of the curve. While most muscles shortened during the ‘‘concentric” (ascending) movements and lengthened during the ‘‘eccentric” (descending) movements, latissimus dorsi, and possibly pectoralis major, was likely the opposite. However, these muscles exhibited the same EMG versus velocity pattern as the other muscles, suggesting they functioned in antagonistic co-contraction proportional to the agonists. Examination of the EMG with respect to velocity of movement elicited consistent relationships between dynamic and isometric contractions for each muscle at a given velocity (Fig. 4). Although the standard deviations were quite large, these relationships identify that shoulder muscle activity essentially doubled (from isometric) when performing fast concentric dynamic exertions even at the relatively slow speeds used in this study.

There were a few limitations in this study. First, for the ‘‘loaded” hand condition, participants were required to hold the dynamometer without gripping. However, the supplementary grip force assessment suggested that a small grip force of 1–1.3% MVC was associated with this condition and may have contributed to the observed change in shoulder muscle activity. Also, while participants were able to maintain grip force at the required level during the dynamic exertions, there was no penalty for gripping outside of the acceptable range. Upon analysis of the additional grip force data, it was observed that mean grip forces were quite consistent with a mean of 28.8% MVC (SD 0.6) for the isometric and 29.2% MVC (SD 0.6) for the dynamic trials. In addition, shoulder angles were defined as the angle of the upper arm relative to vertical and did not reflect scapular or spinal rotation. However, if substantial spine rotation (in any direction) was observed during a trial it was discarded and the trial was repeated. Finally, the speeds of arm motion used in this study were relatively slow when considering the range of velocities in human motion and should be interpreted as such.

Changes in muscle activity in this study were relatively small, however, the true detrimental effect in the workplace may only be realized when the cumulative load borne over the course of a worker’s shift, week, month, or year is considered. Workers who perform repetitive shoulder exertions while gripping may be predisposing weaker rotator cuff muscles to overload and injury (perhaps without perceiving the difference). These combined effects are not typically captured in many ergonomic assessments of the workplace. It should also be noted that there may be a potential benefit of this phenomenon in rehabilitation. Anecdotally, therapists have combined a gripping task with shoulder elevations to improve shoulder range of motion. This process is thought to activate the rotator cuff and improve scapulo-humeral rhythm. Thus the current study provides some evidence to support this practice but future research is required to examine this phenomenon in patient populations.

5. Conclusions

Performing a simultaneous shoulder exertion and hand grip led to a posture specific redistribution of shoulder muscle activity. Gripping led to a decrease of 2% MVE in anterior and middle deltoid activity and an increase of 2% in posterior deltoid, infraspinatus and trapezius activity. These slight increases in muscle activity when gripping may be an important factor in development of muscular injury and rehabilitation of shoulder injuries. In addition, it was found that gripping increased biceps brachii activity by 6% MVE. Since activation of this muscle will generate a moment at the shoulder, this effect may be one factor initiating the observed changes in shoulder muscle activity when gripping.

Acknowledgments

This study was supported by funding from AUTO21 NCE (A201-AHS) and the Natural Sciences and Engineering Research Council (NSERC) of Canada (# 217382-04).

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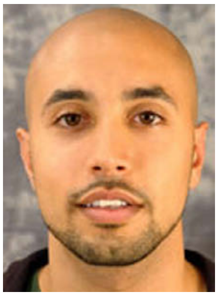

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