

Effects of age on muscle activity and upper body kinematics during a repetitive forearm supination task

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Abstract

The principal objective of this study was to assess the effects of age on upper extremity muscle activation patterns and upper body kinematics during a forearm supination task. Age-related physiological and biomechanical changes in the musculoskeletal system have been documented in the literature. It was hypothesized that these changes may have an impact on muscle recruitment and work technique (postural/kinematic) employed during work tasks. A simple repetitive forearm supination task was used to evaluate these hypotheses. Twenty subjects (ten in each age group 19–29 and 55–65) performed a series of static and dynamic forearm supination tasks on a work simulator. These exertions were performed at eight different levels of supination torque: 5–40 lb-in in 5 lb-in increments. As the subjects performed the static exertions the activation levels of several key muscles of the upper extremity were captured using surface electromyography. As the subjects performed the dynamic exertions, the motions of the upper body and upper extremity were captured using a magnetic field-based motion analysis system. The results of the static exertions showed that older subjects generated 135% greater trapezius muscle activity (significant at $p < 0.05$ level) but no other muscle group sampled showed a significant difference between the age groups. In the dynamic exertions, age had no effect on upper limb/torso kinematic responses. In both the static and dynamic exertions, supination torque level had a significant impact on muscle activity and kinematics. These results provide empirical evidence that age alone does not have a consistent impact on biomechanical responses during physically demanding work tasks.

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1. Introduction

There are a number of recognized risk factors associated with the development of upper extremity musculoskeletal disorders. Included in this list are high force exertions, repetitive motions/exertions and awkward postures. For individuals with different functional capacities, a particular task can impose a different degree of risk, because the task may require a greater percentage of strength capacity or a greater percentage of the available range of motion of a particular joint. Changes in work technique (such as postures assumed, joints involved, muscles used, etc.) may also result as a person nears the limits of their

personal capability for a particular task. As they approach this limit, other body segments in the kinematic chain may be activated in order to achieve the task requirements. A review of the literature reveals that age is one factor that may alter these biomechanical capacities and therefore may lead to the above-mentioned responses.

A number of studies have illustrated important physiological and biomechanical changes that occur with aging, and it is believed that these changes may play an important role in the aforementioned modifications to work technique. Roebuck et al. (1975) note that a person naturally reaches a point of maximum physical strength in his or her late 20s or early 30s. After this, strength tends to decline, resulting in a potential loss of 20 percent of maximum strength by the time a person is 60 years old and this strength reduction is particularly compromised at higher

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shortening velocities (Larsson et al., 1979). The underlying source of this decline can be seen in the work of Klein et al. (2003) who found that older men have smaller muscle area and smaller fiber size, particularly the Type II fibers. In addition to the effects of reduced muscle mass, biomechanical/physiological factors such as increased co-activation and reduced specific tension may contribute to the age-related loss of strength (Klein et al., 2001). Age-related changes in joint range of motion have been documented. These have been attributed to decreased muscle length and changes in the passive tissues surrounding the joints (James and Parker, 1989; Vandervoort et al., 1992). As a consequence of these physiological changes, older adults tend to change their behaviors in normal working conditions. For example, Kinoshita and Francis (1996) performed a lifting study wherein they measured the grip force exerted by older and younger adults. They showed that older people tended to use a higher level of grip force and that there was greater variability in the grip force employed. They noted that these results indicated a loss of control on the precision of the grip force employed as people age. In another study, Graves et al. (2000) examined how age affected steadiness during two tasks that involved the elbow flexor muscles: a static weight holding task and a dynamic lifting task. They found that age had no significant effect on the steadiness for static weight holding tasks. However, steadiness for dynamic tasks for older subjects was significantly lower than their younger counterparts with the lightest loads, with the difference diminishing as the load increased. This result implied that muscle recruitment patterns among the elbow flexor muscles during dynamic tasks differed between the younger and the older subjects. These age-related changes in the strategies employed to perform these tasks may result in increased exposure to recognized risk factors for musculoskeletal disorders.

These findings increase in their importance as one recognizes that the “baby boom” generation is creating an increase in the age of the current working population. Bureau of Labor and Statistics Current Population Survey (CPS) shows an increase in total workers aged 55 and over from 18.3 million in the fourth quarter of 2000 to 21.7 million in the fourth quarter of 2003. As these trends continue, increasing our understanding of the responses of these workers to physically demanding tasks will be vital to maintaining a healthy workforce.

The task chosen for study in the current experiment was a simple repetitive forearm supination task. This particular task was chosen because it would elicit technique changes as the difficulty of the task increased. Specifically, as the required torque increases one would expect more dramatic upper arm motions and possibly torso motions. The aim of the current study was to quantify and compare the effects of age during this task. It was hypothesized that older subjects would have higher muscle co-contraction/co-activation levels and would exhibit greater upper arm and torso movements relative to their younger counterparts.

2. Methods

2.1. Subjects

Twenty subjects were recruited for this experiment: ten younger subjects of ages from 19 to 29 with mean (and standard deviation) of 23.1 (2.77), and ten older subjects of ages from 55 to 65 with mean (and standard deviation) of 57.9 (2.68). Each age group consisted of five males and five females. One subject was left-handed. None of them had reported current or chronic upper extremity disorders. The experimental procedure was approved by the university Institutional Review Board for the Protection of Human Subjects in Research. All subjects were informed of the requirements of the study and provided written informed consent prior to participation.

2.2. Apparatus

2.2.1. Experimental task apparatus

The Baltimore Therapeutic Equipment (BTE) Work Simulator II (BTE Technologies, MD) system was utilized in the current study to control the repetitive forearm supination task. The screwdriver handle provided by the BTE system was designed after a medium-size manual screwdriver handle in terms of both shape and surface texture. The orientation of the long axis of the screwdriver handle was horizontal with the handle pointing towards the subject and was positioned slightly below elbow height. When performing the experimental trials, the device was set to either isometric or isotonic (free dynamic rotation with pre-set resistance) mode. For isometric tasks, the screwdriver shaped handle was locked in place and the real-time supination torque was measured and displayed to the subject. This allowed the subject to maintain the designated amount of torque for a given trial. This isometric mode was also used to measure each subject's maximum voluntary supination torque. For the dynamic trials, a supination torque level was set and the subjects rotated the screwdriver handle against this resistance torque. In both modes the device allowed the experimenters to set the supination torque to the designated levels.

2.2.2. Data collection apparatus

The data collection apparatus consisted of surface electromyography (EMG) and a magnetic field-based motion tracking system. Six pairs of Ag–AgCl (6 mm-diameter) bipolar electrodes were used to capture the EMG activities of the six sampled muscles during isometric trials. The EMG signals were amplified (2000×) and filtered (0–500 Hz) by a differential amplifier Model TEL100 (Biopac Systems Inc., CA). The EMG data and the angular position and torque data from the BTE work simulator were recorded using AcqKnowledge software (Biopac Systems Inc., CA). The magnetic field-based Motion Star motion tracking system (Ascension Technology Corporation, VT) was utilized to collect the upper body kinematics

data during dynamic trials. Three motion sensors were used: (1) sensor one was placed on the lateral surface of the upper extremity of dominant side at the height of the shoulder joint; (2) sensor two was placed on the lateral surface of the upper extremity of dominant side at the height of the elbow joint; (3) sensor three was placed on the spine at the T9 level. This motion tracking system provided time-dependent information about x , y , z coordinates, and roll, pitch and yaw of each of the three motion sensors. The motion sensor data were collected at 60 Hz. Finally, a hand dynamometer Model 78010 (Lafayette Instrument Company, IN) was used to measure each subject's maximum power grip force.

2.3. Independent variables

There were two independent variables in this study: "age" and "supination torque". The two levels of age were "younger" (19–29) and "older" (55–65). There were eight levels of supination torque in this study: 5–40 lb-in in 5 lb-in increments.

2.4. Dependent variables

The dependent variables considered in the isometric trials were the normalized integrated EMG data that were collected for 6 dominant-side, upper extremity muscles: first dorsal interosseous (FDI), flexor digitorum profundus (FDP), extensor digitorum (ED), biceps brachii (BB), medial deltoid (MD), and trapezius (Trap). Electrodes were placed over the belly of each muscle. The center-to-center distance between an electrode pair was 13 mm for the FDI, FDP, and ED, and 26 mm for the BB, MD, and Trap. While the signal collected from the FDP and ED almost certainly contained cross-talk from adjacent wrist flexor and extensor muscles, the electrode placement locations were chosen to maximize the contribution of the named muscle.

The dependent variables considered in the dynamic trials gave a multi-dimensional perspective on the kinds of upper body motions elicited. These measures included the following postural measures: the 95th and 50th percentiles of the shoulder abduction angle (SA95 and SA50), the 95th and 50th percentiles of the trunk sagittal bending (TSB) angle (TSB95 and TSB50), the 95th and 50th percentiles of the shoulder flexion angle (SF95 and SF50) and the 95th and 50th percentiles of the trunk lateral bending (TLB) angle (TLB95 and TLB50).

2.5. Experimental procedures

The experiment began with a period of stretching and warm-up and was followed by the placement of surface electrodes. Once these were placed and signals verified, the subjects performed a series of maximum voluntary contraction (MVC) exertions specifically designed to isolate the muscle of interest during the contraction.

The MVC of the FDI was measured by having the index finger push against manual, static resistance towards the thumb. The MVC of the FDP was measured by laying the forearm on a flat surface with hand hanging off the edge and palm facing upwards, and then flexing the wrist with hand pushing against static resistance. The MVC of the ED was measured by laying the forearm on a flat surface with hand hanging off the edge and palm facing downwards, and then extending the wrist with the back of the hand pushing against static resistance. The MVC of the BB was measured by having the elbow flexed at 90° with the upper arm hanging naturally from the shoulder and the palm parallel to the sagittal plane, and then maximally flexing the elbow against static resistance provided by the BTE dynamometer. The MVC of the MD was measured by having the subject's arms hanging naturally from the shoulder and then having the subject attempt shoulder abduction against static resistance. The MVC of the Trap was elicited by having the subject pull against a height-adjustable bar whose height was preset to require a slight shrugging of the shoulders to activate the Trap muscles. The EMG values generated during these MVC exertions were used in data processing to normalize all task EMG data. A 1-min break was provided between maximum exertions. All maximum exertions lasted for 3 s. A 5-min break was given after these exertions.

Two additional MVC exertions were performed to characterize the subject's grip and supination strengths. The first exertion utilized the handgrip dynamometer (model 780101, Lafayette Instr. Corp, IN). The subject squeezed the dynamometer for a period of 3 s and the peak grip force was measured. The second exertion provided data regarding the subjects' maximum supination strength. For this exertion the BTE dynamometer was used. The height of the screwdriver-shaped handle of the dynamometer was adjusted relative to the height of the subject's dominant side elbow and the forearm was in mid-pronation. The subject was instructed to assume a comfortable stance. The dynamometer was then set to the isometric mode and an MVC supination exertion was performed. The subject was instructed to ramp-up to the MVC exertion over a period of 2 s, hold the exertion for 1 s and then relax. The peak torque was captured by the data collection system.

After completing these additional MVC exertions, subjects began the experimental phase of the study. Subjects performed all of the isometric exertions first, followed by the dynamic exertions. During each isometric trial, subjects used the visual feedback system and gradually increased the supination torque until the designated torque level was reached. The subject was then asked to remain in this steady state for 2 s. The order of presentation of the eight supination torque conditions was completely randomized.

After the eight isometric trials were completed, the subjects began the dynamic trials. Before beginning these trials the surface electrodes were removed and the three

motion sensors were secured in their designated locations. After the motion sensor placement, subjects were asked to stand still in a natural posture and the baseline kinematic data (static, upright posture) were recorded for 3 s. During the dynamic trials, subjects were asked to turn the screwdriver handle against the designated torque for as many rotations as possible during a 6 s interval and the instantaneous torque and rotation angle of the dynamometer were collected. The order of presentation of the different torque conditions was completely randomized. In both the isometric and dynamic phases of this experiment 1-min breaks were provided between trials to avoid the development of muscular fatigue.

2.6. Data processing

2.6.1. EMG data

The raw EMG data for both MVC trials and isometric screwdriver trials were filtered using a 10–500 Hz band-pass filter and notch filters, designed to eliminate 60 Hz and its aliases. Once filtered, these signals were rectified (full-wave). For each MVC trial, the peak EMG value was obtained by first dividing the rectified data into windows of 1/8 s within which averages were taken, and then choosing the maximum of these 24 average values (8 values per second for 3 s). For the EMG data from each isometric trial, the average of the rectified signal was taken over the full 2-s data collection period. This value was then normalized relative to the MVC EMG for that muscle.

2.6.2. Motion sensor data

The raw kinematics data were processed through the Motion Monitor Ver. 4.10 (Innovative Sports Training, Inc., IL) to obtain time-dependent posture-related information of trunk and dominant-side upper extremity during the dynamic trials. All data were recorded at 60 Hz. The x - y - z coordinates of Sensor 1 (shoulder) and Sensor 2 (elbow) were processed to describe angles of shoulder abduction ($SA = \tan^{-1}((x_2 - x_1)/(z_2 - z_1))$) and shoulder flexion ($SF = \tan^{-1}((y_2 - y_1)/(z_2 - z_1))$). The rotation data from the sensor over the T9 vertebra (Sensor 3) were processed to describe angles of TSB and TLB. TSB was described by the pitch (rotation around x -axis) of the sensor, and TLB was described by the yaw (rotation around y -axis) of the sensor. Forward TSB and TLB towards the dominant side were considered directions that yielded positive angles. The upright neutral posture data were used in the normalization of the task data to yield relative postural measures. For each dynamic trial, the data for all four measures were captured during the “steady-state” performance region (Fig. 1), so that the actual data used (between dashed lines as in Fig. 1) were fluctuating within a consistent range. Finally, the 95th and 50th percentile of SA, SF, TSB, and TLB were calculated from the time-dependent data.

2.7. Data analysis

There were two separate data sets analyzed in this study—the isometric data and the dynamic data. A mixed model of nested design was utilized in both analyses, wherein subjects were nested within each level of age. The assumptions of the ANOVA technique were assessed using the graphical approach advocated by Montgomery (2001) and appropriate data transforms were applied if necessary. A MANOVA was conducted to examine the effects of age, torque and their interactions on the dependent measures collectively. If statistical significance of the MANOVA ($p < 0.05$ for the Wilks' Lambda statistic) was found for a main effect (or interaction), then that effect (or interaction) would be tested using individual ANOVA for each measure. Again, a p -value of less than 0.05 was used as the criterion for statistical significance in these individual ANOVAs.

3. Results

3.1. ANOVA assumptions

All data had residuals that satisfied normality assumptions and were independent of trial order and torque level. However, it was found for the following measures that residuals had non-constant variance across levels of predicted values: normalized EMG for all six sampled muscles, 95th percentile of shoulder abduction, and 95th and 50th percentile of TSB. A logarithmic transformation was applied to these data and subsequent analysis revealed that the residuals of the transformed data showed constant variance. These transformed data were used in all subsequent analyses of these measures.

3.2. MANOVA results

MANOVA results (Table 1) showed no significant interaction effects and showed that age had statistically significant effects on normalized EMG measures, and torque had significant overall effects on both normalized EMG and kinematics measures. Therefore, subsequent ANOVA analysis was required to investigate the effects of age and supination torque on normalized EMG of each muscle individually and the effects of supination torque on each of the kinematics measures individually.

3.3. ANOVA results

The ANOVA of the EMG data collected during the isometric trials showed that supination torque had significant effect on all sampled muscles except the Trap (Fig. 2) while the Trap was the only muscle that was significantly affected by age. The average of the Trap for older subjects was 136% higher than that for younger subjects when averaged again across all supination torque levels (Fig. 3).

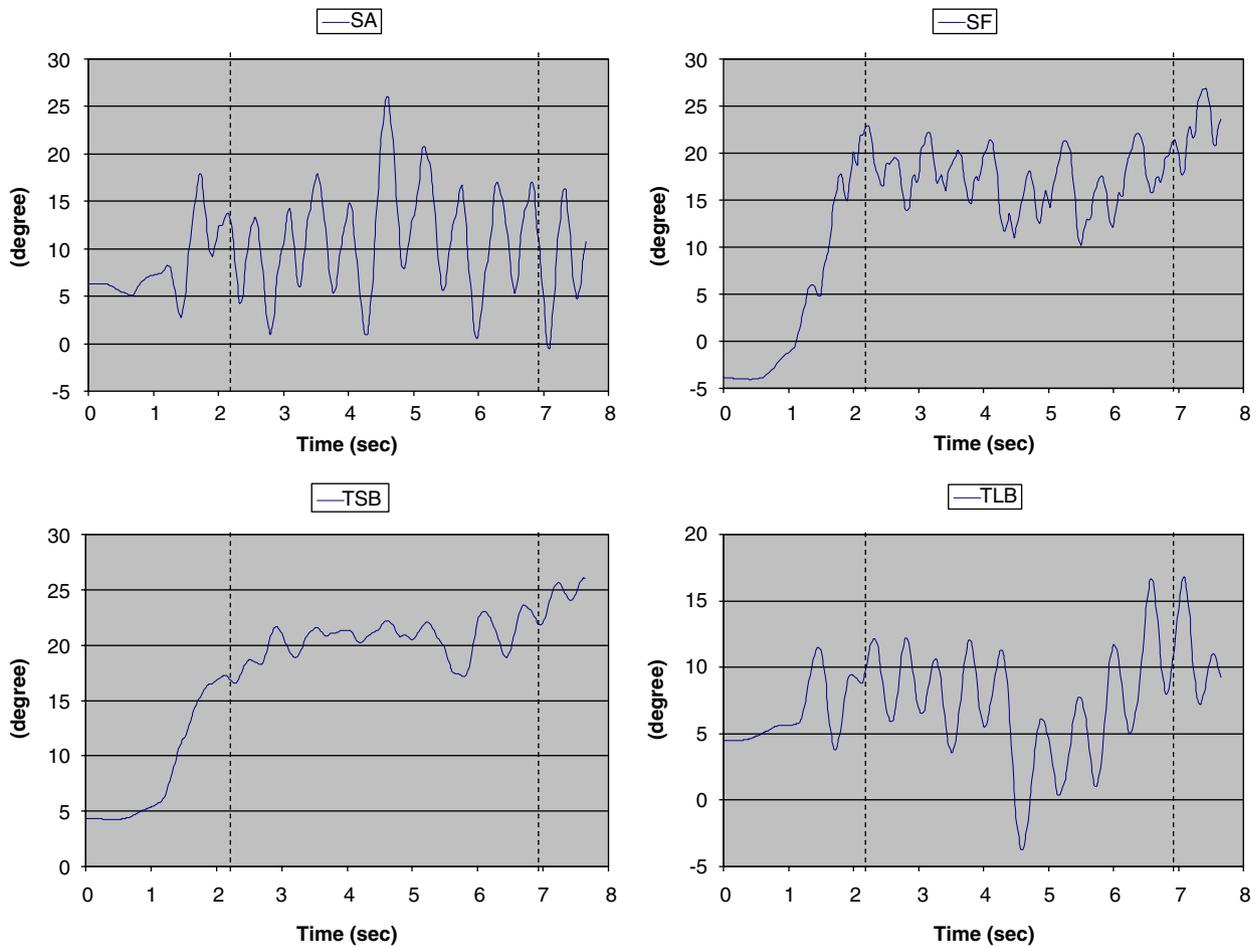


Fig. 1. An example of the kinematics data of a single trial. Only the data between pairs of dashed lines were actually used in the calculations.

Table 1
MANOVA and ANOVA results for isometric and dynamic experiments

| (<i>F</i> , <i>p</i> -value) | MANOVA (Wilks', <i>p</i>) | FDI | FPD | ED | BB | MD | Trap | | | |
|-------------------------------|----------------------------|---------------|----------------|---------------|---------------|---------------|--------------|-------------|-------------|--|
| Age | 3.44, 0.0292 | 0.87, 0.36 | 0.94, 0.35 | 0.24, 0.63 | 1.54, 0.23 | 0.97, 0.33 | 8.99, 0.008 | | | |
| Torque | 12.25, <0.0001 | 88.31, <0.001 | 166.12, <0.001 | 40.60, <0.001 | 53.62, <0.001 | 48.14, <0.001 | 0.74, 0.6361 | | | |
| Age × torque | 0.90, 0.6464 | — | — | — | — | — | — | | | |
| (<i>F</i> , <i>p</i> -value) | MANOVA (Wilks', <i>p</i>) | SA95 | SA50 | SF95 | SF50 | TSB95 | TSB50 | TLB50 | TLB95 | |
| Age | 2.04, 0.1486 | — | — | — | — | — | — | — | — | |
| Torque | 1.71, 0.0005 | 5.95, <0.001 | 4.89, <0.001 | 1.08, 0.38 | 0.51, 0.83 | 3.82, <0.001 | 2.64, 0.014 | 0.94, 0.481 | 3.66, 0.001 | |
| Age × torque | 0.99, 0.5110 | — | — | — | — | — | — | — | — | |

The ANOVA of the postural data collected during the dynamic trials showed that torque had significant effect on the 95th percentile and the median of shoulder abduction, the 95th percentile and median of TSB, and the 5th percentile of TLB towards non-dominant side (or 95th percentile of TLB towards dominant side) (Fig. 4). The magnitude of these increases (from 5 to 40 in lb) ranged from 60% for TLB95 to 26% for TSB50.

4. Discussion

The over-arching hypothesis of this study was that age would impact muscle coactivation patterns and upper extremity kinematics during a repetitive forearm supination task. A review of the literature revealed some important physiological and biomechanical changes with age and the expectation was that these basic changes would

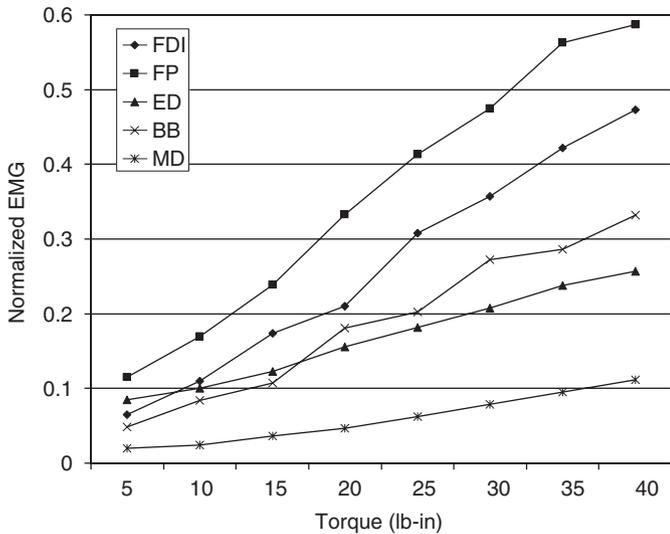


Fig. 2. Significant supination torque effects on activities of the upper extremity muscles.

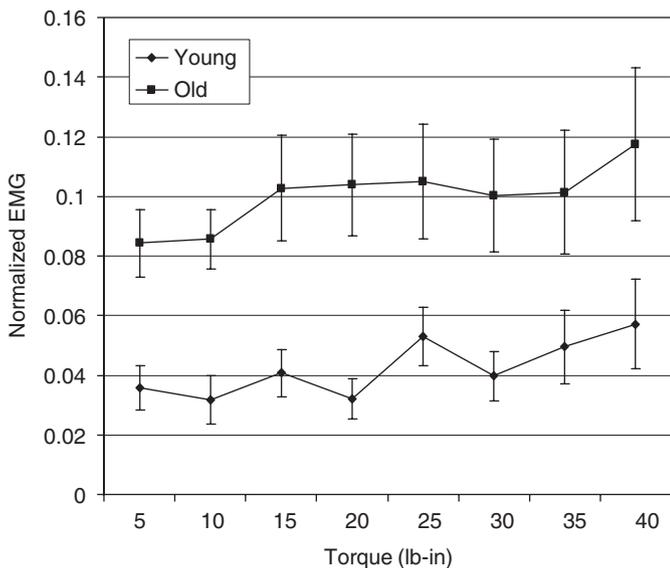


Fig. 3. Normalized trapezius EMG levels averaged separately for two age groups as functions of the supination torque level. The error bars denote the standard errors.

translate into adaptation responses during the performance of a task requiring physical exertion. In general, the data did not support this hypothesis. In terms of EMG response, only the Trap muscle activation level was significantly affected by age and, in terms of upper extremity/torso kinematics, there were no significant effects. Further examination of the data revealed that the variability within age group was quite high (even after controlling for gender in a sub-analysis) indicating that while age-related changes within an individual are expected, the variability within an age group is still considerable, limiting our ability to make population generalizations. Longitudinal studies wherein subjects are

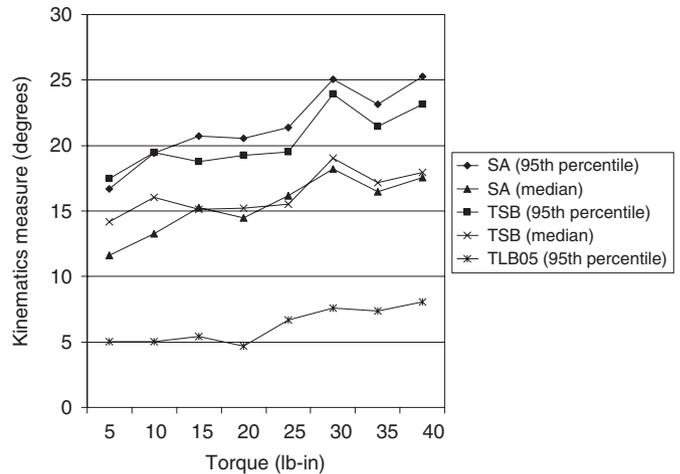


Fig. 4. Significant supination torque effect on upper extremity kinematics measures.

their own control might be able to show the expected performance effects in response to the changes in these documented changes in physiology and biomechanics; but in terms of using these age-related changes in ergonomics applications the results of the current study do not support the concept of needing special accommodations for this population—beyond that which is appropriate for all worker.

There are, however, important results from this study that should be considered in terms of workplace design when designing for any population. These results are focused on the effects related to changes in required supination torque. Increasing the supination torque requirement generated significant increases in activity of both proximal and distal muscles of the upper extremity and these increases were consistent across age groups. Not only were the distal muscle groups impacted by the increased force requirements (as was expected), but muscles all along the kinematic chain were impacted, indicating that the effects of increased torque requirements may impact muscle loading, fatigue and injury risk at multiple sites along the kinematic chain. Likewise, increases in this torque requirement during the dynamic exertions had a significant effect on the upper extremity kinematic profiles. Higher levels of supination torque generated increases in measures of shoulder abduction, TSB, and TLB towards dominant side.

Collectively, these results show that increased levels of supination torque led to greater proximal upper arm exertions to supplement overloaded distal muscles and contribute to the overall supination torque exertion, in response to greater loading. As the subject engages these more proximal (and larger) body segments, musculoskeletal loading is now more distributed thereby reducing the loading of the proximal segments, but at the cost of increasing exposure to recognized risk factors (awkward postures, repetition, and to a lesser extent force) of these proximal segments. The empirical results of the current

study provide valuable quantitative insight into this load sharing response.

There are several issues that limit the generalizability of the results of the current study. First, the handle on the dynamometer was set relative to the subject's standing elbow height. Often industrial working conditions would force an individual to work within the design of the system, not allowing for the adjustment of the height of the screwdriver (or other tool/implement) as was seen in this study. This non-adjustability in a real work environment might have a greater influence on the older worker than on the younger worker because of differences in the range of motion of the joints in the kinematic chain. Second, the cross-sectional design of this study emphasizes the variability within groups and discounts the changes over time of an individual. While this is not truly a limitation from an engineering design perspective, it may have masked some of the more basic science questions that led to the original hypotheses.

5. Conclusions

The objective of this study was to quantify the effects of age and supination torque level on the biomechanical responses during a repetitive supination task. The results of the isometric experiment showed a significant effect of age only on the Trap muscle activity, a result that did not support the original hypothesis. The results of the dynamic experiment showed that there were no age-related effects on the upper extremity/torso kinematics, a result that again did not support the original hypothesis. Further investigation revealed high levels of within group variability indicating that while there may be changes within an

individual with age, the variability in performance among individuals within an age group tends to mask these changes. The supination torque level had a significant effect on all muscle responses except the Trap and also on overall shoulder abduction, trunk sagittal bending, and trunk lateral bending toward dominant side. These empirical results can be used to better understand the load-sharing response of the upper extremity.

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