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ORIGINAL RESEARCH

Shoulder Strength Requirements for Upper Limb Functional Tasks: Do Age and Rotator Cuff Tear Status Matter?

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Understanding upper limb strength requirements for daily tasks is imperative for early detection of strength loss that may progress to disability due to age or rotator cuff tear. We quantified shoulder strength requirements for 5 upper limb tasks performed by 3 groups: uninjured young adults and older adults, and older adults with a degenerative supraspinatus tear prior to repair. Musculoskeletal models were developed for each group representing age, sex, and tear-related strength losses. Percentage of available strength used was quantified for the subset of tasks requiring the largest amount of shoulder strength. Significant differences in strength requirements existed across tasks: upward reach 105° required the largest average strength; axilla wash required the largest peak strength. However, there were limited differences across participant groups. Older adults with and without a tear used a larger percentage of their shoulder elevation ($p < .001$, $p < .001$) and external rotation ($p < .001$, $p = .017$) strength than the young adults, respectively. Presence of a tear significantly increased percentage of internal rotation strength compared to young ($p < .001$) and uninjured older adults ($p = .008$). Marked differences in strength demand across tasks indicate the need for evaluating a diversity of functional tasks to effectively detect early strength loss, which may lead to disability.

Keywords: functional task, simulation, upper limb, reserve strength

The ability to successfully complete activities of daily living (ADLs) is paramount to maintaining independence. Many ADLs (eg, eating, bathing, and dressing) require strength and coordination of the upper extremity.[1] Older adults are at an increased risk for loss of upper extremity function due to age-related declines in strength.[2,3] Further, older adults employ compensatory kinematic strategies, such as decreasing their thoracohumeral elevation angle[4] when performing upper limb tasks.[4–7] These age-related declines can be exacerbated by a rotator cuff tear,[8,9] a degenerative injury disproportionately affecting older adults.[10] The combination of compensatory kinematic strategies and strength loss may significantly influence progression to disability.

Prior work exploring upper extremity strength requirements for successful task completion have primarily emphasized occupational and ergonomic considerations in young adults rather than ADLs in at-risk groups. Studies quantifying strength requirements in occupational tasks,[11,12] such as automotive assembly work,[11] predominantly used young and middle-aged participants. One occupational study analyzing aging effects on upper extremity fatigue during light assembly work found no differences in average strength requirements between young and older adults for shoulder abduction/adduction or flexion/extension strength.[12] Strength requirements for functional tasks relevant to ADLs have been explored for 10 daily tasks, but the study was small, only included young and middle-aged men, and task comparisons for overall strength and difficulty were analyzed qualitatively.[13] External shoulder moment has been quantified for a number of tasks for a group of older adults with symptomatic and asymptomatic rotator cuff impingement, with significant differences in moment required to complete the tasks but with no differences between groups.[14] However, the study did not include young adults and did not explore moment requirements for each degree of freedom at the shoulder.

Shoulder strength is a limiting factor in both functional reaching and pulling tasks,[15] and many multiplane tasks require greater shoulder strength than elbow strength.[16] However, to date, grip strength, which is mechanistically unrelated to many functional tasks, is the only upper extremity measure that has been used to predict future disability.[17] The shoulder experiences exaggerated declines in strength compared to losses at the elbow and wrist,[2] and a rotator cuff tear can exacerbate age-related strength loss at the shoulder.[9] Thus, shoulder strength may be a more appropriate metric for evaluating upper limb function, considering the marked strength declines at the shoulder with age and injury and altered kinematic strategies for task performance, which may influence strength requirements.

Understanding which tasks place the largest demand on the shoulder is critical to identifying individuals at risk for future disability due to strength loss, and ultimately for providing strategies that preserve and improve upper extremity function. Therefore, the objectives of this study were to: (1) quantify required shoulder strength to complete 5 common functional tasks when performed by young adults, uninjured older adults, and older adults with a degenerative supraspinatus tear; (2) determine which functional task required the most strength; and (3) identify whether the

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percentage of available shoulder strength used to complete tasks is altered by age or rotator cuff tear status. It was hypothesized that (1) task and group would significantly affect the required strength at the shoulder, (2) upward reach to 15° above shoulder height would require the most strength, and (3) older adults with a rotator cuff tear would use a significantly higher percentage of their available strength than older adults without a rotator cuff tear and older adults without a rotator cuff tear would use a significantly higher percentage of their available strength than young adults.

Methods

Older adult study participants with and without rotator cuff tears (Table 1) were recruited as part of a larger study exploring how rotator cuff tears affect upper limb morphology, strength, and function.[8,9] Young adults were newly recruited for the current study. Uninjured old and young controls were recruited from the local community and the symptomatic rotator cuff tear participants were recruited from Wake Forest Baptist Hospital orthopaedic clinics. All tear participants had a confirmed major thickness (> 50%) supraspinatus tear, confirmed via magnetic resonance imaging (MRI). Participants were free of medical conditions incompatible with physical testing and any history of neuromuscular or musculoskeletal disorders affecting the upper limb. Uninjured controls were screened with a modified Jobe's test[18] to exclude those with an asymptomatic rotator cuff tear. Older control participants were age- and sex-matched to the participants with a rotator cuff tear. This study was approved by the Wake Forest School of Medicine Institutional Review Board and all participants provided written informed consent. The dominant arm was evaluated for uninjured participants and the injured arm was evaluated for participants with a rotator cuff tear.

We recorded and analyzed the spatial location of 12 retroreflective markers placed on each participant's upper limb at 200 Hz using 7-Hawk cameras (Motion Analysis Corp., Santa Rose, CA) during a static trial and 5 dynamic upper extremity tasks. These tasks spanned the upper limb workspace and included axilla wash, perineal care, forward reach, upward reach to shoulder height, and upward reach to 15° above shoulder height (Figure 1).[8] Participants were seated for all tasks and instructed to maintain an upright posture. Prior to beginning each task, participants were given a verbal explanation and 1 demonstration was performed. During the performance of each task, participants were allowed to choose their movement path as long as they successfully reached the target point and returned to the starting posture. Participants were instructed to stop the task immediately if they felt any pain or discomfort. Task order was randomized and 3 trials of each task were performed. Sixty seconds of rest between trials and 2 minutes of rest between tasks were given to reduce the effects of fatigue. The second trial of each task was used for analysis. Marker data were tracked and smoothed with a 6 Hz filter within Cortex software (Motion Analysis Corp., Santa Rosa, CA).

To calculate the joint moments associated with performing each task, a previously developed and validated dynamic upper limb model[19,20] implemented in OpenSim (Stanford University, CA)[21] representing a 50th percentile male was used as a foundation for a series of simulations. Briefly, the model has 7 degrees of freedom (DOF) describing shoulder, elbow, and wrist rotations defined using International Society of Biomechanics standards.[22] Humeral rotation was defined using the Y-X-Y Euler angles of rotation. Fifty Hill-type muscle-tendon actuators[23] were included to represent the 32 muscle-tendon units of the upper limb; 11 upper limb muscles (20 model actuators) cross the glenohumeral joint. Shoulder elevation angle and axial rotation range of motion (ROM) were expanded from the nominal model to reach postures achieved during task performance.

To identify the joint angles used by each subject for each task, the nominal model was scaled to the individual's anthropometry using the static trial. Inverse kinematics were then performed for each task to calculate joint kinematics for the shoulder, elbow, and wrist. Joint kinematics were filtered with a zero-phase filter using a custom Matlab (The Mathworks, Natick, MA) program.[8] Movement initiation, target achievement, and task completion times were manually identified.

All subsequent simulations were performed using group-specific models representing age, sex, and tear status. Group-specific models reflected the moment-generating capabilities of the young adult male (nominal model), young adult female,[24] older adult male,[2] and older adult female[2] participants (Figure 2). For the 3 new group-specific models, peak force-generating capacities of the muscle-tendon actuators in the model, represented by the peak isometric force parameter, were scaled by the average muscle volumes (V_m) (Equation 1) previously measured from MRI (Supplementary Table 1).[2,24] Specific tension ($\sigma = 50.8$ N/cm^2), optimal fiber length (l_m^o), and moment arms for all group models were unchanged from the nominal model.[19,20]

$$Peak\_Force = \sigma * \frac{V_m}{l_m^o} \tag{1}$$

Mass and inertial properties of the limb segments for female models were scaled to a 50th percentile female (Figure 2).[25] The supraspinatus was removed from the model for older adults in the rotator cuff tear group to simulate that supraspinatus could not transmit force (Figure 2).

Table 1 Participant Demographics

		Height (m)	Weight (kg)	Age (years)	Upper Arm Length (cm)	Forearm Length (cm)
Young adults	Male (N = 8)	1.81 ± 0.08	82.78 ± 10.64	24.0 ± 2.3	33.0 ± 2.4	28.2 ± 1.4
	Female (N = 10)	1.67 ± 0.05	62.14 ± 8.24	21.9 ± 1.9	30.1 ± 1.4	25.5 ± 1.4
Older adults without a tear	Male (N = 5)	1.75 ± 0.07	92.53 ± 9.56	63.4 ± 1.9	33.5 ± 1.5	27.6 ± 1.6
	Female (N = 4)	1.63 ± 0.06	69.06 ± 7.01	64.3 ± 2.3	30.0 ± 1.1	24.1 ± 1.4
Older adults with a tear	Male (N = 5)	1.75 ± 0.07	92.53 ± 9.56	62.8 ± 2.2	32.9 ± 2.1	27.7 ± 1.5
	Female (N = 4)	1.63 ± 0.11	78.81 ± 26.19	63.3 ± 2.0	30.4 ± 3.0	24.0 ± 1.2

Note. Mean ± standard deviation.

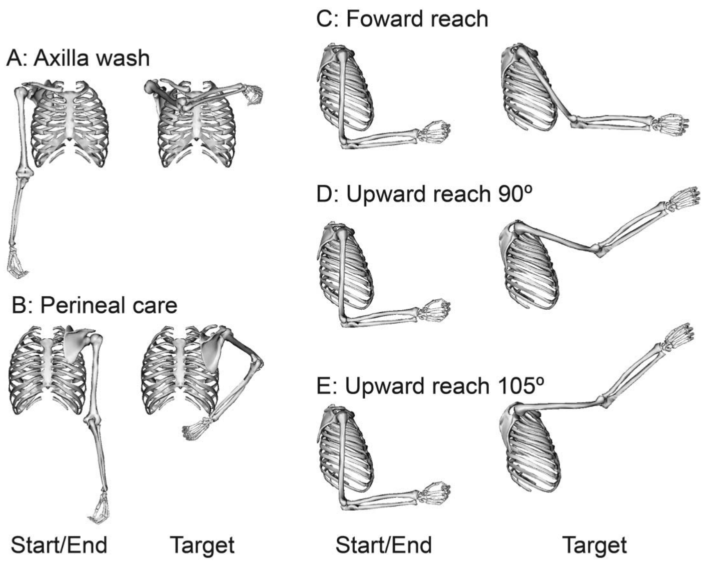

Figure 1 — Each participant performed 5 upper limb tasks at a self-selected velocity. Participants were allowed to choose any kinematic path as long as they reached the start, middle, and end points.[8] (A) Axilla wash: Each participant started with their arm by their side, then reached across their body and grasped the outside of their opposite shoulder, and then returned to the initial position. (B) Perineal care: Each participant started with their arm by their side, then reached behind them and placed their palm on the approximate location of the middle belt loop on the waistband on their pants (palm facing anteriorly), and then returned to the initial position. For tasks C, D, and E, the participant started with their upper arm parallel to their torso and their elbow flexed to 90° and reached either forward or upward to a horizontal distance of 80% of their forearm length from their starting position, and then returned to the starting position. (C) Forward reach: Each participant reached forward with a 0.91-kg (2-lb) dumbbell ensuring it did not drag on the table top and then returned to the start position. (D) Upward reach 90°: Each participant reached upward to shoulder height with a 91-kg (2-lb) dumbbell, set the weight down on the shelf, and then returned to their starting position. (E) Upward reach 105°: Each participant reached upward to 15° humeral elevation above shoulder height with a 0.91-kg (2-lb) dumbbell, set the weight down on the shelf, and then returned to their starting position.

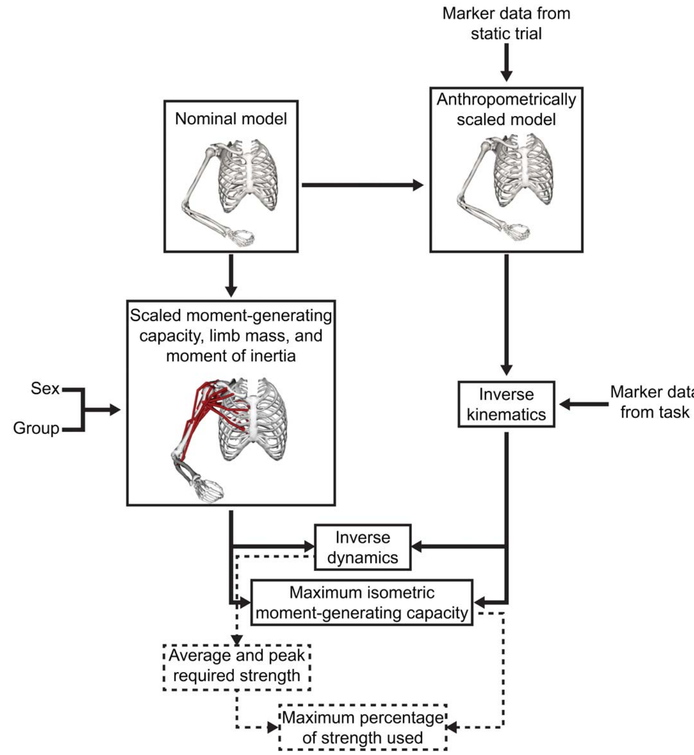

Figure 2 — Modeling methodology flow chart. Marker data from the static trial was used to scale the limb length of the nominal model of the group corresponding to the participant of interest. Marker data from the task was used with the anthropometrically scaled model as inputs to the inverse kinematics tool in OpenSim[21] to determine the joint angles necessary to complete the task. The nominal model was scaled to the force-generating capacity of each group by scaling the muscle volume from previously obtained data.[2,24] Additionally, although limb length was consistent with the nominal model, limb mass and moment of inertia were set based on the participant's sex. The joint kinematics obtained through the inverse kinematics analyses were combined with the group- and sex-specific model to determine the moment necessary to complete each task using the inverse dynamics tool in OpenSim. All of the shoulder muscles in the group- and sex-specific model were fully activated in each posture generated from the inverse kinematics to determine the maximum moment-generating capacity for each moment direction[22]: *+elevation plane, −elevation plane, +shoulder elevation, −shoulder elevation, internal rotation, external rotation*. Average and peak required strength are calculated from output of the inverse dynamics analysis and the maximum percentage of strength used is calculated by dividing the required strength throughout the task by the maximum available strength.

The shoulder strength required for each participant to perform each task was calculated from their self-selected kinematic strategy and the group-specific model associated with the particular participant. Joint moments were calculated using inverse dynamics within OpenSim for each of the 3 DOFs, with positive and negative values representing antagonist muscle groups acting at each DOF for a total of 6 moment directions (*+elevation plane, −elevation plane, +shoulder elevation, −shoulder elevation, internal rotation, external rotation*). The full upper limb model was used during inverse dynamics to account for distal mass and inertia of the forearm and hand.

From the time series profiles of the required strength, the average and peak moment values for each of the 6 moment directions was calculated for each task. These values were then used to estimate the total strength required (T_s) at the shoulder (Equation 2), where i represents a moment direction. Total average strength and total peak strength were each calculated using average and peak moment measurements, respectively.

$$T_s = \sqrt{\sum_{i=1}^{6} Joint\,Moment_i^2} \tag{2}$$

To identify the percentage of available strength used, the tasks that required the largest moment for each of the 6 moment directions was identified from the peak required strength values. The maximum isometric moment-generating capacity available in each posture during each task was then calculated using the participant's corresponding group-specific model. To replicate experimental tests of maximum voluntary moment-generating capacity, maximum activation of each muscle was assumed, and contributions from all muscles with moment arms contributing to the moment direction of interest were summed. Previous application of this approach using the model resulted in estimates of strength consistent with experimentally measured maximum isometric shoulder strength.[19] Percentage of available strength used was calculated in each posture by dividing maximum isometric moment-generating capacity by the required moment calculated from inverse dynamics.

Mixed-model repeated-measures 2-way ANOVA with interaction using random effects to represent missing data and adjusting for sex were used to determine if main effects of task and group significantly affected the average and peak required strength. Bonferroni correction was applied to the ANOVA analyses. When a significant interaction term ($p < .050$) was present, 9 post hoc analyses were subsequently performed: group effects for the 6 tasks and task effects for the 3 groups. Holm-sequential Bonferroni correction was applied for the post hoc analyses. Family-wise error was set to $p < .050$. Statistical correction was applied for average and peak strength analyses independently.

Six 1-way ANOVAs, using random effects to represent missing data and adjusting for sex were used to analyze group differences in peak percentage of available moment used for all 6 ISB defined moment directions during the most demanding tasks for each direction. Tukey-Kramer post hoc tests were used when an ANOVA demonstrated significance.

Results

Data were available for all but 3 subject-task combinations. One older male and 1 older female with tears were unable to perform perineal care and upward reach to 105°, respectively, due to pain during task performance. Data collected for perineal care for 1 young adult male was unusable because the kinematic data were unable to be analyzed.

Corresponding to our hypothesis, analyses of the effect of task and group on required moment in the 6 directions showed that task had a significant main effect (all $p < .001$). However, contrary to our hypothesis, group only had a main effect for maximum positive shoulder elevation ($p = .007$). Study cohort averages for average and peak strength required to perform the 5 tasks are reported in Figure 3. Task*group interaction was significant for both average ($p < .001$) and peak ($p < 001$) internal rotation strength. Therefore, post hoc analyses were performed. The post hoc tests resulted in significant task effects for each group for both average and peak required strength (all $p < .001$), while significant group effects only existed for average internal rotation strength for perineal care ($p < .001$).

Upward reach to 105° required the largest average and peak moment for positive shoulder elevation, which supports our hypothesis. Additionally, upward reach to 105° also required the largest total average strength (Table 2). However, axilla wash required the largest total peak strength (Table 2) and perineal care required the largest average and peak moments for positive elevation plane and internal rotation.

Contrary to our hypothesis, older adults with a rotator cuff tear did not consistently use a larger percentage of their available strength than older adults without a rotator cuff tear, and older adults without a rotator cuff tear did not consistently use a larger percentage of their available strength than the young adults. We found that older adults with ($p < .001$) and without ($p < .001$) a rotator cuff used more available positive shoulder elevation strength than young adults. There was also a larger demand on external rotation strength for older adults with ($p < .001$) and without ($p = .017$) a tear. Loss of strength due to a rotator cuff tear resulted in significantly greater use of internal rotation available strength compared to both the young adults ($p < .001$) and uninjured older adults ($p = .008$) (Figure 4). No other moment direction exhibited group differences. No group used more than 43% of their maximum moment-generating capacity for any functional muscle group.

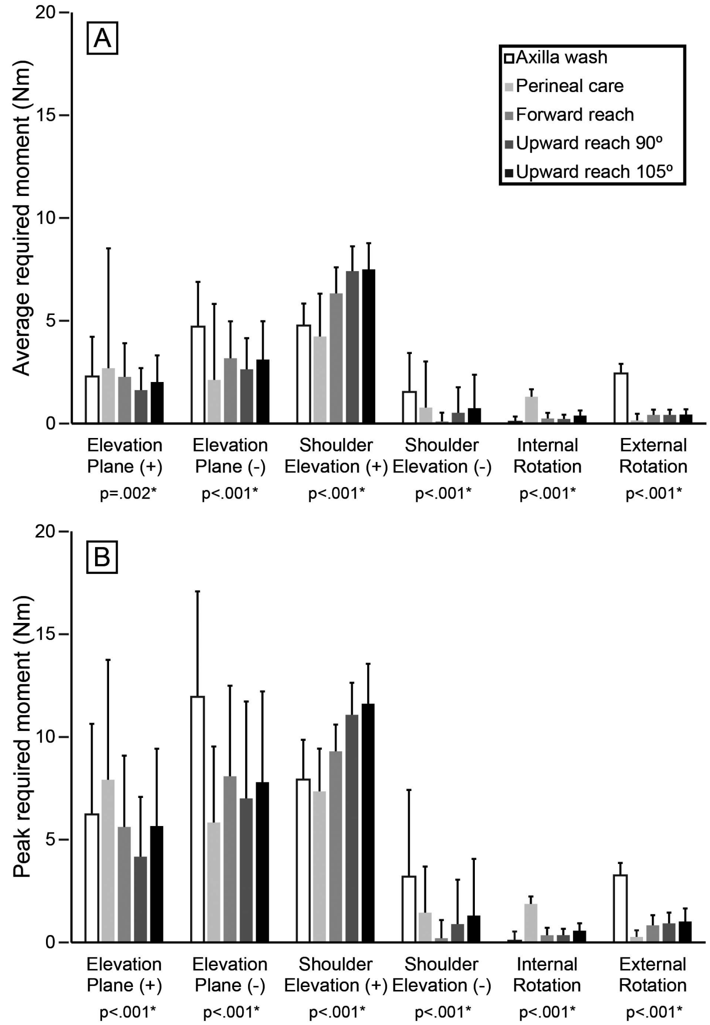

Figure 3 — Study cohort average (A) and peak (B) required shoulder strength for each moment direction within each task. Following correction, task was significant for all moment directions. * Significant task effect based on Bonferroni correction with family-wise error rate set to $p < .050$. Largest average and peak required strength for any moment direction for any task for any participant were 10.0 N˙m (shoulder elevation [+] upward reach 105°) and 25.2 N˙m (elevation plan [+] perineal care), respectively.

Discussion

This study reports new measurements of strength for all 3 DOFs at the shoulder required to perform 5 upper limb functional tasks. Both older adult groups required similar strengths as young adults during task performance. This is despite previously reported differences in kinematic strategies between groups for the same tasks, such as less elevated postures for uninjured older adults compared to young adults[4] and more internally rotated postures for older adults with a rotator cuff tear compared to uninjured older adults.[8] However, the different kinematic requirements of the tasks themselves resulted in larger average demand in upward reaching tasks and larger peak demand in the axilla wash task. Lower available strength of the older adult groups significantly increased the proportion of available strength required when lifting the arm

Table 2 Total Average and Total Peak Strength Required for Functional Tasks Across All Study Participants Calculated From Equation 2

	Axilla Wash	Perineal Care	Forward Reach	Upward Reach 90°	Upward Reach 105°
Average (N˙m)	8.11 ± 2.49	5.93 ± 1.42	7.85 ± 1.35	8.34 ± 1.35	8.74 ± 2.00
Peak (N˙m)	17.06 ± 6.50	13.19 ± 6.31	14.08 ± 4.49	14.46 ± 4.47	15.80 ± 5.16

Note. Mean ± standard deviation.

away from the body (ie, increasing thoracohumeral angle) and externally rotating the humerus. Strength loss resulting from the rotator cuff tear resulted in significant increases in the percentage of strength used for internal rotation compared to both young adults and uninjured older adults. These findings suggest that age- and tear-related disability due to loss of strength may manifest in multiple tasks. However, with the exception of internal rotation, for the tasks used within this study, it does not appear that a degenerative supraspinatus tear further increases the available strength used compared to normal age-related declines in strength.

Using a quantitative estimate that included all 3 DOFs at the shoulder but none at the elbow, we found upward reaching tasks required the highest average strength, supporting 2 previous studies demonstrating that upward reaching tasks require the most strength.[13,14] However, in contrast to the earlier studies, we identified axilla wash as requiring the largest peak total strength, indicating the importance of considering methodological differences between the analyses. Another study reported that axilla wash required the eighth highest level of strength of the 10 tasks

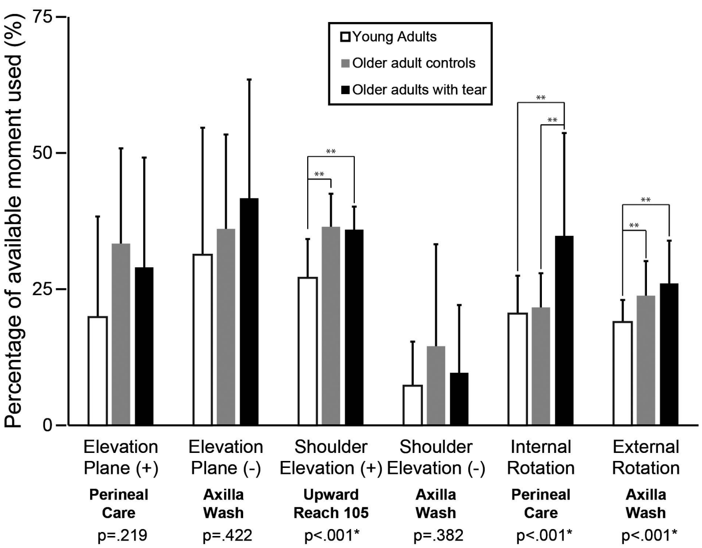

Figure 4 — Peak percentage of available moment used for young adults, uninjured older adults, and older adults with a supraspinatus tear. Moment directions by task combinations analyzed represent the tasks that required the largest peak moment for the particular moment direction. * Significant ($p < .050$) difference determined from a 1-way ANOVA using mixed analysis with random effects to account for missing data adjusting for sex. ** Significant ($p < .050$) differences between groups following Tukey-Kramer post hoc tests. These post hoc tests demonstrated that young adults used significantly less positive shoulder elevation strength ($p < .001$) and external rotation strength ($p = .017$) compared to uninjured older adults. Young adults used significantly less positive shoulder elevation ($p < .001$), internal rotation ($p < .001$), and external rotation ($p < .001$) moment compared to older adults with a supraspinatus tear. Uninjured older adults used significantly less internal rotation strength than older adults with a rotator cuff tear ($p = .008$).

studied but used a qualitative metric that included elbow strength and employed clinical definitions of shoulder rotations (eg, abduction, flexion) which are inconsistent with ISB recommendations. This makes direct comparisons to our study challenging.[26] Hall et al compared the overall resultant moment at the shoulder, which is a different formulation of strength than what was evaluated in this study, and found axilla wash required less average strength than the upward reaching tasks.[14]

Despite the known effects of age and rotator cuff injury, such as decreases in strength[2,8] and altered movement strategies,[4–6,8] group differences in required strength only manifested for positive shoulder elevation moment and average internal rotation strength during the perineal care task. Our results extend previous findings in light of assembly work, which demonstrated similar required shoulder strength across age groups.[12] Research demonstrating similar strength requirements for upper extremity tasks between symptomatic and asymptomatic older adults with rotator cuff impingement also provide support for our findings.[14] Tasks performed in both studies required that participants were seated and handle only small or no load. Altered postural or load demands that place a larger burden on the upper limb have been shown to elicit functional changes.[7,27] However, the previous studies on postural or load demands analyzed kinematic strategies and it is unclear if those kinematic changes manifest themselves as significant changes in necessary upper limb strength.

Required strength is presented in light of the available strength capacity of the shoulder. All functional tasks require a minimum strength below which successful performance is not possible[28]; strength capacity above this limit is referred to as reserve strength.[28] Even with the age- and tear-related declines in strength capacity, older adults in this study appeared to have sufficient reserve strength, potentially indicating that functional limitations in the upper limb may be due to pain, discomfort, or perceived weakness and not necessarily an inability of the muscles to generate the necessary moment. Positive shoulder elevation and external rotation exhibited the greatest sensitivity to age-related strength loss. Internal rotation exhibited the greatest sensitivity to strength loss related to a rotator cuff tear. Combined with the more internally rotated postures used by older adults with a rotator cuff tear,[8] this indicates the importance of understanding ROM and strength loss for this DOF following a rotator cuff tear. However, no group used more than 43% of their available strength for any moment direction, leaving at worst 57% of the available strength in reserve. It has been reported that gait becomes impaired when lower limb muscles are weakened by 40% of their maximum force-generating capacity.[29] If the upper limb has a similar threshold, at a minimum, all groups, for all tasks tested, could withstand an additional 17% reduction in strength and still ensure successful performance of the functional tasks using similar kinematic strategies. Methods which allow for the calculation of strength requirements for individual muscles, such as computed muscle control,[30] which was used in the gait study,[29] should be exploited to quantify this threshold in the upper limb and provide information for targeted interventions.

It is important to consider the results of this study in light of its limitations. We calculated required strength for the kinematic trajectories chosen by the participants in this study. Other trajectories are available and may require less strength; in particular, the rotator cuff tear population may make postural choices due to discomfort rather than strength or other considerations. However, it was previously demonstrated that participants performing pointing tasks throughout the workspace choose postures that require minimal muscle effort,[31] suggesting that our participants were likely to be using task trajectories that minimize strength requirements. Upper limb strength was not directly measured for the participants. Older adults participating in this study were between the ages of 61 and 68 years old; generalization to individuals older than this range should be done with caution. Peak available strength was calculated in static postures with full muscle activation, representing the maximum isometric strength of the model in that posture. Therefore, the calculated percentage of available moment used was conservative. Muscle volumes used in this study were previously correlated only to abduction and adduction moment generating capacity.[2,24] However, subsequent work has demonstrated that the volume of each rotator cuff muscle is highly correlated to the joint moment of a muscle's primary action, suggesting that the correlation between joint moment and muscle volume holds regardless of direction.[9] Although the supraspinatus was completely removed from the model for the rotator cuff tear participants, it is likely that a partially torn supraspinatus could still transmit force. However, fully removing the supraspinatus allowed consistency across participants since the degree of force transmission is unknown.

Specific tension, muscle moment arms, and optimal muscle length were held consistent among all models; these factors affect the moment-generating capacity of the muscles at the shoulder. There is a paucity of information regarding if or how these characteristics change with age, sex, and injury in the shoulder musculature. To determine if these parameters have a large influence on the overall model strength, abduction moment generating capacity of the older adult male (28.1 N·m) and female (18.2 N·m) uninjured models at 60° of abduction were calculated. They were then compared against experimentally measured isometric abduction moments at 60° of abduction for the participants whose group average muscle volumes were used to create the older adult models.[2] The model demonstrated excellent agreement with both male (31.7 ± 7.2 N·m) and female (18.2 ± 11.0 N·m) experimentally-derived isometric moment-generating capacity.[2] Scapular motion was constrained via a regression equation[32] and held constant for all participants. Altered scapular motion, such as a reduction in posterior tilt which has been reported in older adults with a rotator cuff tear,[33] would likely affect moment-generating capacity of the muscles with attachments to the scapula. However, here we were able to isolate the effects of strength reduction and kinematic changes on the functional capability of the upper limb.

In conclusion, we observed that age, separately or in concert with a degenerative supraspinatus tear, has a limited effect on the strength requirements at the shoulder for the upper limb daily tasks studied here. Although there were limited differences across the groups in required shoulder strength for a given task, older adults with and without a supraspinatus tear used a larger portion of their available strength than the young adults for shoulder elevation and external rotation. This finding suggests that age-related strength loss in elevation and external rotation may limit future functional capability the most. However, tear-related strength loss resulted in the use of significantly more internal rotation reserve strength above what the younger adults and uninjured older adults used, indicating the importance of this DOF when analyzing disability following a rotator cuff tear. Task requirements significantly influenced required strength at the shoulder, with upward reach task requiring the largest average strength and axilla wash requiring the largest peak strength. This study provides motivation to explore other tasks and portions of the upper limb workspace in the context of age and musculoskeletal injury.

Funding and Conflict of Interest

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