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Short communication

The effects of a rotator cuff tear on activities of daily living in older adults: A kinematic analysis

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ABSTRACT

Rotator cuff tears (RCT) in older individuals may compound age-associated physiological changes and impact their ability to perform daily functional tasks. Our objective was to quantify thoracohumeral kinematics for functional tasks in 18 older adults (mean age $=63.3\pm2.2$), and compare findings from nine with a RCT to nine matched controls. Motion capture was used to record kinematics for 7 tasks (axilla wash, forward reach, functional pull, hair comb, perineal care, upward reach to 90°, upward reach to 105°) spanning the upper limb workspace. Maximum and minimum joint angles and motion excursion for the three thoracohumeral degrees of freedom (elevation plane, elevation, axial rotation) were identified for each task and compared between groups. The RCT group used greater minimum elevation angles for axilla wash and functional pull ($p\leq0.0124$) and a smaller motion excursion for functional pull ($p=0.0032$) compared to the control group. The RCT group also used a more internally rotated maximum axial rotation angle than controls for functional reach, functional pull, hair comb, and upward reach to 105° ($p\leq0.0494$). The most differences between groups were observed for axial rotation, with the RCT group using greater internal rotation to complete functional tasks, and significant differences between groups were identified for all three thoracohumeral degrees of freedom for functional pull. We conclude that older adults with RCT used more internal rotation to perform functional tasks than controls. The kinematic differences identified in this study may have consequences for progression of shoulder damage and further functional impairment in older adults with RCT.

1. Introduction

Sarcopenia and reduced strength are well-known sequelae of aging contributing to functional declines older adults experience (Clark and Manini, 2010). Presence of a shoulder injury, like a rotator cuff tear (RCT), can further reduce an individual's ability to perform functional tasks (Lin et al., 2008; van Schaardenburg et al., 1994). RCT is a common musculoskeletal injury for older adults, with prevalence increasing from 25.6% to 50.0% for adults in their sixties and eighties, respectively (Yamamoto et al., 2010). Shoulder injury may result in adaptive movements caused by muscle weakness or force imbalance (Lippitt and Matsen, 1993; Lippitt et al., 1993; Magarey and Jones, 2003; Phadke et al., 2009), or used as a pain avoidance strategy (Hall et al., 2011; Mell et al., 2005). In addition to limiting functionality, altered kinematics may expose the glenohumeral joint to new contact force scenarios, which could lead to further joint damage (Hsu et al., 2003; Vidt, 2014).

The upper limb is critical for daily functional tasks, including eating and personal hygiene (Katz et al., 1963). Studies evaluating upper limb functional task performance have primarily focused on younger or uninjured individuals (Magermans et al., 2005; Safaee-Rad et al., 1990; van Andel et al., 2008). Little work has focused on older adults (Hall et al., 2011) or investigated functional task performance in those with RCT. Therefore, our objective was to quantify thoracohumeral kinematics for a group of older adults

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with and without RCT during performance of functional tasks spanning the upper limb workspace. Kinematics for three thoracohumeral degrees of freedom were compared between groups. The null hypothesis was that task kinematics for RCT and control groups would not be different.

2. Methods

2.1. Participants

Eighteen older individuals (mean age=63.3 ± 2.2) participated (Table 1); 9 participants (4F/5M) had RCT of the supraspinatus tendon; 9 were age- and sex-matched controls. RCT participants had an MRI-confirmed supraspinatus tendon tear (≥50% tendon thickness) and were recruited from our institution's orthopedic clinic, where they sought treatment for RCT symptoms. Controls were recruited from the local community, had no history of shoulder pain or injury, and were screened for shoulder pain and weakness using a modified lateral Jobe's test (Gillooly et al., 2010), whereby manual resistance was applied to arms elevated 90° in the scapular plane with neutral axial rotation. RCT participants' injured arm was studied and the dominant arm was investigated for controls. Wake Forest Health Sciences Institutional Review Board approved this study; all participants provided written informed consent prior to participation.

2.2. Functional tasks

Participants completed 7 functional tasks spanning the upper limb workspace: forward reach, functional pull, upward reach to a shelf at shoulder height (upward reach 90°) and 15° above horizontal (upward reach 105°), axilla wash, perineal care, and hair comb. All tasks were completed while seated (chair height=0.53 m) at a table (height=0.775 m). Descriptions of each task and associated loads, selected to mimic typical loads in daily performance, are described in Table 2. Participants were given instructions on start and finish hand positions for each task, but could freely choose their joint postures and speed during each movement. Task order was randomized; three trials of each task were recorded before proceeding to the next task. Participants were provided 60 s rest between trials and 2 min rest between tasks. Participants were instructed to stop a task if they experienced any pain or discomfort (see below). The second trial of each task for each participant was used for analysis.

Positions of twelve 1 cm retro-reflective markers placed on the upper limb and torso (Fig. 1) were tracked at 200 Hz (60 Hz for 3 participants) using 7 Hawk motion capture cameras (Motion Analysis Corporation, Santa Rosa, CA). Marker data was post-processed and smoothed with a 6 Hz Butterworth filter using Cortex software (Motion Analysis Corporation).

2.3. Kinematic calculations

A dynamic upper limb model (Saul et al., 2015) was implemented in OpenSim (v.3.1) (Delp et al., 2007). The model was scaled to each participant using marker locations from one static trial. Following scaling, the inverse kinematics tool calculated joint kinematics for each task. Kinematic trajectories were filtered with a zero-phase filter using a custom Matlab program (The Mathworks, Natick, MA). Consistent with ISB standards describing thoracohumeral motion (Wu et al., 2005), joint angles were decomposed by applying *Y*–*X*–*Y* rotation order, corresponding to elevation plane, elevation, and axial rotation, using axes defined from anatomical landmarks. Elevation in 0° elevation plane is abduction; elevation in 90° elevation plane is forward flexion; positive axial rotation is internal rotation; negative axial rotation is external rotation. Maximum and minimum angles were calculated for each degree of freedom (Fig. 1). Motion excursion was calculated by subtracting the minimum angle from the maximum angle. To compare across participants, kinematics were normalized by task completion time and are presented as a percentage of total movement time.

2.4. Statistical analysis

Mixed model ANCOVA, using random effects to represent matched pairs and adjusting for hand dominance, was used to separately evaluate differences between RCT and control groups for maximum angle, minimum angle, and motion excursion of each degree of freedom for each task (v.9.3, SAS Institute, Inc., Cary, NC). Significance was set at $p \leq 0.05$. We did not adjust for type I error due to the exploratory nature of these analyses.

3. Results

Six RCT participants had full-thickness supraspinatus tear. Tears extended into infraspinatus in 7 participants and subscapularis in 5 participants. Three RCT participants did not complete all tasks due to pain: one could not complete perineal care and hair comb; one could not complete hair comb; one could not complete upward reach 105°. RCT participants completed several tasks with different kinematics than controls (Fig. 2; Supplement 1, 2). Elevation plane was similar between groups for most tasks, but RCT participants used a smaller (closer to abduction plane) maximum elevation plane for forward reach ($p=0.0300$) and functional pull ($p=0.0020$) (Fig. 2; Table 3). Minimum elevation angle for RCT participants was greater (more elevated) for axilla wash

Table 1
Participant characteristics.

Subject	Age (years)	Height (cm)	Body mass (kg)	Dominant arm	Injured arm
RF01	65	149.9	53.5	Right	Left
RF02	63	160	73.5	Right	Right
RF03	60	180.3	122.5	Right	Right
RF04	65	162.6	65.8	Right	Left
RM01	61	167.6	83.9	Right	Left
RM02	64	177.8	108	Left	Left
RM03	64	182.9	88.5	Right	Left
RM04	62	177.8	95.3	Left	Left
RM05	66	168.9	87.1	Right	Left
CF01	67	172.7	70.8	Right	N/A
CF02	65	162.6	65.8	Right	N/A
CF03	60	157.5	79.4	Right	N/A
CF04	64	160	60.3	Right	N/A
CM01	61	177.8	99.8	Right	N/A
CM02	64	182.9	86.2	Right	N/A
CM03	62	172.7	73.5	Right	N/A
CM04	61	175.3	70.3	Right	N/A
CM05	66	182.9	83.9	Right	N/A
RCT mean ± SD	63.3 ± 2.0	169.8 ± 11.0	86.4 ± 21.0		
Control mean ± SD	63.3 ± 2.4	171.6 ± 9.5	76.7 ± 12.0		

R: rotator cuff tear subject
C: control subject
F: female subject
M: male subject
N/A: not applicable

Table 2
Functional tasks representative of activities of daily living. Participants were given instructions on the start and target hand locations for each task, and were allowed to freely choose their arm postures to reach the defined hand locations.

Task	Task instructions	Load
Forward reach[a]	Start with the humerus in 0° elevation in the 90° elevation plane (sagittal plane) and 2 lb dumbbell resting on the table, reach with the weight a distance of 80% of forearm length, then return hand to starting position.	0.91 kg (2 lb) dumbbell (to mimic the weight of a typical kitchen object, like a plate)
Functional pull[a]	Start with humerus elevated in the 90° elevation plane (sagittal plane) such that the hand reaches a distance of 80% of the subject's forearm length, holding the handle from a weight machine (6 lb resistance), pull the handle until the humerus is in 0° elevation in the 90° elevation plane, then return hand to starting position.	2.72 kg (6 lb) resistance from pulley system (to mimic the resistance associated with opening a door)
Upward reach[a] shoulder height (upward reach 90°) 15° above horizontal (upward reach 105°)	Start with humerus in 0° elevation in the 90° elevation plane (sagittal plane) and 2 lb dumbbell resting on the table, reach upward to set the weight on the shelf, then return hand to starting position.	0.91 kg (2 lb) dumbbell (to mimic the weight of a typical kitchen object, like a plate)
Axilla wash[b]	Start with elbow extended and the humerus in 0° elevation in the 90° elevation plane (sagittal plane), resting quietly at the side, reach across the torso to touch the lateral aspect of the contralateral shoulder, then return hand to the starting position.	No load
Perineal care[b]	Start with elbow extended and the humerus in 0° elevation in the 90° elevation plane (sagittal plane), resting quietly at the side, reach behind the torso and touch the center of the small of the back with the palmar side of the fingers/hand, then return hand to the starting position.	No load
Hair comb[b]	Start with elbow extended and the humerus in 0° elevation in the 90° elevation plane (sagittal plane), resting quietly at the side holding a pencil (used to represent a comb), reach to the forehead, comb the center of the hair from front to back once and return hand to the starting position.	No load; subjects were given a pencil to mimic holding a comb

[a] Subjects were seated at a table to perform the task.
[b] Table was removed for task performance.

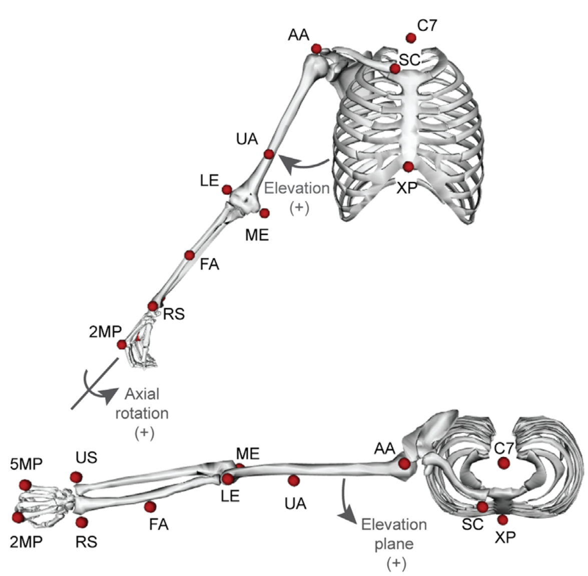

Fig. 1. Motion definitions and marker locations. Thoracohumeral motion was defined as elevation plane, elevation, and axial rotation and calculated in accordance with ISB standards (Wu et al., 2005). Elevation in the 0° elevation plane is abduction and elevation in the 90° elevation plane is forward flexion; positive axial rotation is internal rotation and negative axial rotation is external rotation (Wu et al., 2005). Retro-reflective motion capture markers (red spheres) were placed on anatomical locations, including: the 7th cervical vertebra (C7), the most ventral aspect of the sternoclavicular joint (SC), xiphoid process (XP), the most lateral aspect of the scapular acromial angle (AA), the mid-upper arm (UA), the lateral epicondyle of the humerus (LE), the medial epicondyle of the humerus (ME), the mid-forearm (FA), the styloid process of the radius (RS), the styloid process of the ulna (US), the 2nd metacarpophalangeal joint (2MP), and the 5th metacarpophalangeal joint (5MP). One marker (not shown) was affixed to the top of the dumbbell weight (forward, upward reaches), the weight machine handle (functional pull), and the pencil (hair comb). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

($p=0.0124$) and functional pull ($p=0.0047$). RCT participants had smaller motion excursion for elevation during functional pull ($p=0.0032$). RCT participants used greater maximum internal rotation angles for forward reach ($p=0.0004$), functional pull ($p=0.0296$), hair comb ($p=0.0494$), and upward reach 105° ($p=0.0337$) than controls, and greater minimum internal rotation during upward reach 105° ($p=0.0089$) compared to controls.

4. Discussion

We found older individuals with RCT completed functional reach, functional pull, hair comb, and upward reach 105° with more internal rotation than controls. The RCT group completed functional pull most differently, with differences identified in all three degrees of freedom. Kinematic differences identified for RCT participants across tasks may precipitate glenohumeral joint damage and increase functional impairment.

Three RCT participants could not complete all tasks due to pain because of extreme motion excursion requirements for hair comb and upward reach 105°. Pain observed in these participants is consistent with elevation and external rotation pain assessed clinically with physical (e.g. Beaudreuil et al., 2009) and self-report (e.g. MacDermid et al., 2004) assessments. One subject could not perform perineal care because axial rotation and sagittal plane elevation movements were limited by concomitant biceps tendon and superior labral pathology. While our analyses did not detect statistically different movements between groups for these tasks, this may be because failed trials were excluded from analyses. Movements requiring large motion excursion should be targets for adaptive movement strategy development to facilitate independence for older adults (Hall et al., 2011). Identification of individuals in this small cohort who could not perform these tasks suggests many older adults with RCT would be limited in move-

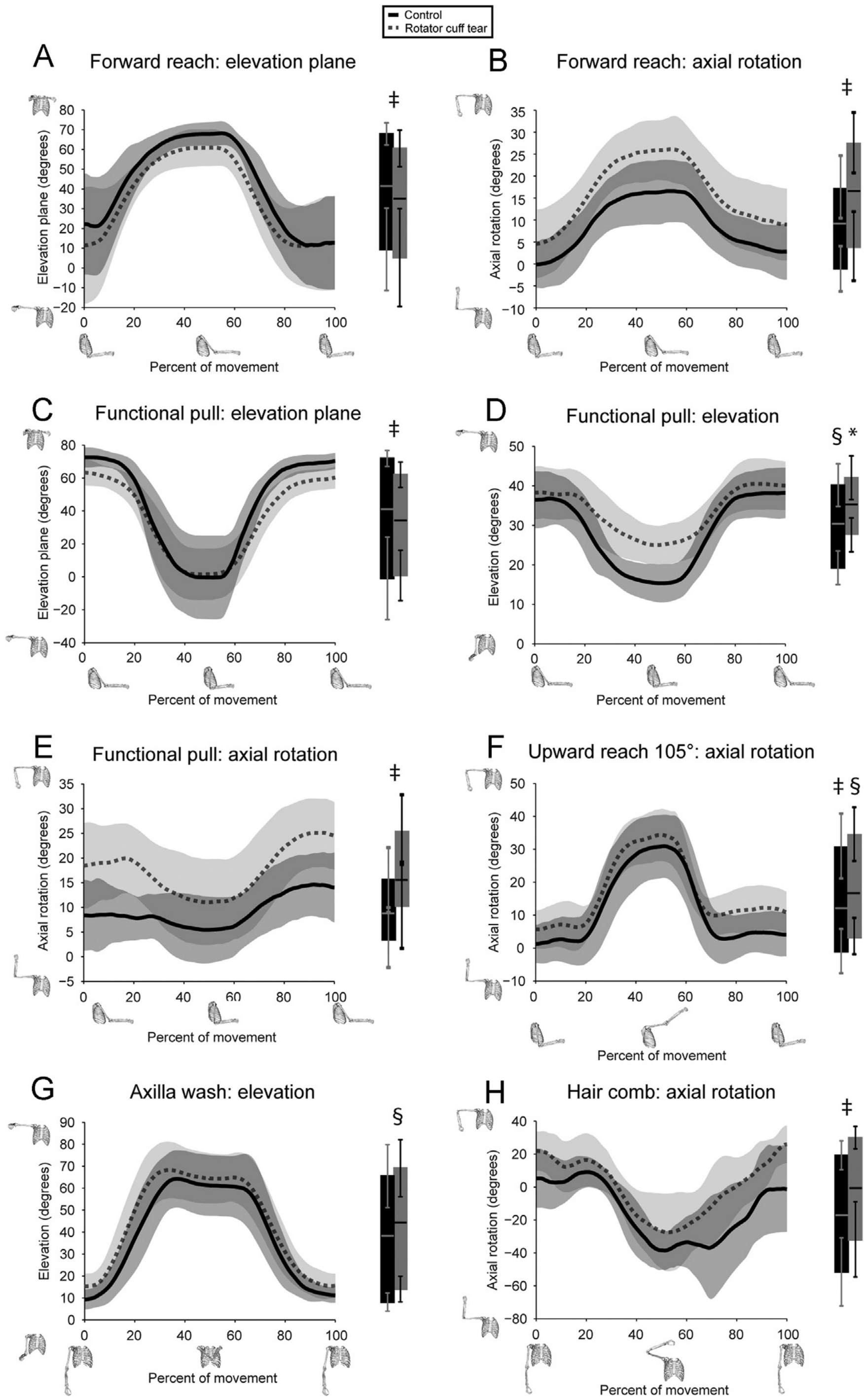

Fig. 2. Thoracohumeral kinematics during the performance of planar functional tasks. Mean ± standard deviation (SD) of kinematics are shown for the rotator cuff tear (RCT) group (gray dashed line, light shaded band) and control group (solid black line, dark shaded band). Mean maximum (± SD), mean minimum (± SD), and mean motion excursion are shown with bars to the right of the plot, with the horizontal line in the bars representing the mean joint angle for the task. ‡ indicates significant difference in maximum angle; § indicates significant difference between groups in minimum angle; * indicates significant difference between groups for motion excursion. For the forward reach task, the RCT group had a smaller (closer to abduction plane) maximal elevation plane ($p=0.0300$) angle (A) and greater maximum internal rotation angle ($p=0.0004$) (B) than the control group. For the functional pull, the RCT group used a smaller (closer to abduction plane) maximal elevation plane ($p=0.0020$) (C), greater minimum elevation angle ($p=0.0047$), and a smaller elevation motion excursion ($p=0.0032$) (D), and a greater maximal internal rotation joint angle ($p=0.0296$) (E). For the upward reach 105°, the RCT group used a greater maximum internal rotation angle ($p=0.0337$) and a greater minimum internal rotation angle ($p=0.0089$) (F) than controls. For the axilla wash, the RCT group used a greater minimum elevation angle ($p=0.0124$) (G) than controls. For the hair comb, the RCT group used a greater maximum internal rotation angle ($p=0.0494$) (H) than controls.

ments requiring relatively large motion excursions in one (e.g. upward reach 105°) or more (e.g. hair comb) degrees of freedom.

These RCT participants consistently demonstrated greater internal rotation during functional reach, functional pull, hair comb, and upward reach 105°. This suggests internal rotation may be an adaptive strategy, possibly to avoid pain. Seven RCT participants had tears extending into infraspinatus, and external rotation can exacerbate pain when infraspinatus is involved (Beaudreuil et al., 2009). Efforts to avoid painful postures may expose the shoulder to impingement, particularly at more elevated

Table 3
Group mean differences adjusting for hand dominance for maximum, minimum, and motion excursion (95% confidence interval) for elevation plane, elevation, and axial rotation for each functional task.

	Axilla wash	Forward reach	Functional pull	Hair comb	Perineal care	Upward reach 90°	Upward reach 105°
Maximum							
Elevation plane	1.0 (−8.3, 10.2)	9.5 (1.1, 17.9)	13.9 (6.0, 21.8)	2.9 (−10.6, 16.4)	−5.9 (−40.6, 28.8)	3.5 (−4.3, 11.3)	3.5 (−4.4, 11.3)
	$p=0.8290$	$p=0.0300$*	$p=0.0020$*	$p=0.6319$	$p=0.7033$	$p=0.3473$	$p=0.3588$
Elevation	−7.4 (−25.0, 10.3)	−0.0 (−7.9, 7.9)	0.6 (−7.2, 8.4)	−3.0 (−19.7, 13.6)	−3.2 (−13.5, 7.1)	−1.1 (−8.5, 6.2)	0.7 (−8.3, 9.6)
	$p=0.3875$	$p=0.9974$	$p=0.8770$	$p=0.7007$	$p=0.5153$	$p=0.7478$	$p=0.8721$
Axial rotation	−9.7 (−20.7, 1.3)	−13.2 (−18.3, −8.0)	−10.4 (−19.6, −1.2)	−13.2 (−26.4, −0.0)	−7.5 (−30.9, 16.0)	−4.8 (−18.5, 8.9)	−9.5 (−18.1, −1.0)
	$p=0.0778$	$p=0.0004$*	$p=0.0296$*	$p=0.0494$*	$p=0.4953$	$p=0.4664$	$p=0.0337$*
Minimum							
Elevation plane	−21.0 (−63.1, 21.0)	5.7 (−24.7, 36.1)	5.1 (−22.1, 32.3)	5.5 (−26.4, 37.3)	−3.1 (−25.3, 19.0)	−1.4 (−28.1, 25.3)	11.2 (−11.2, 33.6)
	$p=0.2902$	$p=0.6944$	$p=0.6947$	$p=0.6975$	$p=0.7580$	$p=0.9122$	$p=0.3005$
Elevation	−8.4 (−14.7, −2.1)	−6.0 (−13.3, 1.3)	−10.0 (−16.4, −3.6)	−5.5 (−15.3, 4.2)	−3.1 (−10.9, 4.7)	−5.1 (−13.7, 3.6)	−1.1 (−6.9, 4.7)
	$p=0.0124$*	$p=0.0992$	$p=0.0047$*	$p=0.2289$	$p=0.4024$	$p=0.2199$	$p=0.6696$
Axial rotation	−20.8 (−42.7, 1.1)	−6.2 (−15.4, 3.1)	−8.6 (−19.0,1.8)	−1.5 (−28.9, 25.9)	−21.2 (−56.6, 14.2)	−5.2 (−11.3, 1.0)	−8.7 (−14.3, −3.0)
	$p=0.0601$	$p=0.1674$	$p=0.0969$	$p=0.9088$	$p=0.2140$	$p=0.0897$	$p=0.0089$*
Motion excursion							
Elevation plane	23.8 (−20.1, 67.8)	4.5 (−20.4, 29.4)	8.8 (−16.5, 34.1)	−3.1 (−29.8, 23.5)	−4.0 (−37.6, 29.6)	4.9 (−21.2, 31.0)	−7.8 (−29.7, 14.2)
	$p=0.2657$	$p=0.7061$	$p=0.4700$	$p=0.7867$	$p=0.7964$	$p=0.6939$	$p=0.4613$
Elevation	1.0 (−16.5, 18.5)	6.2 (−0.5, 12.8)	10.5 (4.1, 17.0)	3.5 (−17.3, 24.2)	−0.0 (−11.3, 11.2)	4.3 (−1.6, 10.2)	2.0 (−6.6, 10.6)
	$p=0.9038$	$p=0.0669$	$p=0.0032$*	$p=0.7250$	$p=0.9951$	$p=0.1346$	$p=0.6123$
Axial rotation	12.7 (−7.8, 33.3)	−6.0 (−13.0, 1.0)	−1.9 (−6.8, 3.0)	−11.8 (−43.7, 20.1)	15.2 (−9.5, 39.8)	0.6 (−8.8, 10.1)	−1.1 (−9.1, 6.9)
	$p=0.1971$	$p=0.0880$	$p=0.4325$	$p=0.4395$	$p=0.1991$	$p=0.8876$	$p=0.7590$

* Indicates significance.

postures (Ellenbecker and Cools, 2010). Alternatively, increased internal rotation may result from muscle force imbalance; strength assessments for these same RCT participants (Vidt et al., 2015) demonstrated markedly reduced external rotation strength. Force imbalances may affect glenohumeral loading characteristics, which can lead to further joint damage (Hsu et al., 2003) and other pathology, like humeral head translation. Contrasting our findings, Hall et al. (2011) studied functional upper limb tasks and reported older adults with impingement used less internal rotation than controls; these conflicting findings may result from studying different shoulder pathologies, or the high prevalence of concomitant infraspinatus tears in this study's cohort.

Increased internal rotation for RCT participants may be due to deltoid and pectoral muscle compensation in the absence of a fully functional rotator cuff. Normally, muscular activation and co-activation strategies provide glenohumeral stability during movement (Hawkes et al., 2012a). Following RCT, other muscles must compensate for damaged rotator cuff muscle(s) to maintain stability (Hawkes et al., 2012b). Kinematic differences observed here, particularly for internal rotation, may reflect altered muscle activation patterns following RCT (Hawkes et al., 2012b), or age-associated altered co-contraction (Klein et al., 2001). Future work should explore relationships between muscle activation and functional task kinematics, including tasks requiring large motion excursion (e.g. hair comb) and load movement (e.g. forward reach) for individuals with RCT. Such work would provide insight into which treatment paradigms could best improve functional performance or aid in adaptive strategy development promoting functional independence.

Kinematic differences identified following RCT may expose the shoulder to increased risk for subsequent damage and functional impairment. For example, greater internal rotation observed for RCT participants may indicate subacromial impingement, which reduces the space between the humeral head and acromion, compressing the subacromial bursa and rotator cuff tendons (Braman et al., 2014; Michener et al., 2003). Previous work reports glenohumeral internal rotation is associated with increased risk for impingement of anterior structures (Flatow et al., 1994; Ludewig and Braman, 2011; Werner et al., 2006; Yanai et al., 2006). The underlying cause of RCT is likely multifactorial, and additional factors, like overuse, overhead activities, or acromial anatomy, may further contribute to RCT development (Soslowsky et al., 2002). While it remains unknown whether impingement causes or results from RCT (Braman et al., 2014; Ludewig and Braman, 2011; Michener et al., 2003), RCT-associated impingement can contribute to further RCT progression (Ludewig and Braman, 2011), possibly exacerbating functional limitations. Restoration of internal rotation during functional tasks could reduce impingement risk, but pain associated with concomitant infraspinatus tearing may preclude use of externally rotated postures.

This work has limitations. A small cohort of 18 individuals was studied. Our sample included individuals with full- and partial-thickness supraspinatus tears, and included participants with tears extending into infraspinatus or subscapularis tendons, although none were full-width. However, all patients experienced RCT symptoms, sought treatment, and had tear confirmation with MRI. Controls were screened using a lateral Jobe's test. Sensitivity of this manual exam is 81% (Gillooly et al. 2010), thus it is possible that an asymptomatic tear was not identified. Controls did not receive an MRI to screen for asymptomatic RCT, but since 16.9% of the population has been reported to have an asymptomatic RCT (Yamamoto et al., 2010), future studies should use MRI to screen for asymptomatic tears. This study evaluated thoracohumeral kinematics but did not examine scapulothoracic or glenohumeral kinematics. Since all joints of the shoulder girdle contribute to upper limb movement, future work should also examine a RCT's effect on scapulothoracic and glenohumeral kinematics. The significant differences in kinematics identified here motivate further exploration of these and additional functional tasks in a larger cohort to more comprehensively characterize functional implications of RCT in older adults.

This study provides baseline measures of thoracohumeral kinematics associated with several common functional tasks in older adults with and without RCT, which can be compared to other pathologies or groups following treatment. Additionally, these data may be used in conjunction with computational analysis (e.g. Vidt, 2014) to further explore strength requirements, joint loading, and clinical implications of RCT-induced alterations to upper limb kinematics.

Conflict of interest statement

Michael Freehill serves as a consultant for Smith and Nephew. No financial remuneration was received related to information from this study and it does not represent a conflict of interest. Christopher Tuohy declares an ownership interest in a medical device with research applications that measures rotator cuff tendon repair tension; all participation in device development and testing is beyond the scope of this manuscript and does not represent a conflict of interest. No other authors have any conflicts of interest to disclose related to this manuscript.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jbiomech.2016.01.029.

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