Adductor co-contraction during abduction: a friend or foe

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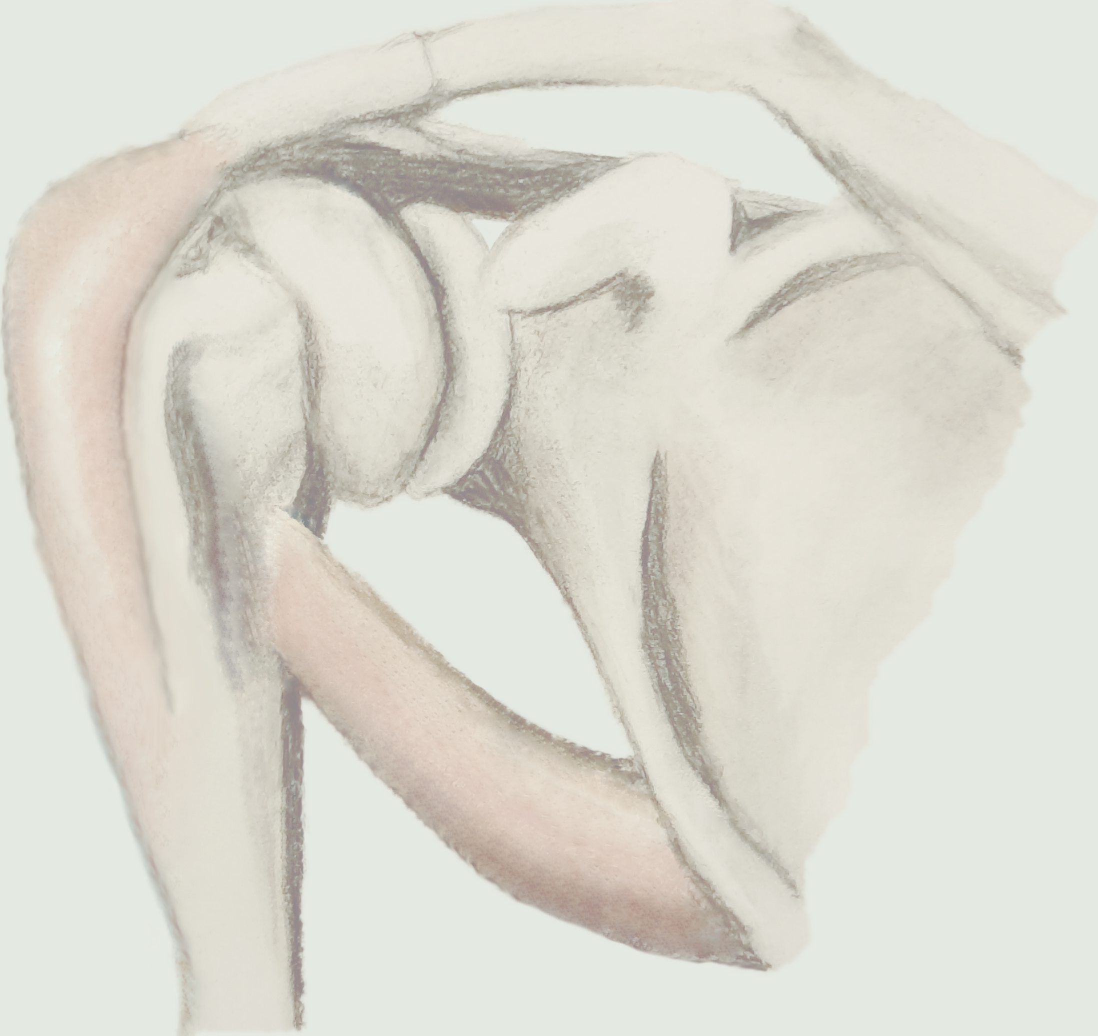
PART I |

The role of adductor co-contraction in the asymptomatic and symptomatic ageing shoulder



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Middle-aged adults co-contract with arm Adductors during arm Abduction, while young adults do not. Adaptations to preserve pain-free function?

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ABSTRACT

Middle-aged individuals co-contract with adductor muscles during abduction. This may be crucial for counteracting deltoid forces, depressing the humerus and ensuring free passage of subacromial tissues underneath the acromion during abduction. We questioned whether adductor co-contraction is always present, or develops during ageing, in which case it may explain the age-related character of common shoulder conditions such as Subacromial Pain Syndrome. In a cross-sectional analysis with electromyography (EMG), activation patterns of the latissimus dorsi, teres major, pectoralis major and deltoid muscle were assessed during isometric force tasks in 60 asymptomatic individuals between 21 and 60 years old. Co-contraction was expressed as the degree of antagonistic activation relative to the same muscle's degree of agonistic activation, resulting in an activation ratio between -1 and 1, where lower values indicate more co-contraction. Using linear regression analyses, we found age-related decreases in the activation ratio of the latissimus dorsi (regression estimate: -0.004, 95% CI: -0.007 – 0.0, p-value: 0.042) and teres major (regression estimate: -0.013, 95% CI: -0.019 – -0.008, p-value: <0.001). In contrast to young individuals, middle-aged individuals showed a high degree of adductor co-contraction during abduction. This may indicate that during ageing, alterations in activation patterns are required for preserving pain-free shoulder function.

INTRODUCTION

Shoulder pain is the second most common musculoskeletal disorder in the general population, with prevalence rates ranging between 15% and 22%[1-3]. The incidence of shoulder pain increases with ageing, suggesting that age-related factors play a role in the pathogenesis[4-8]. Numerous studies have investigated the effect of ageing on the shoulder complex (e.g., rotator cuff degeneration), however factors that may directly relate to the onset and/or perpetuation of shoulder pain are yet unidentified[4].

In the most common age-related shoulder condition, the Subacromial Pain Syndrome (SAPS), repetitive overloading of subacromial tissues during abduction may be the key factor leading to complaints[9-11]. A recent study showed that during abduction, patients with SAPS have significantly less activation of two potent humeral depressors, the latissimus dorsi and teres major, than asymptomatic controls[12]. This finding explains overloading of subacromial tissues in SAPS, but also supports a stabilising function of the latissimus dorsi and teres major in asymptomatic adults that was only recently suggested[13].

Based on the results of this study, we questioned whether adductor co-contraction is always present, or develops during ageing, in which case it may explain the age-related character of age-related shoulder conditions such as SAPS. In this cross-sectional analysis we assessed the effect of age on the degree of latissimus dorsi, teres major and pectoralis major co-contraction in asymptomatic individuals.

PATIENTS AND METHODS

Data of three individual cohorts were combined, resulting in a study population of 60 participants, between 21 and 60 years old, with no current or past shoulder complaints. This age range covers the age at which common non-osteoarthritic shoulder complaints, such as SAPS, generally develop[14]. The first group of twenty participants aged 19 to 50 years was recruited between February 2010 through October 2010[15]. Second, ten asymptomatic participants aged between 35 and 60 years were recruited in September 2012[16]. The third group, comprising thirty asymptomatic participants was evaluated between January 2016 and November 2016. Exclusion criteria were: less than 18 years old, limited range of motion during physical examination, malignancy, neurologic/muscle disease, symptomatic osteoarthritis, rheumatoid arthritis, adhesive capsulitis, diabetes mellitus, previous injury/ fracture or infection of the shoulder, a pacemaker in situ, or insufficient Dutch language skills. Asymptomatic shoulder pathology was not ruled out. All participants were analysed at the laboratory of Kinematics and Neuromechanics (Leiden University medical Centre, Leiden, the Netherlands). The review board of the institutional medical ethical committee approved this study (P09.243, P11.002 and P15.046) and all participants gave written informed consent.

Assessment of muscle activation patterns

We were interested in evaluating the activation patterns of muscles that may translate the humerus cranially (towards the acromion) or caudally (away from the acromion) during abduction. In biomechanical evaluations and a recent systematic review on the topic, it has been shown that the deltoid muscle (DM) is the most potent cranial translator of the humerus during abduction[13,17]. The arm adductors, specifically the latissimus dorsi (LD), teres major (TM), and, to a lesser extent, the pectoralis major (PM), are the strongest caudal translators (humeral depressors) during abduction[13,17]. Of these muscles, the activity during an isometric abduction and adduction task was determined, in order to obtain a standardised degree of task-specific activation. Participants were measured while standing and facing a computer monitor which gave force feedback information. The target arm was in external rotation at the side touching a 1-dimensional force transducer at the wrist. This set-up was previously described in detail[15]. During a resting task and isometric ab- and adduction tasks, electromyography (EMG) of three muscles involved in humeral depression during abduction, i.e., the LD, TM and PM, and the main humeral elevator, i.e., the medial part of the DM was recorded with surface EMG-electrodes (DelSys system Bagnoli-16, Boston, MA, USA, two parallel 10 mm silver bar electrodes, inter-electrode distance 10 mm, bandwidth 20–450 Hz, gain adjusted to 1000)[15]. Electrodes were placed at the middle of the muscle bellies, with the silver bar contacts perpendicular to the muscle fibres. The electrode for the LD was placed 6 cm below the angulus inferior scapulae; for the TM 4 cm cranial and 2 cm lateral to angulus inferior scapulae; for the PM 1 cm below the clavicle and for the DM 2-4 cm below the acromion, laterally. For conductivity, the skin was abraded with scrubbing cream, cleaned with alcohol and conductive cream was applied to the electrode contact bars prior to adherence to the skin. The EMG and force signals were analogue-digital (AD) converted and simultaneously recorded at a sample rate of 2500 Hz with 16-bit resolution. Post-processing of the EMG consisted of offset removal (1Hz recursive low-pass Butterworth filter), rectification and enveloping using the moving average over intervals of 0.1 seconds and averaging to a single value per task ($\mathrm{mEMG}^{\mathrm{IP/OP}}$) through custom made software in Matlab (MathWorks inc., version R2016a, Natick, USA).

For the assessment of muscle activation, participants first performed a maximal abduction and maximal adduction task. The lowest value of either of these maximums was set as the maximum voluntary force (MVF). Subsequently, a target force of 60%

with a tolerance of ± 3.75% of the MVF was presented to the participants on a computer screen[15]. Finally, participants performed a 15-second isometric force task in abduction and adduction where they attempted to exert a force level within the target force tolerances (60% MVF ± 3.75%). The target force level was equal during the abduction and adduction task for the purpose of computing a standardised measure of the degree of antagonistic versus agonistic activation. The mean of the post-processed EMG-data of when the exerted force lied within the target force tolerances ($mEMG^{IP/OP}$) was used for the analyses.

Outcome measure

For this study, we were interested in the degree of adductor activation during abduction, i.e., adductor co-contraction. Analysing the plain EMG-amplitude, hampers comparability between participants and studies and therefore it is preferable to normalise EMG-output. This can be done using the maximum voluntary contraction, however this method may be limited in symptomatic participants due to the unpredictability when pain is present[18]. The EMG-assessment used in the current study has and will be applied in patients with pain, and therefore EMG was standardised using the Activation Ratio (AR) for generalisability (Eq.1)[15].

$$AR_{muscle} = \frac{mEMG^{IP} - mEMG^{OP}}{mEMG^{IP} + mEMG^{OP}} \qquad \textbf{Eq.1}$$

where muscle represents the LD, TM, PM or DM and the superscripts IP and OP indicate ‘in phase’ agonist activation and ‘out of phase’ antagonist muscle activation respectively, in relation to the force task in abduction or adduction.

The AR indicates the task related degree of antagonist activation relative to the same muscle’s degree of agonist activation, and has been proved reliable[15]. The AR ranges between -1 and 1 and equals 1 in case of sole agonist muscle activation and decreases with antagonist muscle activation, i.e., co-contraction, up to -1 with the muscle being solely active as antagonist. An AR = 0 indicates equal activity during the agonist and antagonist task.

In order to prevent overestimation of the degree of co-contraction as assessed with the AR, the post-processed mean EMG-amplitude during the agonistic task ($mEMG^{IP}$, i.e., the activity of the deltoid muscle during abduction and the activity of adductors during adduction) was verified to be twice the mean EMG-amplitude of the 10% lowest EMG-signals during the relative rest, abduction or adduction task (a signal-to-noise ratio of $SNR \geq 2.0$). In case this condition was not met or in case EMG-data was corrupt (e.g., loose electrode), the ARs were excluded.

Statistical analysis

Descriptive statistics

Categorical data are described with numbers and percentages; continuous parameters with means, standard deviation (SD) and 95% confidence intervals (95% CI) or with medians and percentiles depending on the distribution of data. The Statistical Package of Social Sciences (SPSS®) version 23 (IBM® Corp, Armonk, NY, USA) was used for statistical analysis.

The activation ratio, force task and age, were verified to have normal distributions by visual interpretation of histograms. Missing values in activation ratios were verified to be missing completely at random (e.g., loose electrode) or at random (e.g., not meeting the SNR) and imputed with multiple imputation based on the study group, sex, arm dominance, assessment of dominant arm, force task and AR, using 50 iterations, to avoid possible bias, use all available data and increase power[19]. For statistical analyses, we used the pooled results automatically generated by SPSS® in multiple imputed datasets. The analyses were additionally performed on the original database for verification of the results using multiple imputation. Results are presented as intercepts with unstandardised regression estimates and corresponding 95% CI intervals and p-values. A two-sided p-value of 0.05 or less was considered statistically significant.

Association between age and activation ratios

For the primary study question, the association between the independent variable age and dependent variable AR was assessed using linear regression analysis, with controlling for the magnitude of force task, sex and the assessment of the dominant arm (or non-dominant arm).

Mediation analysis

To rule out that a possible association between age and AR was explained by differences in the torque level at which participants performed the measurements, a mediation analysis was performed. This was done using the product-method, where four associations were tested: 1) age and AR, 2) age and force task, 3) force task and AR and 4) age and AR, corrected for force task[20]. If either of the associations assessed in step 1-3 is non-significant, it is unlikely that force task is a mediator[20]. As verification, we assessed whether the unstandardised beta describing the association between age and AR (step 1) changed significantly when controlling for force task (step 4). For this, we calculated the standardised z-score from Eq. 2 and determined the corresponding p-value with standard statistical tables.

$$z = \frac{B1 - B2}{\sqrt{{SE_{B1}}^2 + {SE_{B2}}^2}} \qquad \textbf{Eq.2}$$

Where B1 represents the unstandardised beta from step 1 and B2 the unstandardised beta from step 4. The SE describes the standard errors associated with B1 and B2 respectively.

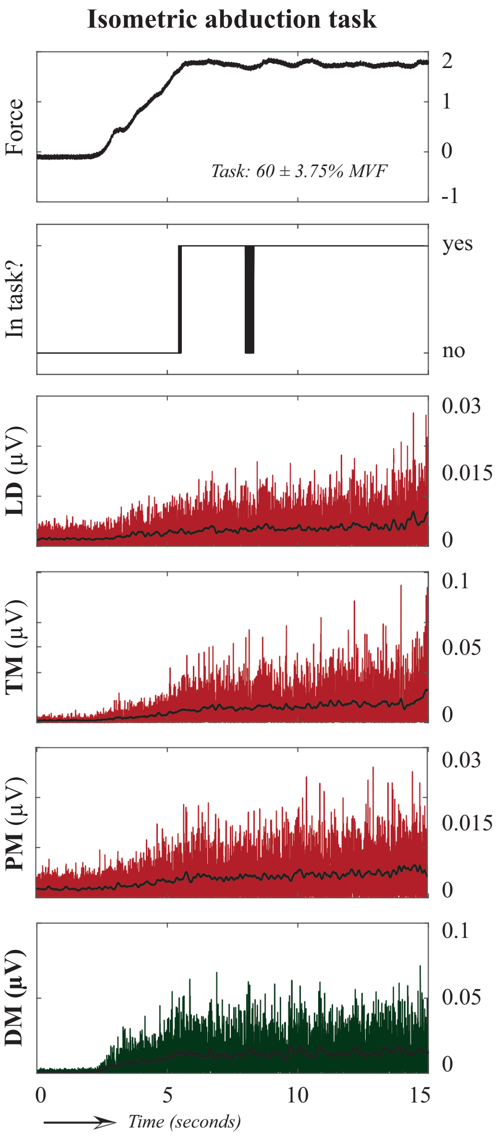

Figure 1 | Rectified and offset-subtracted electromyography during a 15 second isometric abduction force task at 60 ± 3.75% of the Maximal Voluntary Force (*MVF*). The line curve represents the processed signal with which the *activation ratio* is determined. In the latter panel, it is indicated whether patients were in or out of the force task; in-task EMG data was used for the assessment of co-contraction. It shows that with abduction, mainly achieved with deltoid muscle (DM) activation, there is concomitant increased activation of the pectoralis major (PM), latissimus dorsi (LD) and teres major (TM) activation (i.e., co-contraction).

RESULTS

Baseline characteristics of the study group are presented in **Table 1**. Multiple imputation was performed for nine missing values in the activation ratio of the LD (4 due to a technical problem with the amplifier, 4 due to not reaching the SNR and 1 because of a loose electrode); six missing values in the AR of the TM (3 due to a technical problem with the amplifier, 2 due to not reaching the SNR and 1 because of a loose electrode); six missing values in the AR of the PM (4 due to a technical problem with the amplifier, 1 due to not reaching the SNR and 1 because of a loose electrode) and lastly three missing values in the AR of the DM, all due to a technical problem with the amplifier.

Table 1 | Demographics of asymptomatic participants

Demographics	Asymptomatic participants	
Total group (n=60)		
Age, yrs (mean, SD)	42 (13)	Range 21 – 60
Female (n, %)	27	45
Right side dominance (n, %)	50	83
Dominant side assessed (n, %)	45	75
Per group		
Cohort 2010 (n=20)		
Age, yrs (mean, SD)	25 (2.5)	Range 21 – 29
Female (n, %)	5	25
Right side dominance (n, %)	16	80
Dominant side assessed (n, %)	19	95
Cohort 2012 (n=10)		
Age, yrs (mean, SD)	50 (6.6)	Range 39 – 59
Female (n, %)	5	50
Right side dominance (n, %)	10	100
Dominant side assessed (n, %)	10	100
Cohort 2016 (n=30)		
Age, yrs (mean, SD)	51 (5.7)	Range 39 – 60
Female (n, %)	17	57
Right side dominance (n, %)	24	80
Dominant side assessed (n, %)	16	53

SD, standard deviation; n, number; yrs., years; NA, not applicable.

Association between age and activation ratios

A typical example of the raw antagonistic (EMG^{OP}) signals of the LD, TM and PM and raw agonistic (EMG^{IP}) signal of the DM with simultaneously exerted force is presented in **Figure 1**. The associations between age and activation ratio of the LD, TM, PM and DM are illustrated in **Figure 2** and described by the regression models in **Table**

2. For the LD, higher age was associated with lower ARs (-0.004, 95% CI: [-0.007, 0.0], p=0.042). The AR of the TM also decreased with increasing age (-0.013, 95% CI: [-0.019, -0.008], p<0.001). There was no significant association between age and the AR of the PM. Lastly, the AR of the assessed abductor, the DM, decreased with increasing age (-0.003, 95% CI: [-0.005, 0.0], p=0.046), although the regression model did not explain much variance in the AR of the DM (adjusted R^2 of 0.024). Except for an association between male sex and a higher AR of the TM (0.17, 95% CI: [0.015, 0.32], p=0.031), sex the assessment of the dominant arm or the magnitude of force task were not related with the ARs (**Table 2**).

The analyses were performed on the original dataset with missing values and on the imputed dataset and outcomes obtained from the original dataset (**Appendix 1**).

Table 2 | Association between age and activation ratios in asymptomatic participants

	Activation Ratio			
Independent variables	*Estimate*	*95% CI*	*p-value*	*Adjusted R^2*
LD				
Intercept	0.96	(0.77 – 1.2)	–	
Age (years)	-0.004	(-0.007 – 0.00)	**0.042**	
Force task (N)	-0.073	(-0.23 – 0.086)	0.367	0.17
Sex (female is ref.)	0.095	(-0.007 – 0.20)	0.068	
Assessment of dominant arm (yes is ref.)	-0.038	(-0.15 – 0.069)	0.484	
TM				
Intercept	1.2	(0.88 – 1.4)	–	
Age (years)	-0.013	(-0.019 – -0.008)	**<0.001**	
Force task (N)	-0.20	(-0.43 – 0.025)	0.082	0.42
Sex (female is ref.)	0.17	(0.015 – 0.32)	**0.031**	
Assessment of dominant arm (yes is ref.)	0.11	(-0.044 – 0.27)	0.160	
PM				
Intercept	0.75	(0.59 – 0.90)	–	
Age (years)	-0.001	(-0.004 – 0.002)	0.543	
Force task (N)	0.090	(-0.038 – 0.22)	0.169	-0.011
Sex (female is ref.)	-0.002	(-0.087 – 0.084)	0.967	
Assessment of dominant arm (yes is ref.)	0.023	(-0.063 – 0.11)	0.605	
DM				
Intercept	0.98	(0.84 – 1.1)	–	
Age (years)	-0.003	(-0.005 – 0.00)	**0.046**	
Force task (N)	-0.028	(-0.14 – 0.087)	0.635	0.024
Sex (female is ref.)	0.002	(-0.075 – 0.079)	0.965	
Assessment of dominant arm (yes is ref.)	0.034	(-0.042 – 0.11)	0.383	

Multivariable regression analysis with dependent variable *activation ratio* and independent variables *age*, *force task*, *sex* and *assessment of the dominant arm*. LD, latissimus dorsi; TM, teres major; PM, pectoralis major; DM, deltoid muscle. Adjusted R^2 represents the mean adjusted R^2 from multivariable regression analyses with 20 iterations. Significant values at the level of alpha=0.05 are in bold.

Mediation analysis

We did not perform a mediation analysis for the PM since there was no significant relation between the AR of the PM and age (step 1 of mediation analysis). Simple regression analyses between age and force task (0.002, 95% CI: [-0.005, 0.008], p=0.596) and between force task and ARs of the LD (-0.007, 95% CI: [-0.16, 0.14], p=0.928), TM (-0.11, 95% CI: [-0.36, 0.14], p=0.375) and DM (-0.036, 95% CI: [-0.13, 0.062], p=0.476) revealed no significant associations. Furthermore, the changes in non-standardised beta describing the relation between age and AR of the LD, TM or DM after controlling for force task, were negligible (at maximum 1%, all p>0.99). Thus, force task was not a mediator in the association between ARs and age.

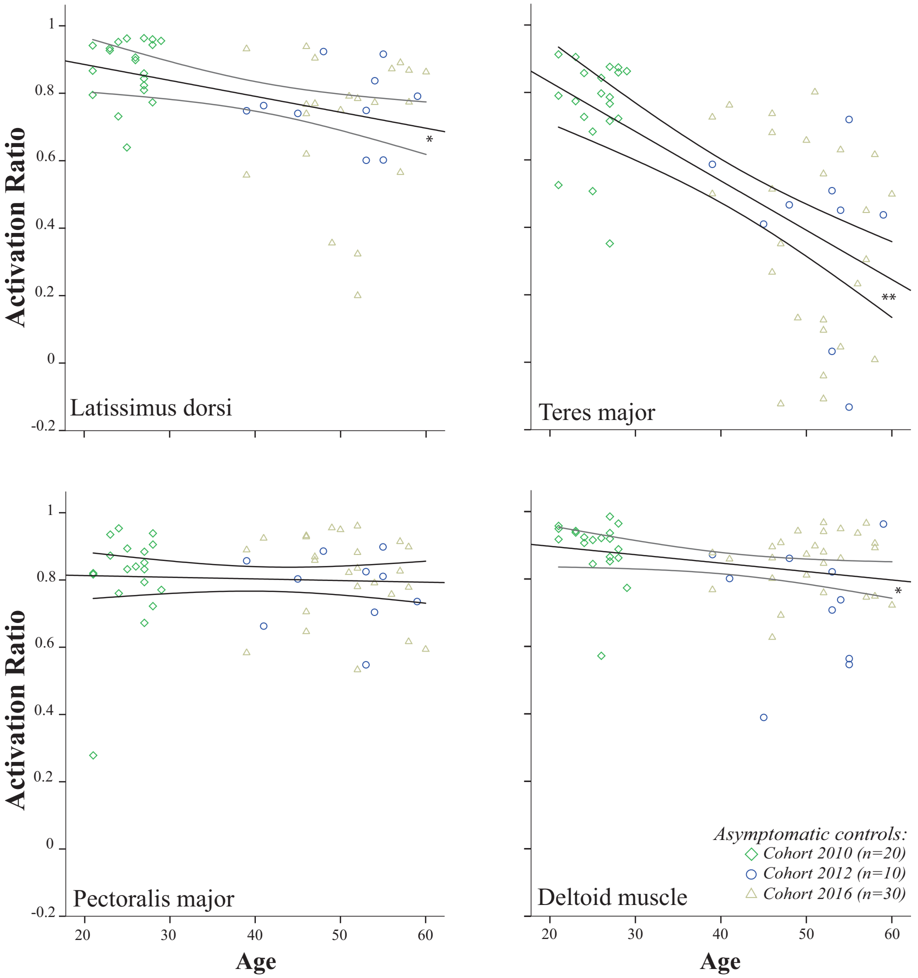

Figure 2 | Association between age and activation ratios in asymptomatic participants. Scatter plot with linear regression line and 95% confidence intervals.

* Significant at the level of alpha=0.05, ** Significant at the level of alpha=0.01

DISCUSSION

In this cross-sectional evaluation we found that during abduction young adults did not co-contract with arm adductors whereas middle-aged individuals did. This age-related increase in adductor co-contraction suggests that during ageing, counteraction of cranial deltoid forces and thus glenohumeral stabilisation, becomes more reliant on adductor co-contraction.

There have been no previous studies on the effect of ageing on adductor muscle activation during abduction. In biomechanical evaluations and a recent systematic review on the topic, it was shown that the arm adductors, specifically the latissimus dorsi, teres major, and, to a lesser extent, the pectoralis major, have the greatest contribution to humeral-head depression during arm abduction[13,17]. We suggest that the age-related increase in adductor co-contraction observed in our study may represent a compensation for reduced rotator cuff quality, loss of proprioception as well as altered bone morphology in the ageing shoulder, that is necessary for preserving shoulder stability and function[4,6,21-25].

Our study has some limitations. First, three previously recruited cohorts were combined for this study. Except for age, the selection criteria as well as measurement procedures were the same across these cohorts and therefore, we do not think bias was introduced by the design. This may also be interpreted from Figure 1 where no clustering by cohorts is recognisable. Second, 24 activation ratios were missing (10%), which was in 58% (14 activation ratios) due to a technical problem with the amplifier. There was also missing data (7 in total, 29%), because the mean agonistic EMG amplitude did not exceed the signal to noise ratio. In order to avoid bias and use all available data in the analyses, these missing values were imputed using multiple imputation[19]. The conclusions obtained from the dataset with missing values and the imputed dataset were similar although the p-value associated with the effect of age on the activation ratio of the LD was no longer significant in the dataset with missing values, possibly because of reduced power. Lastly, we only evaluated a selection of muscles that affect the craniocaudal position of the humerus the most[13,17,26]. Our conclusion may be supported by adding an analysis of other adductors, for example, the teres minor and lower parts of the infraspinatus and subscapularis.

Previously, it has been shown that patients with the age-related shoulder condition SAPS have reduced activation of the latissimus dorsi and teres major during abduction[12]. As these adductors are crucial for depressing the humerus (away from the acromion), this finding explained overloading of subacromial tissues and thereby pain in patients with SAPS[12,27]. Following this line of reasoning, our finding of increased adductor co-contraction during ageing in asymptomatic participants, could explain the age-related character of SAPS.

CONCLUSION

In this cross-sectional evaluation of muscles that directly act on the position of the humerus relative to the scapula, we found that in contrast to young individuals, middle-aged individuals have a high degree of teres major and latissimus dorsi activity during abduction. It was previously suggested that next to the rotator cuff, these two adductor muscles have a crucial contribution to counteracting deltoid forces, depressing the humerus and ensuring free passage of subacromial tissues underneath the acromion during abduction[13]. The age-related increase in adductor co-contraction observed in our study, suggests a shift in muscle activation patterns during ageing, that may be crucial for maintaining pain-free shoulder function. In a future study it should be tested whether inability to make this shift may contribute to the onset of age-related shoulder conditions like SAPS.

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Appendix

Appendix 1 | Association between age and activation ratios in asymptomatic participants examined in original dataset

	Activation Ratio			
Independent variables	*Estimate*	*95% CI*	*p-value*	*Adjusted R^2*
LD				
Intercept	0.94	(0.74 – 1.1)	–	
Age (years)	-0.003	(-0.007 – 0.000)	0.064	
Force task (N)	-0.051	(-0.22 – 0.12)	0.544	0.14
Sex (female is ref.)	0.091	(-0.013 – 0.20)	0.085	
Assessment of dominant arm (yes is ref.)	-0.045	(-0.16 – 0.066)	0.421	
TM				
Intercept	1.2	(0.89 – 1.4)	–	
Age (years)	-0.014	(-0.019 – -0.009)	**<0.001**	
Force task (N)	-0.18	(-0.41 – 0.044)	0.112	0.43
Sex (female is ref.)	0.15	(-0.0 – 0.31)	0.051	
Assessment of dominant arm (yes is ref.)	0.11	(-0.052 – 0.27)	0.183	
PM				
Intercept	0.74	(0.58 – 0.90)	–	
Age (years)	-0.001	(-0.004 – 0.002)	0.560	
Force task (N)	0.092	(-0.042 – 0.23)	0.174	-0.018
Sex (female is ref.)	-0.0	(-0.089 – 0.090)	0.991	
Assessment of dominant arm (yes is ref.)	0.027	(-0.062 – 0.12)	0.547	
DM				
Intercept	0.98	(0.84 – 1.1)	–	
Age (years)	-0.003	(-0.006 – 0.00)	**0.041**	
Force task (N)	-0.028	(-0.15 – 0.090)	0.632	0.028
Sex (female is ref.)	0.003	(-0.076 – 0.082)	0.940	
Assessment of dominant arm (yes is ref.)	0.041	(-0.038 – 0.12)	0.303	

Multivariable regression analysis with dependent variable *activation ratio* and independent variables *age*, *force task*, *sex* and *assessment of the dominant arm* on the original dataset without imputed values. LD, latissimus dorsi; TM, teres major; PM, pectoralis major; DM, deltoid muscle. Significant values at the level of alpha=0.05 are in bold.