Implications on older women of age- and sex-related differences in activation patterns of shoulder muscles: A cross-sectional study

Cristina Lirio-Romero, Christoph Anders, Pedro De La Villa-Polo & María Torres-Lacomba

Published online: 25 Sep 2018.

Submit your article to this journal

View Crossmark data

Routledge
Taylor & Francis Group

Check for updates

Implications on older women of age- and sex-related differences in activation patterns of shoulder muscles: A cross-sectional study

Cristina Lirio-Romero[a], Christoph Anders[b], Pedro De La Villa-Polo[c], and María Torres-Lacomba[d]

[a]Department of Physical Therapy, State Center of Attention to Brain Injury, Madrid, Spain; [b]Division of Motor Research, Pathophysiology and Biomechanics, Clinic for Trauma, Hand and Reconstructive Surgery, Jena University Hospital, Jena, Germany; [c]Department of Systems Biology, University of Alcalá, Madrid, Spain; [d]Physiotherapy in Women´s Health Research Group, Department of Physical Therapy, University of Alcalá, Madrid, Spain

ABSTRACT

We conducted a cross-sectional study to assess differences in neuromotor attributes of shoulder muscles between age groups in both sexes and to better understand functional disorders in older women. Twenty young (20–42 years old), 20 middle-aged (43–67), and 20 older (> 68) adults participated in a comparative surface-electromyography study of five muscles. We identified age-related differences in women, especially in scapula stabilizer muscles. There was a tendency for both sexes of delayed onset times with increasing age, excepting the upper trapezius muscle in females. The results highlight the importance of understanding musculoskeletal aging in women to adequately guide physical therapeutic approaches.

Introduction

Age-related changes in the musculoskeletal system greatly impact activities of daily living, reducing quality of life (Walker-Bone, Palmer, Reading, Coggon, & Cooper, 2004). Declines in muscle function start at mid-adulthood (> 50 years old) and significantly progress in people beyond their 70s (Taylor & Johnson, 2008). Skeletal muscles decline progressively with age: A decrease in muscle mass, especially of Type II fibers, is accompanied by a decrease in strength, as well as an increase in muscle weakness (the strength per unit of a muscle's cross-sectional area) (Ohlendieck, 2011). Further, any age-related decline in muscle function is also the result of altered neural factors such as muscle recruitment (Faulkner, Larkin, Claflin, & Brooks, 2007). These changes are a natural part of aging, and the condition that begins developing past the sixth decade or earlier is

CONTACT María Torres-Lacomba ✉ maria.torres@uah.es 🖂 FPSM Research Group, University of Alcalá, External Campus, High Road Madrid-Barcelona, Km. 33,600, Alcalá de Henares 28871, Madrid, Spain

Cristina Lirio-Romero and Christoph Anders are both first authors; they contributed equally to this study.
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/wjwa.

defined clinically as geriatric sarcopenia. The European Working Group on sarcopenia in older people (EWGSOP) describes it as "a syndrome characterized by progressive and generalized loss of skeletal muscle mass and strength with a risk of adverse outcomes such as physical disability, poor quality of life and death" [sic] (Cruz-Jentoft et al., 2010). Up to now evidence is still needed relating neuromuscular factors to the occurrence of this geriatric syndrome. With the world population aging, it is important to establish normative data related to sarcopenia in the hopes of improving diagnosis, treatment, and prevention to lessen suffering and the burden on health and social service systems (Carbonell-Baeza, García-Molina, & Delgado-Fernández, 2009).

The effect of aging on muscle mass for men and women does not occur at the same rate. Women lose muscle mass and strength earlier, around menopause (Phillips, Rook, Siddle, Bruce, & Woledge, 1993), since menopausal loss of ovarian function has been suggested as a contributing factor to aging-related muscle deterioration (Laakkonen et al., 2017). Even though in older women musculoskeletal dysfunction of the shoulder is prominent, it is not thoroughly characterized or understood. Decreased shoulder muscle function limits the use of the arms and hands for activities of daily living, impairs balance, and increases fall risk. Moreover, if the lower extremities decline, the arms are vital as auxiliary support for ambulation (Raz et al., 2015). To facilitate diagnosis and further research, it is interesting to know how the active stability of the shoulder appears at different ages and between sexes using myoelectrical assessment. In this regard, it should be noted that the normal recruitment pattern of periarticular shoulder muscles has already been objectified in healthy adults using electromyographic analysis (Wickham, Pizzari, Stansfeld, Burnside, & Watson, 2010). An understanding of physiological age-related alterations of shoulder muscle activity may help in the development of more specifically targeted physical therapies that focus on restoring or maintaining age-appropriate motor recruitment patterns and proper shoulder mobility in older women.

Regarding sex differences, features in body composition in men and women explain force differences (Perissinotto, Pisent, Sergi, Grigoletto, & Enzi, 2002), suggesting that due to their higher muscle mass men have greater force levels that are retained with aging (da Silva et al., 2016). Furthermore, men and women are characterized by a different fiber-type distribution with smaller cross-sectional area, especially of type II fibers in women (Mannion et al., 1997), suggesting that age-related changes in muscle recruitment patterns also differ between sexes.

For the assessment of shoulder function, abduction is a commonly applied movement. During abduction, the scapula is in a favorable position since the passive scapulothoracic forces do not require metabolic energy (Veeger & Van Der Helm, 2007). There is agreement on the statement that abduction

provides useful and reliable information about the quality and motion control of the upper limb (Kapanji, 2007).

The analysis of muscle recruitment patterns has often been used to understand functional changes in muscles due to diverse diseases. Surface electromyography (sEMG) is considered an appropriate tool for kinesiologic analysis of movement disorders (De Luca, 1997; Pullman, Goodin, Marquinez, Tabbal, & Rubin, 2000). The electromyographic signal represents the electric voltage generated by muscle contraction evoked by neuromuscular activity (Reaz, Hussain, & Mohd-Yasin, 2006). To obtain reliable data it is essential to minimize the influence of factors on the sEMG, such as cross talk, movement artifacts, noise from the electrical current supply, and skin contact impedance, which can be addressed and reduced by correct electrode type and placement and signal filters (Villarroya-Aparicio, 2005). Physical therapists are increasingly using sEMG to better understand the function and dysfunction of the neuromuscular system (Soderberg & Knutson, 2000).

In the present study, muscle recruitment patterns were analyzed during shoulder abduction to precisely identify age- and sex-related functional differences. We hypothesized that the neuromuscular activity at a submaximal force level of 70%–80% of maximum isometric voluntary contraction (MIVC) during glenohumeral abduction in healthy older women would show lower values than men and if compared to middle-aged and young adults. Moreover, we anticipated a delay in the onset latency in older women, all due to neuromuscular changes of the normal aging process such as muscle weakness or alterations in transmissions (Magnoni, Govoni, Battaini, & Trabucchi, 1991; Taylor & Johnson, 2008). The aim of this study was to provide data during shoulder abduction in healthy adults of different age groups and sexes and facilitate functional shoulder diagnostics to improve women's geriatric physical therapy management.

Methods

Study design

We conducted a cross-sectional descriptive study (Registration: NCT02974452 https://register.clinicaltrials.gov/) in which the sEMG activity of the upper trapezius (UT), middle deltoid (MD), infraspinatus (IS), lower trapezius (LT), and serratus anterior (SA) muscles was compared in three age groups: older adults (OA), middle-aged adults (MA), and young adults (YA). All study participants were fully aware of the study purpose, participated voluntarily, and signed the informed consent. The Ethics Committee for Clinical Research at the University of Alcalá (Madrid, Spain) approved the study (2012/038/01/20,120,924).

Participants

Participants came from the Ocaña Senior Center (Toledo, Spain) and voluntarily participated after reading an ad about the need to recruit healthy people for a research study. They participated from December 2015 to January 2016 at the Teaching Assistant and Research Unit in Physical Therapy in the University of Alcalá and the Ocaña Senior Center. A physical therapist conducted the electromyographic tests.

Sixty participants, with no previously manifested symptoms in the shoulder joint and/or the neck during the past year, were selected and assigned to the respective age groups: (a) older than 68 years old (OA), (b) 43 to 67 years old (MA), and (c) 20 to 42 years old (YA) (Newman & Newman, 2017; Petry, 2002). We excluded potential participants who showed signs of moderate or severe cognitive impairment, rheumatologic diseases, massive osteoarthritis, tumors, shoulder joint instability, circulatory disorders (hemophilia clotting problems), and dermatological problems exacerbated by
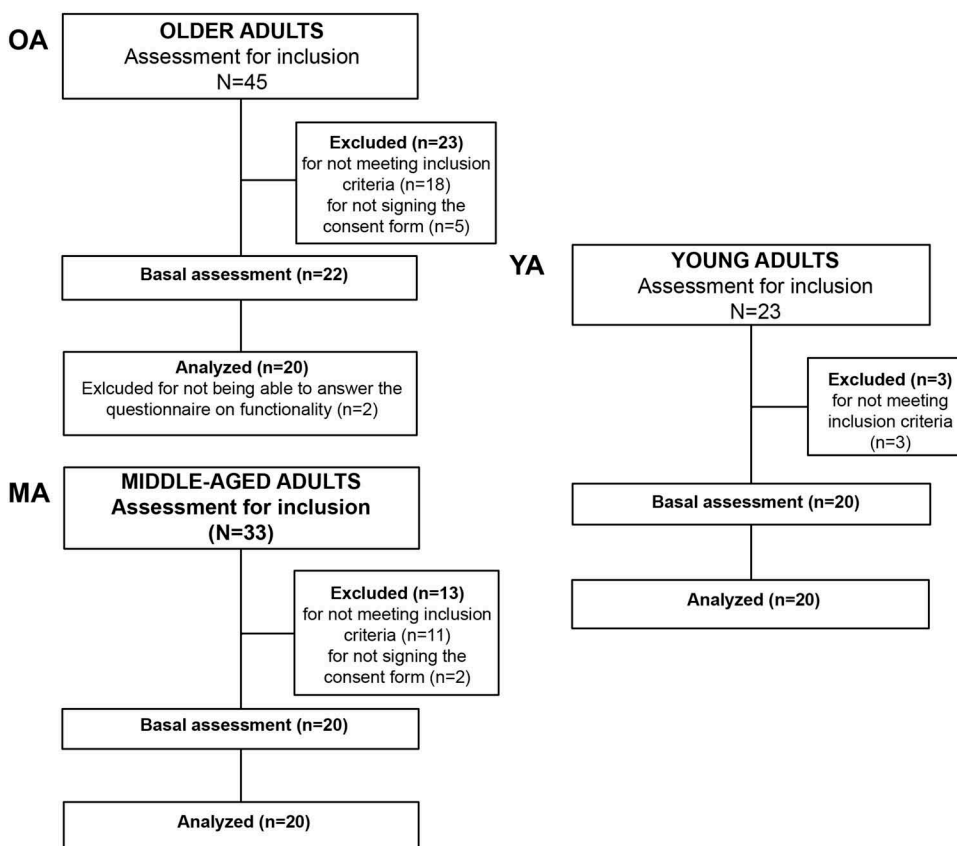

Figure 1. Flow diagram of participants: OA; MA; YA.

contact with skin were excluded from the study. The flowchart of participation and interventions carried out throughout the study is shown in Figure 1.

Measurement

The shoulder abduction movement functionally involves the deltoid, rotator cuff (supraspinatus, infraspinatus, teres minor, and subscapularis muscles), trapezius, serratus anterior, and spinal muscles. Depending on their phase of displacement, function differs. Up to 45° of glenohumeral abduction, the agonists are the middle deltoid and supraspinatus muscles. The rotator cuff stabilizes the glenohumeral joint, while trapezius and serratus anterior muscles stabilize the scapula (Kapanji, 2007). Therefore, for measurement of abduction up to 45°, we measured the electromyographic activity of UT, MD, and IS, representing the rotator cuff, and LT and SA to assess scapula stabilization of the dominant side (Sainburg & Kalakanis, 2000).

For determination of MIVC force values, participants held a dynamometer (Çelik, Dirican, & Baltaci, 2012) while maintaining an upright standing position with back against a wall and arm in neutral position (with the arm close to the body and the palm of the hand toward the body). To detect the MIVC the participants elevated the arm up to 45° of glenohumeral abduction. The handheld dynamometer was placed on the forearm at middle distance between wrist and elbow. This position was marked for reliable dynamometer positioning during the submaximal tests. Then participants isometrically abducted their arm at maximum effort while the dynamometer was firmly fixed by the physical therapist. Participants repeated this three times, and the average value was further used to determine the submaximal contraction level of 70%–80% of the MIVC. The submaximal isometric contraction was assessed after abducting the unloaded arm within about 2 seconds from 0° to 45° abduction (Ashour, 2014). Abduction displacement was captured by the electronic goniometer.

For the submaximal tests the physical therapist coached the participants to perform an isometric glenohumeral abduction of 45° for 5 seconds using the handheld dynamometer to score the respective submaximal force level. During these tests, sEMG data were recorded of all investigated muscles (Figure 2). This procedure was repeated three times (between-trial intervals of 2 minutes), and the average sEMG values were then used for analysis (Andersen, Christensen, Samani, & Madeleine, 2014; Çelik et al., 2012).

The surface electromyograph used was a PowerLab 15T from ADInstruments, Oxford, UK. An experienced physical therapist placed sEMG electrodes for exact positioning (Figure 3). Conductive adhesive hydrogel surface (27 mm) disk electrodes (Kendall[TM] 100 Series Foam Electrodes, Covidien, Massachusetts, USA) were used utilizing an interelectrode distance of 30 mm. The skin was alcohol cleaned and electrodes were placed at the midline of the
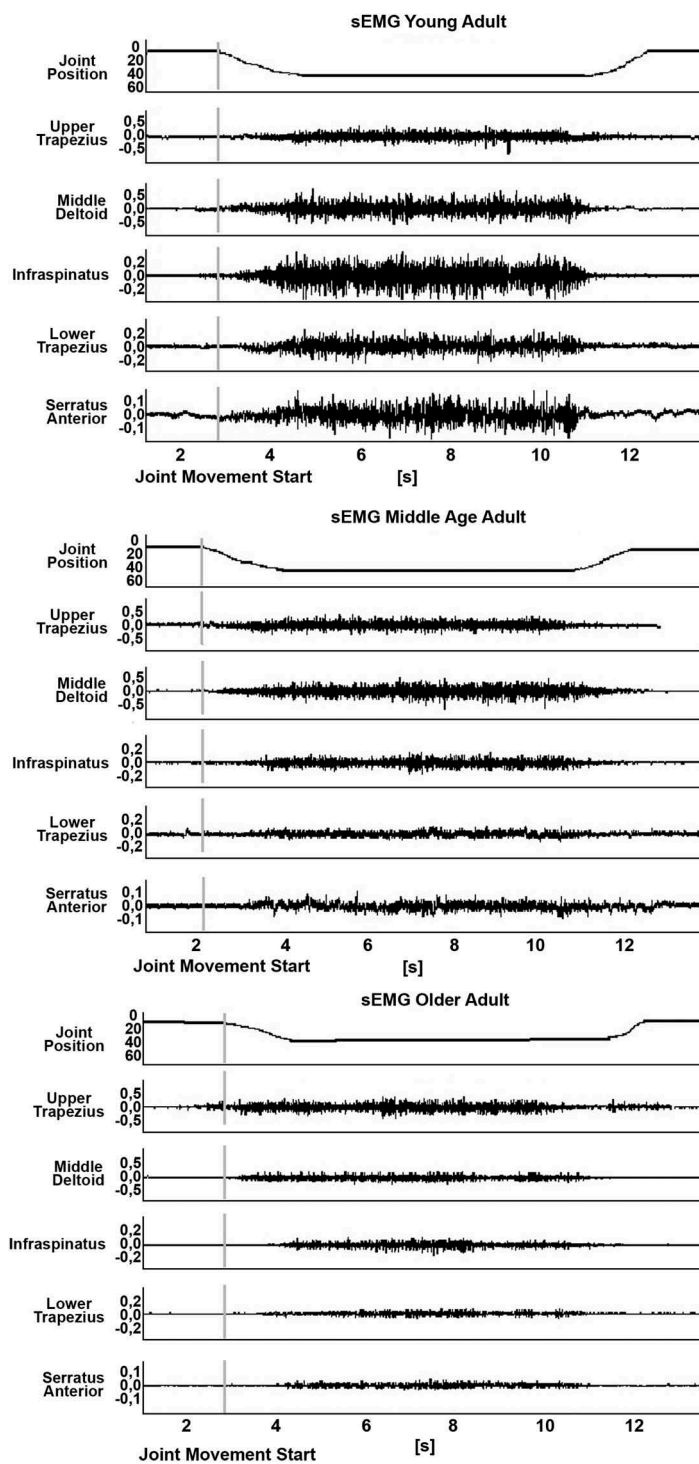
Figure 2. Raw sEMG recordings obtained from one representative participant from OA (older adults), one from MA (middle-aged adults), and one from YA (young adults), displaying the abduction movement (from 0° to 45°). A total of five muscles were recorded simultaneously (indicated to the left).
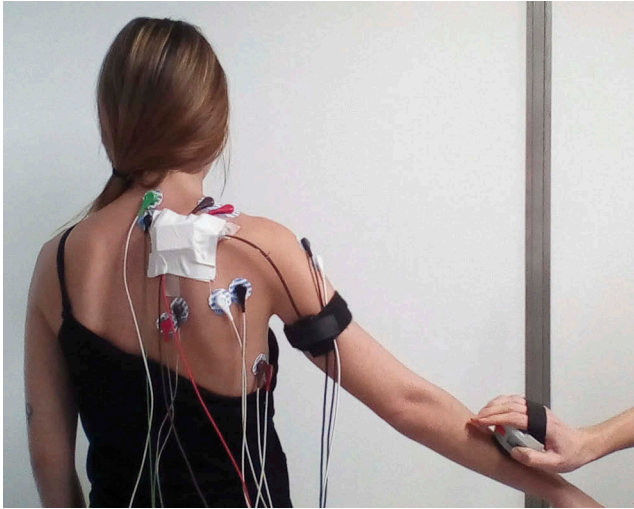
Figure 3. Electrode placement and sEMG recording position.

respective muscle belly, aligned along the muscle fibers. In addition, ground electrodes were placed on bony sites (processus spinosus C6, C7, and the posterior part of the acromion). The electrical goniometer (MLTS700, ADInstruments, Oxford, UK) was placed so that one sensor was fixed on top of the scapula and the other at the back of the arm at an angle of 90° between both sensors and preset to the 0° position (i.e., neutral position) on the sEMG registration software (Figure 2). Adhesive tape was used to secure the electrodes and wires. sEMG (gain: 1,000) and goniometric signals were simultaneously sampled at a rate of 1,000 samples per second, using a 16-bit AD-Converter. sEMG signals were band pass filtered (10–500 Hz, 8th Bessel filter) to improve signal/noise ratio (Hermens et al., 1999).

The sEMG data were captured simultaneously on a PC by using the LabChart® software (ADInstruments, Oxford, UK). Within the time interval from 2 to 4 seconds after contraction initiation (i.e., the submaximal isometric contraction), the mean RMS values were automatically obtained from the software. Muscle onset latency values were obtained from graphical analyses that included the simultaneously registered sEMG and arm displacement data. The latency was determined as the time distance of the intercept between the linearly interpolated RMS slope and the preactivation level relative to the onset of arm displacement (Villarroya-Aparicio, 2005; Wickham et al., 2010).

Variables

We determined demographic variables, i.e., age, sex, body mass index, dominant limb, and previous physical therapy treatments.

The analyzed clinical variables were glenohumeral range of motion (ROM) and the shoulder disability questionnaire. For ROM measurements we used a universal goniometer (Enraf Nonius Ibérica®) and included glenohumeral flexion, external and internal rotation, and abduction. The shoulder disability questionnaire was used to assess shoulder functionality (Alvarez-Nemegyei, Puerto-Ceballos, Guzman-Hau, Bassol-Perea, & Nuno-Gutierrez, 2005). The shoulder disability questionnaire is widely used in research and clinical practice in several countries. Its score ranges from 0 (no functional limitation) to 100 (affirmative to all items), so higher scores mean higher disability.

We determined the MIVC at 45° abduction (Andersen et al., 2014) by applying a handheld dynamometer (MicroFET®2, Hoggan Health Industries, West Jordan, Utah, USA). These data served as reference values to determine the submaximal isometric contraction levels that were defined between 70% and 80% of the respective MIVC level. During this test, we did not measure sEMG. We recorded the sEMG signal during glenohumeral abduction movement, and from this signal we calculated the root mean square (RMS) value (μV) and latency of muscle contraction onset(s). To predict the sequence and initiation of the joint movement, we captured joint angles simultaneously with the sEMG data. By this, the time lag between the contraction initiation of each muscle and the start of the abduction movement was determined (Villarroya-Aparicio, 2005).

We used the RMS value to assess muscular electrical activity as amplitude estimation (Villarroya-Aparicio, 2005; Hermens et al., 1999). The onset latency specifies the activation order of the different muscles involved and thus contributes to a better understanding of the shoulder recruitment patterns (Phadke, Camargo, & Ludewig, 2009; Wickham et al., 2010).

Sample size

We calculated sample size by taking into account the differences in MIVC levels among the three groups. Considering three groups of 20 participants each and assuming an intersubject standard deviation of 30 units (within-group), in the ANOVA a standard deviation of 15.1 could be detected between groups with 80% of power and type-I error of 0.05. Moreover, assuming identical within-group variations and power, a difference of 32 units between any pair of groups in a post hoc analysis is necessary to detect group differences if the Bonferroni correction is applied.

Statistical analysis

We analyzed data using IBM SPSS Statistics 20 for Windows (SPSS Inc., 2011). Normal distribution was tested with the Shapiro–Wilks test. As measures of central tendency, the mean and standard deviations were

estimated in the normally distributed variables and the median and inter-quartile range in the nonnormally distributed variables. Significant differences in motor recruitment between OA, MA, and YA as well as differences between males and females were calculated using univariate ANOVAs and Kruskal–Wallis tests. For the univariate ANOVA, also bilateral interactions including the respective profile plots between the main factors were considered for analysis and interpretation of the results. Multiple comparisons using either t-tests or Mann Whitney U-tests were Bonferroni corrected (significance $p < .017$). A confidence interval of 95% for each estimator was used.

Results

All participants who gave their consent were assessed (see flowchart in Figure 1).

Age-related differences

Demographic and clinical data
Independent of sex, we observed statistically significant differences between age groups in body mass index ($p < .01$, YA < MA = OA) and MIVC together with active ROM for flexion, external rotation, and abduction ($p < .01$, YA > MA = OA) as well as number of previous physical therapies ($p < .05$, YA < MA = OA). Active ROM for internal rotation showed no significant differences between age groups.

   Table 1 shows the respective values separately for males and females. MIVC levels differed significantly between age groups in males ($p < .01$, YA > MA = OA). Conversely, females' MIVC levels were not affected by age. Additionally, women exhibited significant differences in body mass index ($p < .01$, YA < MA = OA) as well as active ROM for flexion together with external rotation ($p < .05$, YA > MA) and abduction ($p < .05$, YA > MA> OA). Concerning males, there were differences among age groups in body mass index ($p < .05$, YA < OA), previous physical therapy treatments ($p < .05$, YA < MA), and active ROM for flexion ($p < .01$, YA > MA) and external rotation ($p < .01$, YA > MA = OA).

sEMG amplitudes
According to the univariate ANOVA independent of the muscle, RMS values were generally influenced by age group, showing a progressive decrease with increasing age in all analyzed muscles ($p < .01$). Multiple comparisons also exposed a significant difference in all muscles ($p < .01$, YA > OA). In addition, DM, IS, and SA muscles differed between YA and MA ($p < .01$, YA > MA).

Table 1. Demographic and clinical characteristics of the participants, age- and sex-related differences.

Characteristics	Women (n = 31)				Men (n = 29)			
	OA (n = 13)	MA (n = 10)	YA (n = 8)	†p value	OA (n = 7)	MA (n = 10)	YA (n = 12)	†p value
Dominant limb: right, n (%)	13 (100)	10 (100)	8 (100)	–	6 (86)	9 (90)	12 (100)	.47
Previous physical therapy treatments: yes, n (%)	5 (39)	4 (40)	0 (0)	.12	0 (0)	4 (40)	0 (0)	.01[b]
Body mass index: kg/m*m, mean (SD)	29.6 (4.0)	26.1 (2.1)	21.7* (2.6)	< .01[b, c]	29.1 (3.6)	28.3 (4.3)	25.1* (2.1)	.03[c]
MVIC: newton, mean (SD)	71 (20.9)	91.9 (38.1)	94.7* (38.6)	< .01[b,c]	29.1 (36.6)	92.8 (26.6)	157.6* (30.4)	< .01[b]
Shoulder functionality Score: points, median (Per)	12.5* (0–12.5)	0 (0–14.1)	0 (0–4.7)	.25	0* (0–0)	0 (0–1.6)	0 (0–0)	.72
ROM Gh flexion: °, mean (SD)	150.4 (11.1)	157.0* (8.6)	165.6 (11.8)	.01[b]	154.3 (9.3)	148.0* (4.8)	161.7 (6.2)	< .01[b]
ROM Gh internal rotation: °, mean (SD)	70.0 (11.7)	76.5* (11.1)	71.9 (12.5)	.42	67.1 (13.2)	64.0* (14.3)	72.9 (9.4)	.24
ROM Gh external rotation: °, mean (SD)	70.0 (14.9)	79.0 (19.8)	88.1 (5.3)	.04[b]	77.1 (7.6)	72.0 (12.3)	87.9 (4.0)	< .01[b, c]
ROM Gh abduction: °, mean (SD)	148.1 (10.5)	153.5* (11.6)	169.4 (11.5)	< .01[a,b]	150.7 (12.1)	143.5* (4.1)	162.1 (7.0)	< .01

Note. Abbreviations: OA = older adults; YA = young adults; MA = middle-aged adults; ROM = Range of motion; MVIC = Maximum isometric voluntary contraction; Gh = Glenohumeral; SD = standard deviation; Per = percentile (25–75).

†p value obtained by χ^2 test, ANOVA, and Kruskal–Wallis test.

*Differences between women and men (p < .05).

[a]Differences between OA and MA; [b]differences between MA and YA; [c]differences between OA and YA.

In detail age-related differences in each sex include the following: (a) the UT, MD, and SA muscle amplitudes did not differ between age groups in the males, but RMS values of these muscles differed for the females ($p < .01$, YA > MA = OA); (b) IS showed higher amplitudes in YA compared to OA and MA in both sexes (males: $p < .05$, females: $p < .01$); (c) for LT no significant differences between the age groups could be identified in both sexes (see Figure 4).

Onset times

With respect to onset times, the performed Kruskal-Wallis tests showed progressively delayed onset latencies with age for each analyzed muscle in the glenohumeral abduction, except for the UT muscle (Table 2). The delay in the onset times was significantly different between age groups for IS ($p < .05$, YA < OA) and in the scapula stabilizers, LT and SA ($p < .01$, YA < OA). SA muscle showed significant differences between MA and OA groups ($p < .05$, MA < OA). Indeed, in half of the older adults SA muscle was recruited more than one second later than the initiation of the joint movement. Interestingly, UT muscle latency decreased with increasing age and was the first muscle to be recruited in OA and MA, even before the start of the joint movement, but not in YA. However, onset time differences in UT muscle were not statistically significant between age groups. In addition, all observed differences in muscle onset times resulted in recruitment order differences between age groups. In females the delay in muscle contraction onset showed significant differences for LT and SA muscles ($p < .01$, YA < OA). Males showed significant differences in MD muscle latencies ($p = 0.01$, YA < OA).

Sex-related differences

Demographic and clinical data

As for the sex differences of the clinical variables, significant differences occurred in OA for shoulder functionality ($p < .05$, females > males); in MA for flexion, internal rotation, and abduction ($p < .05$, females > males); and in YA for body mass index ($p < .01$, males > females). MIVC only showed significant sex differences in YA ($p < .01$, males > females (see Figure 5)).

sEMG amplitudes

There were sex differences in RMS value in MA for UT ($p = .01$) and LT ($p = .02$) muscles (always males > females). In contrast, RMS values of females significantly exceeded those of the males for SA in YA ($p < .05$; see Figure 4).
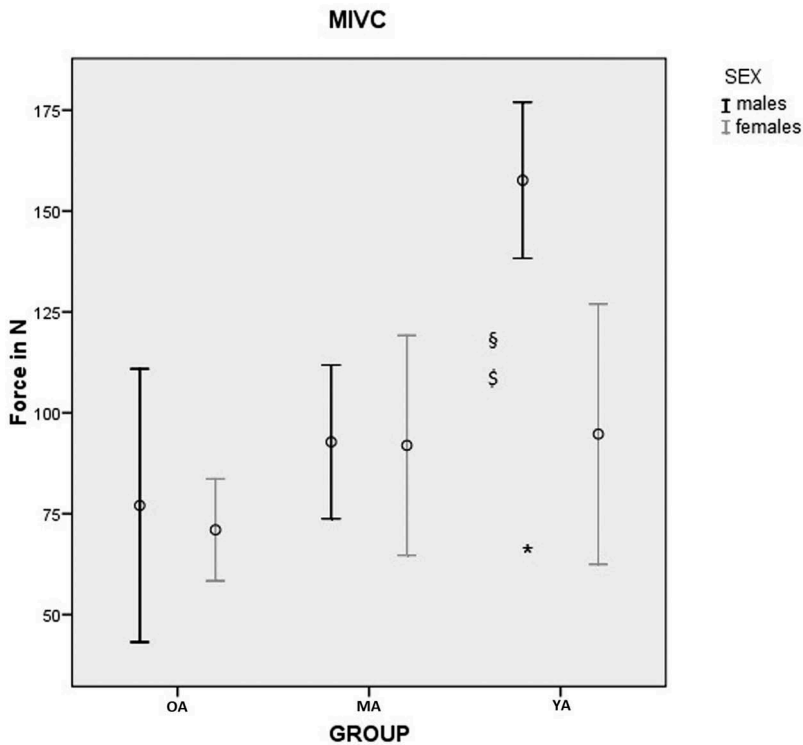
Figure 4. MIVC interactions between groups and sexes.*p < .05 between sexes; §p < .05 YA vs. OA; Ṡ p < .05 YA vs. MA.

**Table 2.** Comparison of RMS values and onset latencies between age groups (pooled for both sexes).

Variables	OA (n = 20)	MA (n = 20)	YA (n = 20)	p value[†]
RMS, µV mean (SD)				
Upper trapezius	138 (84)	198 (142)	292 (175)	< .01[c]
Middle deltoid	214 (88)	246 (111)	531 (294)	< .01[b, c]
Infraspinatus	72 (32)	90 (47)	184 (69)	< .01[b, c]
Lower trapezius	74 (35)	75 (56)	119 (85)	.04[c]
Serratus anterior	43 (22)	47 (29)	125 (123)	< .01[b, c]
Onset time, ms median (percentile 25–75)				
Upper trapezius	−.250 (−500 to 0)	−230 (−500 to 0)	−50 (−200 to 0)	.29
Middle deltoid	0 (−240 to 200)	−100 (−300 to 290)	−200 (−450 to −50)	.06
Infraspinatus	650 (210 to 1400)	500 (0 to 1150)	200 (−80 to 650)	.04[c]
Lower trapezius	1150 (580 to 1500)	550 (80 to 1080)	400 (0 to 780)	.01[c]
Serratus anterior	1600 (500 to 2210)	750 (0 to 1230)	100 (0 to 930)	< .01[c]

Note. Abbreviations: OA = older adults; YA = young adults; MA = middle-aged adults; RMS = root mean square.
[†]p value obtained by ANOVA and Kruskal-Wallis test.
[a]Differences between OA and MA; [b]differences between MA and YA; [c]differences between OA and YA.
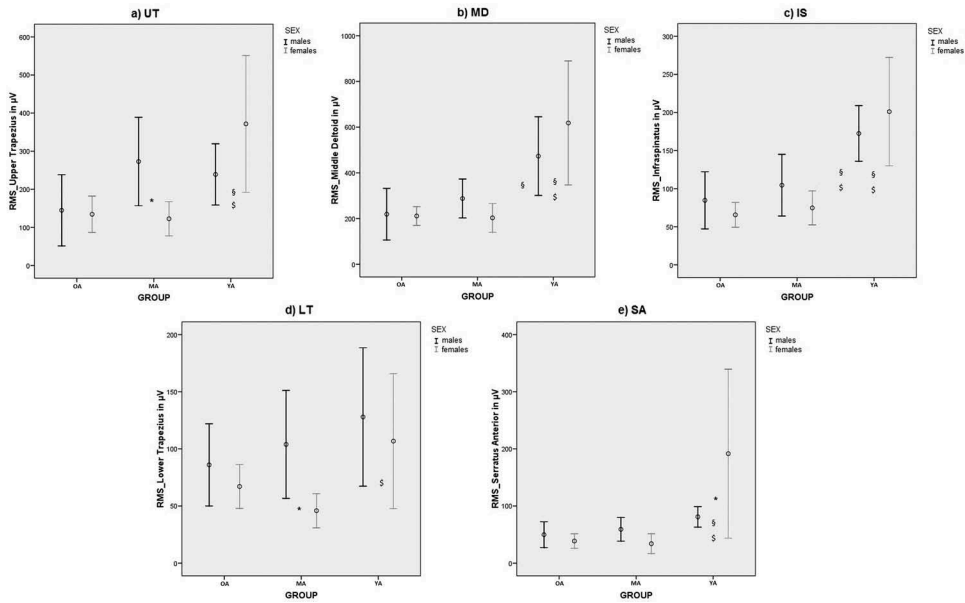
Figure 5. RMS values for each muscle. Data are displayed separately for every group and sex. *$p < .05$ between sexes; §$p < .05$ YA vs. OA; Ṩ $p < .05$ YA vs. MA.

Onset time

According to the present study, female versus male comparisons in onset latencies showed statistical significance in OA for UT and MD ($p < .05$, females < males) and MD in MA ($p < .05$, females < males).

Discussion

The current report presents a study that systematically investigated differences between age and sex groups on the activation characteristics of shoulder muscles during glenohumeral abduction. The main outcome measures were sEMG amplitudes and onset times. Clinical variables were also considered. In general, MA and OA groups showed lower sEMG amplitudes during isometric abduction in comparison with YA. With increasing age, the latency relative to the arm displacement in most analyzed onset times was found to be prolonged in both sexes. Age-related differences in shoulder ROM were found only if comparing YA with the two other groups but not between MA and OA. The body mass index showed differences between age groups in both sexes, especially between YA and MA in females. As for the sex differences of the clinical variables, significant differences were found in OA for shoulder functionality and in MA with respect to ROM (flexion, internal rotation, abduction). These data support observations that older females exhibit a tendency toward a decreased ROM, an increase of body

mass, and a progressive decrease in shoulder functionality (Wahlstedt, Norbäck, Wieslander, Skoglund, & Runeson, 2010). The loss of muscle mass has been related to the loss of function (strength or performance), and the function may be related to the range of motion (Eriks-Hoogland, de Groot, Post, & van der Woude, 2011). In addition to the age, it would be appropriate for the hormonal status to be considered. Although in this study we have not asked about the hormonal status, taking into account that the MA group included women between 43 and 67 years old, this group could then include women in premenopausal, menopausal, and postmenopausal conditions. Menopausal condition has been suggested as a contributing factor to aging-related muscle deterioration and BMI increase. Menopause entails a decline in estrogen and, consequently, a decline of growth hormone, dehydroepiandrosterone, and insulin-like growth factor-1, all related negatively with muscle mass. This could also have influenced the women's groups results, especially those between YA and MA groups (Maltais, Desroches, & Dionne, 2009). To differentiate if those changes are due to menopause or age remains difficult to address.

Sex differences of muscle fibers and force levels

Generally, the fiber type distribution is similar between the sexes, but women have a considerably smaller cross-sectional area, especially of type II fibers (Lindman, Eriksson, & Thornell, 1991) in comparison with men (Mannion et al., 1997). Independent of sex, the number of muscle fibers decreases with increasing age and predominantly affects type II fibers. This may help to explain patterns of age-related differences and must be understood as a secondary effect due to a decrease of the number of motoneurons (Faulkner et al., 2007).

With respect to MIVC levels, sex differences could only be statistically proven in YA with higher force levels in males. With increasing age, males showed a continuous decrease, while the respective force levels of the female participants remained almost unaffected by age. This fact is again in agreement with the mentioned characteristics of sex-specific age-related differences in fiber types and could be confirmed by other authors (Svendsen & Madeleine, 2010). Anthropometric features help to explain force differences between age groups as well as between sexes (Perissinotto et al., 2002), in which the results showed greater force and better aerobic capacity in males than females (Faber, Hansen, & Christensen, 2006).

sEMG amplitudes

According to RMS, amplitude measures only provide a crude estimation of the neural drive and contain no information about the muscle force.

Consequently, differences in RMS levels cannot directly be related with differences in force capacity (Farina, Merletti, & Enoka, 2014; Villarroya-Aparicio, 2005). In order to better understand the found age-related variations, it is essential to consider other degenerative peculiarities, such as changes of fiber type composition, decrease of fiber size together with its cross-sectional area (Doherty, 2003), and the replacement of contractile structures by connective tissue or fat that already starts at mid-adulthood (Merletti, Farina, Gazzoni, & Schieroni, 2002).

Males and females also showed diverging amplitude differences with aging. Since the glenohumeral abduction was performed at a 45° abduction angle, the leading agonist muscle is MD along with the supraspinatus (Kapanji, 2007). For the MD, no differences between sexes have been found, but the results showed a progressive amplitude decrease with age that is in agreement with the previously mentioned studies about age-related changes of muscles. This was more pronounced in females (Lindman et al., 1991; Mannion et al., 1997). The IS, during abduction, mainly balances the MD-caused cranial displacement of the humerus, while at the same time it also controls for external rotation of the humerus (Sahrmann, 2010). Not surprisingly, it behaved similar to the MD, showing the same progressive amplitude decline with age that was slightly more pronounced in females.

This tendency was not observed in the other investigated muscles: UT, LT, and SA, which at a 45° abduction angle work as scapula stabilizers (Kapanji, 2007), did not show this tendency. In women, both trapezius muscle parts (UT and LT) showed significantly lower amplitude levels in MA compared with YA. In contrast, no systematic age-related effects could be observed in trapezius muscle in the male participants, who also showed superior amplitude levels in comparison with women in MA. As females are known to show less activation of muscles acting in the main force direction (Anders, Bretschneider, Bernsdorf, Erler, & Schneider, 2004), and at the same time active synergistic muscles were generally more activated in women than in men, the actual results argue for age-related alterations of this feature, since it could be proven in YA but not in the other groups.

Continuing with scapular stabilizers, the SA muscle only showed significant differences between sexes in YA that was lower in males. Anders et al. (2004) also reported that males, despite generally showing higher amplitudes in muscles acting along the force vector, showed less coactivation of stabilizing muscles in isometric shoulder requirements. Conversely, that is not in agreement with females in this study, who expressed an evident decrease of RMS value of MA compared with YA. This may be interpreted since, in spite of the fact that women demonstrated more scapula stability, there is a tendency of losing it with increasing age, probably due to the decline in muscle mass and the atrophy of type II muscular fibers generated in menopause and postmenopausal conditions (Deane et al., 2017; Maltais et al.,

2009). Similar findings of a decrease in SA muscle activity have also been observed as an altered pattern in shoulder pathologies (Phadke et al., 2009). In this regard, the results in the SA muscle in the present study may be distorted by the elevated body mass index in MA in females that shows regional differences of subcutaneous fat location, particularly localized at the trunk, coinciding with the location of SA muscle (Nordander et al., 2003).

Onset latencies

The onset latency was significantly different between age groups in three of the five analyzed muscles, but sex only slightly influenced onset latency analysis. UT anticipation with age is a remarkable finding in both sexes that corresponds with the tendency to compensate the reduced stability of LT and SA. This is in agreement with previous studies that investigated altered patterns in shoulder injuries (Phadke et al., 2009).

With regard to sex differences, the present study could only find significant differences in UT and MD muscles in OA and in MD in MA, always with earlier onset times in the females. Rohr (2006) found opposite results by testing specific movements, and they could prove that females seemed to use strategies resulting in greater precision that also could be explained by a greater proportion of type I fibers.

The present study could show that the SA muscle, acting as the main scapula stabilizer muscle, showed a significant loss of recruitment and a delay in the onset of contraction with aging that further differed between sexes. These findings together with the decrease of RMS values confirm the known tendency of reduced scapular stability that may underlie certain shoulder disorders, such as upper crossed syndrome, impingement, and rotator cuff tendinopathies; which are known to occur more frequently with increasing age in women (Cruz-Jentoft et al., 2010; Larsson, Søgaard, & Rosendal, 2007). For this reason, the actual findings provide a guide for geriatric physical therapy to prevent the appearance of shoulder pathologies with increasing age, as well as to facilitate the management of the treatment of shoulder disorders, requiring special attention to strengthen the scapular stabilizer muscles. In the present study, UT anticipation seems to be a compensatory pattern with respect to the delay of SA and LT onset, which provides further arguments as to why females may suffer from negative effects of this anticipation due to their greater number of type I or slow-twitch fibers. Therefore, females may need special consideration regarding the prevention of shoulder injuries with increasing age. The potential effect of resistance exercise (Asikainen, Kukkonen-Harjula, & Miilunpalo, 2004) (and hormone replacement therapy and/or vitamin D supplementation: Maltais et al., 2009) could prevent the appearance of shoulder pathologies with increasing age, as well as facilitate the management of the treatment of shoulder disorders. In this

sense, literature shows some discrepant findings regarding resistance exercise, hormonal therapy, and Vitamine D supplementation. More high-quality work is needed to support their benefits, especially on overweight and obese adults (Deane et al., 2017).

Physical therapists may in the future pay special attention to strengthening the scapular stabilizer muscles in both men and women, with special attention on women.

Limitations

In the present study, sEMG was used as a reliable in vivo method to determine functional characteristics (i.e., amplitude and timing) of shoulder muscles. The study design took into account the problems inherent in sEMG measurement (Nordander et al., 2003; Villarroya-Aparicio, 2005). Limitations have been previously mentioned and taken into account throughout this cross-sectional study. Another limitation could be the sample size calculation that only considered different age groups but did not anticipate sex differences. For detecting differences in some parameters with respect to sex, the study may be underpowered. Finally, for a better results interpretation, more information about the current pharmacological intake of participants would be needed.

Clinical implications and future research directions

Motor recruitment patterns of shoulder muscles suffer alterations with age in women differently than in men. In general, a loss in muscle recruitment and a delay in the onset time of muscle contraction have been found with increasing age. Important sex differences could be identified in muscles that stabilize the scapula during glenohumeral abduction, affecting mainly females. Moreover, a more extensive registration of any pharmacological treatment should be considered in sex-related comparison studies, including vitamin D supplementation, hormone therapy, or oral contraceptives to assess a possible influence on the results. Furthermore, the findings provide hints for the prevention or therapy of certain shoulder pathologies observed in women's aging: Physical therapy might focus on strengthening the scapula stabilizer muscles, SA, and LT. However, the presented results are far from being indisputable or complete and may therefore draw interest to the launch of related studies.

References

Alvarez-Nemegyei, J., Puerto-Ceballos, I., Guzman-Hau, W., Bassol-Perea, A., & Nuno-Gutierrez, B. L. (2005). Development of a spanish-language version of the shoulder disability questionnaire. *Journal of Clinical Rheumatology: Practical Reports on Rheumatic & Musculoskeletal Diseases*, *11*(4), 185–187. doi:10.1097/01.rhu.0000173229.50674.31

Anders, C., Bretschneider, S., Bernsdorf, A., Erler, K., & Schneider, W. (2004). Activation of shoulder muscles in healthy men and women under isometric conditions. *Journal of Electromyography and Kinesiology*, *14*(6), 699–707. doi:10.1016/j.jelekin.2004.04.003

Andersen, K. S., Christensen, B. H., Samani, A., & Madeleine, P. (2014). Between-day reliability of a hand-held dynamometer and surface electromyography recordings during isometric submaximal contractions in different shoulder positions. *Journal of Electromyography and Kinesiology*, *24*(5), 579–587. doi:10.1016/j.jelekin.2014.05.007

Ashour, A. A. (2014). Relationship between isometric muscle force and surface EMG of wrist muscles at different shoulder and elbow angles. *Journal of American Science*, *10*(5), 26-34.

Asikainen, T. M., Kukkonen-Harjula, K., & Miilunpalo, S. (2004). Exercise for health for early postmenopausal women: A systematic review of randomised controlled trials. *Sports Medicine*, *34*, 753–778.

Carbonell-Baeza, A., García-Molina, V. A., & Delgado-Fernández, M. (2009). Involución de la condición física por el envejecimiento. *Apunts.Medicina De L'Esport*, *44*(162), 98–103. doi:10.1016/S1886-6581(09)70115-X

Çelik, D., Dirican, A., & Baltaci, G. (2012). Intrarater reliability of assessing strength of the shoulder and scapular muscles. *Journal of Sport Rehabilitation*, *29*, 1–5.

Cruz-Jentoft, A. J., Baeyens, J. P., Bauer, J. M., Boirie, Y., Cederholm, T., Landi, F., ... Topinkosà, E. European Working Group on Sarcopenia in Older People. (2010). Sarcopenia: European consensus on definition and diagnosis: Report of the european working group on sarcopenia in older people. *Age and Ageing*, *39*(4), 412–423. doi:10.1093/ageing/afq034

da Silva, A. P., Matos, A., Valente, A., Gil, Â., Alonso, I., Ribeiro, R., ... Gorjão-Clara, J. (2016). Body composition assessment and nutritional status evaluation in men and women portuguese centenarians. *The Journal of Nutrition, Health & Aging*, *3*(20), 256–266. doi:10.1007/s12603-015-0566-0

De Luca, C. J. (1997). The use of surface electromyography in biomechanics. *Journal of Applied Biomechanics*, 13, 135–163. doi:10.1123/jab.13.2.135

Deane, C. S., Wilkinson, D. J., Phillips, B. E., Smith, K., Etheridge, T., & Atherton, P. J. (2017). Nutraceuticals in relation to human skeletal muscle and exercise. *American Journal of Physiology. Endocrinology and Metabolism*, 312, E282–E299. doi:10.1152/ajpendo.00230.2016

Doherty, T. J. (2003). Invited review: Aging and sarcopenia. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 95(4), 1717–1727. doi:10.1152/japplphysiol.00347.2003

Eriks-Hoogland, I. E., de Groot, S., Post, M. W., & van der Woude, L. H. (2011). Correlation of shoulder range of motion limitations at discharge with limitations in activities and participation one year later in persons with spinal cord injury. *Journal Rehabilitation Medicine*, 43(3), 210–215. doi:10.2340/16501977-0655

Faber, A., Hansen, K., & Christensen, H. (2006). Muscle strength and aerobic capacity in a representative sample of employees with and without repetitive monotonous work. *International Archives of Occupational and Environmental Health*, 79(1), 33–41. doi:10.1007/s00420-005-0025-z

Farina, D., Merletti, R., & Enoka, R. M. (2014). The extraction of neural strategies from the surface EMG: An update. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, 117(11), 1215–1230. doi:10.1152/japplphysiol.00162.2014

Faulkner, J. A., Larkin, L. M., Claflin, D. R., & Brooks, S. V. (2007). Age-related changes in the structure and function of skeletal muscles. *Clinical and Experimental Pharmacology and Physiology*, 34(11), 1091–1096. doi:10.1111/j.1440-1681.2007.04752.x

Hermens, H. J., Freriks, B., Merletti, R., Stegeman, D. F., Blok, J., & Rau, G. (1999). European recommendations for surface electromyography, results of the SENIAM project. *Enschede: Roessingh Research and Development*, 8(2), 13–54.

Kapanji, A. (2007). *The physiology of the joints, vol. 1, the upper limb*. Edingburgh, UK: Churchill Livingstone.

Laakkonen, E. K., Soliymani, R., Karvinen, S., Kaprio, J., Kujala, U. M., Baumann, M., … Lalowski, M. (2017). Estrogenic regulation of skeletal muscle proteome: A study of pre-menopausal women and postmenopausal MZ cotwins discordant for hormonal therapy. *Aging Cell*, 16(6), 1276–1287. doi:10.1111/acel.12661

Larsson, B., Søgaard, K., & Rosendal, L. (2007). Work related neck–Shoulder pain: A review on magnitude, risk factors, biochemical characteristics, clinical picture and preventive interventions. *Best Practice & Research Clinical Rheumatology*, 21(3), 447–463. doi:10.1016/j.berh.2007.02.015

Lindman, R., Eriksson, A., & Thornell, L. (1991). Fiber type composition of the human female trapezius muscle: Enzyme-histochemical characteristics. *American Journal of Anatomy*, 190(4), 385–392. doi:10.1002/aja.1001900406

Magnoni, M., Govoni, S., Battaini, F., & Trabucchi, M. (1991). The aging brain: Protein phosphorylation as a target of changes in neuronal function. *Life Sciences*, 48(5), 373–385.

Maltais, M. L., Desroches, J., & Dionne, I. J. (2009). Changes in muscle mass and strength after menopause. *Journal of Musculoskeletal & Neuronal Interactions*, 9(4), 186–197.

Mannion, A. F., Dumas, G. A., Cooper, R. G., Espinosa, F., Faris, M. W., & Stevenson, J. M. (1997). Muscle fibre size and type distribution in thoracic and lumbar regions of erector spinae in healthy subjects without low back pain: Normal values and sex differences. *Journal of Anatomy*, 190(4), 505–513.

Merletti, R., Farina, D., Gazzoni, M., & Schieroni, M. P. (2002). Effect of age on muscle functions investigated with surface electromyography. *Muscle & Nerve*, 25(1), 65–76. doi:10.1002/(ISSN)1097-4598

Newman, B. M., & Newman, P. R. (2017). *Development through life: A psychosocial approach*. Boston, MA: Cengage learning.

Nordander, C., Willner, J., Hansson, G., Larsson, B., Unge, J., Granquist, L., & Skerfving, S. (2003). Influence of the subcutaneous fat layer, as measured by ultrasound, skinfold calipers and BMI, on the EMG amplitude. *European Journal of Applied Physiology*, 89(6), 514–519. doi:10.1007/s00421-003-0819-1

Ohlendieck, K. (2011). Proteomic profiling of fast-to-slow muscle transitions during aging. *Frontiers in Physiology*, 2, 105.

Perissinotto, E., Pisent, C., Sergi, G., Grigoletto, F., & Enzi, G. (2002). Anthropometric measurements in the elderly: Age and gender differences. *British Journal of Nutrition*, 87 (02), 177–186.

Petry, N. M. (2002). A comparison of young, middle-aged, and older adult treatment-seeking pathological gamblers. *The Gerontologist*, 42(1), 92–99.

Phadke, V., Camargo, P., & Ludewig, P. (2009). Scapular and rotator cuff muscle activity during arm elevation: A review of normal function and alterations with shoulder impingement. *Brazilian Journal of Physical Therapy*, 13(1), 1–9. doi:10.1590/S1413-35552009005000012

Phillips, S. K., Rook, K. M., Siddle, N. C., Bruce, S. A., & Woledge, R. C. (1993). Muscle weakness in women occurs at an earlier age than in men, but strength is preserved by hormone replacement therapy. *Clinical Science*, 84(1), 95–98.

Pullman, S. L., Goodin, D. S., Marquinez, A. I., Tabbal, S., & Rubin, M. (2000). Clinical utility of surface EMG: Report of the therapeutics and technology assessment subcommittee of the american academy of neurology. *Neurology*, 55(2), 171–177.

Raz, Y., Henseler, J. F., Kolk, A., Riaz, M., van der Zwaal, P., Nagels, J., ... Raz, V. (2015). Patterns of age-associated degeneration differ in shoulder muscles. *Frontiers in Aging Neuroscience*, 7. doi:10.3389/fnagi.2015.00236

Reaz, M., Hussain, M., & Mohd-Yasin, F. (2006). Techniques of EMG signal analysis: Detection, processing, classification and applications. *Biological Procedures Online*, 8(1), 11–35. doi:10.1251/bpo115

Rohr, L. E. (2006). Gender-specific movement strategies using a computer-pointing task. *Journal of Motor Behavior*, 38(6), 431–437. doi:10.3200/JMBR.38.6.431-137

Sahrmann, S. (2010). *Movement system impairment syndromes of the extremities, cervical and thoracic spines*. St. Louis, MO: Mosby.

Sainburg, R. L., & Kalakanis, D. (2000). Differences in control of limb dynamics during dominant and nondominant arm reaching. *Journal of Neurophysiology*, 83(5), 2661–2675. doi:10.1152/jn.2000.83.5.2661

Soderberg, G. L., & Knutson, L. M. (2000). A guide for use and interpretation of kinesiologic electromyographic data. *Physical Therapy*, 80(5), 485–498.

SPSS, I. (2011). *20.0 for Windows*. Computer software. Chicago, IL: SPSS Inc.

Svendsen, J. H., & Madeleine, P. (2010). Amount and structure of force variability during short, ramp and sustained contractions in males and females. *Human Movement Science*, 29(1), 35–47. doi:10.1016/j.humov.2009.09.001

Taylor, A. W., & Johnson, M. J. (2008). *Physiology of exercise and healthy aging*. Champaign, IL: Human Kinetics.

Veeger, H., & Van Der Helm, F. (2007). Shoulder function: The perfect compromise between mobility and stability. *Journal of Biomechanics*, 40(10), 2119–2129. doi:10.1016/j.jbiomech.2006.10.016

Villarroya-Aparicio, M. (2005). Electromiografía cinesiológica. *Rehabilitación*, 39(6), 255–264. doi:10.1016/S0048-7120(05)74359-0

Wahlstedt, K., Norbäck, D., Wieslander, G., Skoglund, L., & Runeson, R. (2010). Psychosocial and ergonomic factors, and their relation to musculoskeletal complaints in the swedish workforce. *International Journal of Occupational Safety and Ergonomics*, *16*(3), 311–321. doi:10.1080/10803548.2010.11076848

Walker-Bone, K., Palmer, K. T., Reading, I., Coggon, D., & Cooper, C. (2004). Prevalence and impact of musculoskeletal disorders of the upper limb in the general population. *Arthritis Care & Research*, *51*(4), 642–651. doi:10.1002/art.20535

Wickham, J., Pizzari, T., Stansfeld, K., Burnside, A., & Watson, L. (2010). Quantifying 'normal'shoulder muscle activity during abduction. *Journal of Electromyography and Kinesiology*, *20*(2), 212–222. doi:10.1016/j.jelekin.2009.06.004