Gender Differences in Shoulder Performance Fatiguability are Affected by Arm Position, Dominance and Muscle Group

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Abstract

Background: Injury prevalence data, muscle strength, and fatiguability have shown differences between males and females. In addition, arm spatial orientation affects muscle activation and strength of the shoulder muscles, but little to no research has been conducted in relation to the shoulder rotator muscles comparing men and women. Therefore, the main aim of of this study was to perform a comparative investigation between two arm spatial orientations (45° and 90° of abduction in frontal plane) during a fatigue assessment of shoulder internal rotator (IR) and external rotator (ER) muscles. Secondly, the interaction of gender and dominance with muscular performance was assessed.

Methods: Forty healthy sedentary participants, 20 males and 20 females took part in this study. Participants performed a fatigue resistance protocol consisting of 30 consecutive maximal concentric contractions of the IR and ER shoulder muscles in a supine position at a speed of 180°/s. The upper limb was abducted to an angle of 45° or 90° in frontal plane and each subject was tested on dominant and nom-dominant side, counterbalanced in order of administration. Performance measures of Induced Fatigue (IF), Cumulated Performance (C.Perf) and Best repetition (BR) were calculated and used for further analysis.

Results: There was a significant difference in angle, with higher values observed in 90° of abduction compared to 45° of abduction for C.Perf by 6% and 7% for BR ($P < 0.0005$) in the ER. The dominant arm was significantly higher than the non-dominant arm for C.Perf with higher values of 9.7% at 90° of abduction compared to 45° of abduction ($P = 0.017$) and BR with higher values of 4.2% at 90° of abduction compared to 45° of abduction ($P < 0.0005$) in the ER in males. There was a significant difference in muscle group, with higher values observed in the IR for C.Perf (88.2%), BR (22.5%) and IF (36.9%); at 90° of abduction compared to 45° of abduction in males ($P < 0.0005$). Significantly higher values were observed for C.Perf in females between the dominant and non-dominant arm for the IR and ER ($P < 0.0005$). The females showed significantly lower values for C.Perf (47.74-55.10%) and BR (47.30-53.41%) in both muscle groups, both testing positions and in both limbs, when compared to males ($P < 0.05$)

Discussion: It was established that an increase in the abduction angle will influence the strength of ER muscles in favour of the 90° angle without any differences observed in IR muscles. Males were found to produce approximately double the amount of work done compared to females, but the amount of induced fatigue was no different between both groups.

Conclusion: Therefore, these findings are useful for clinicians throughout the monitoring of rehabilitation programs in sedentary individuals following shoulder injuries.

Background

The use of isokinetic dynamometry has been widely used by clinicians and scientists to assess muscular performance of different muscle groups [1–3], as obtained data can be objectively used for the diagnosis, the evaluation and the monitoring of specific rehabilitation and training programs. It has previously been established that muscular fatigue negatively affects human performance as a result of a reduction of the muscular force generating capacity that occurs during repetitive muscular contractions [4, 5] Fatigue in the shoulder rotator muscles has been shown to have implications for the upper limb activity [5, 6] and further been linked with sub-acromial impingement injury [7]. Injury prevalence data has indicated that females are at higher risk than their male counterparts when it comes to musculoskeletal disorders in the shoulder area in a sedentary population [8, 9].

Isokinetic assessments of the internal rotators (IR) and external rotators (ER) in the shoulder have previously been investigated to assess muscular performance [10–12]. The utilisation of the isokinetic machine to asses the fatigue resistance of shoulder rotator muscles using different protocols has demonstrated very high reproducibility [13–15]. However, considering the large differences between previously utilised protocols, it renders difficult for clinicians to compare between studies. Differences wich have been previously been observed in muscle strength between IR and ER muscles are due to muscle size differences [14, 16], with further differences also observed between arm abduction angles [17].

Therefore, current observations within the literature clearly establish that differences between testing positions greatly influence the properties of muscular strength [11, 17], highlighting the need for the fatigue assessment protocol to be reproducible [3, 14, 18]. Previous research has found that the optimal position for isokinetic assessment of the shoulder rotators muscles' strength was in a supine position with the arm abducted in a frontal plane, at an angle of 45° or 90° [17]. A recent investigation conducted by Horobeanu et al. [14] established that lying in a supine position with the arm abducted in a frontal plane is a suitable and reliable option for assessing shoulder rotators fatigue resistance as well, irrespective of arm abduction amounts to 45° or 90°. However, a study conducted by Golebiewska et al. [19] found that an increase in the abduction angle in frontal plane from 45° to 90°, provoked a decrease in torque values, thus stressing the importance for more research to be conducted within this area.

Considering previous findings that 30 consecutive maximal concentric contractions on the shoulder IR and ER muscles in a supine position at a speed of 180°/s, with the upper limb abducted to an angle of 45° or 90° in frontal plane is a reliable and valid protocol to assess fatigue resistance, there is still a lack of understanding whether differences would still be present in a testing population assessing differences between males and females, in the dominant and non-dominant limb. Differences have previously been established between males and females but seem to be highly dependent on body part (e.g. ankle, arms, lower back) and type of muscle contractions (e.g. isometric or isotonic) utilised [20, 21]. Therefore, due to the diversity of assessment protocols used it is very difficult for clinicians to establish whether assessment of shoulder rotator muscles fatigue resistance would yield similar results as other body limbs. In addition, previous findings related to limb dominance effects on muscular performance as a result of fatigue differ and are not well established [22, 23].

To our knowledge there is no work investigating the influence of arm spatial orientation (in frontal plane) on shoulder rotators performance during a fatigue resistance assessment considering differences between genders and arm-dominance. We consider this type of evaluation to be of interest for scientists involved in overhead sport disciplines and clinicians engaged in treating different shoulder pathologies. Assessments of the shoulder muscular performance and aspects of functional dynamic stability, by incorporating fatigue, is useful for clinicians and can help with the set-up and monitoring of specific rehabilitation programs and provide a clearer understanding in relation to injury in a sedentary population

Therefore, the main aim of this study was to perform a comparative investigation of muscular performance, between two arm spatial orientations (45 and 90 of abduction in frontal plane), during an isokinetic fatigue resistance assessment of the shoulder rotator muscles. The second aim was to assess the possible interactions of gender and dominance taking into account the muscular performance of both IR and ER.

Materials And Methods

Design

A cross-sectional design was used to compare muscular performance in the shoulder rotator muscles following a fatigue resistance assessment between males and females.

Participants

Forty sedentary young adults, of which 20 males (mean ± SD: age 23.6 ± 2.3 yrs, height 1.79 ± 0.06 m and body mass 72.5 ± 10.7 kg) and 20 females (mean ± SD: age 22.1 ± 1.8 yrs, height 1.66 ± 0.06 m and body mass 58.7 ± 7.4 kg) volunteered for this study. None of the participants were involved in regular upper arm activities or presented with a history of upper extremity bone fractures and/or a history of musculoskeletal abnormality; and none of the participants were receiving any pharmacological treatment during this study. Female participants required to meet the following criteria: a) have consistent, “normal” menstrual cycles during the last 3 months; b) report no use of any hormonal contraceptive use during the last 3 months; c) have been menstruating over the last 12 months; d) tests were performed during the luteal phase of the menstrual cycle. All participants were free to live a “normal life” between testing sessions. They were told to refrain from drinking alcoholic or caffeinated beverages and from training or heavy exertion 48 h prior to each experiment.

Verbal explanation of the experimental procedure was provided to each individual; this included the aims of the study, the possible risks associated with participation and the experimental procedures to be utilized. Any questions were answered. Individuals then provided written, informed consent before participating in the study. The experimental procedures were approved by the Human Ethics Committee at the Faculté de Médecine, Université de Liège. The study was conducted in accordance with the ethical standards of the journal and complied with the Declaration of Helsinki. All the participants used in the study were right-hand dominant, except for 2 female and 4 male participants.

Procedure

All sessions took place under standard laboratory conditions. Before taking part in the main experiment, each participant completed one familiarisation session. This session ensured that participants were fully familiarised with the experimental conditions required for the study. They were required to perform as many repetitions until they felt comfortable performing maximal concentric contractions on the dominant and non-dominant shoulder at speeds of 120°/s and 180°/s. Following the familiarisation process, all participants then completed two identical experimental sessions which took place 10 days apart to minimize any learning effect and to exclude any muscle soreness.

Prior to the experimental session, the subjects undertook a standardised warm-up consisting of 2 sets of 20 IR and 20 ER using an elastic band attached to a fixed point allowing the elbow to be bent at 90° and be maintained close to the body. After comfortable positioning on the machine, the subjects were asked to undertake a task-specific warm up consisting of 10 gradual repetitions at 120°/s and 3 sub-maximal repetitions at 180°/s. Participants were then allowed a 3-min rest period after which they performed the fatigue resistance protocol consisting of 30 consecutive maximal concentric contractions of the shoulder IR and ER muscles in a supine position at a speed of 180°/s. The upper limb was abducted to an angle of 45° or 90° in frontal plane and each subject was tested on dominant and nom-dominant side, which were counterbalanced in order of administration. All measurements were performed by the same investigator using the same dynamometer (Biodex Medical Systems, Shirley, New York). The range of movement was pre-set on every occasion to mimic the testing conditions; 70° for ER and 50° for IR. All participants confirmed to be comfortable and pain free during both sessions. Standardised strong verbal encouragement was given during all sessions

Outcome measures

The work (in Joule) during each repetition (*x*) was computed and used to calculate the performance individually for following parameters: 1) Induced fatigue (IF); 2) Cumulated Performance (C.Perf); and 3) Best repetition (BR). The following formulas have been used for calculations:

1. IF (%)– represents the difference between the amount of work done over the last 3 and first 3 repetitions:

$$IF = \left(\left(\frac{average\ work\ done\ during\ last\ 3\ reps}{average\ work\ done\ during\ first\ 3\ reps} \right) \text{x } 100 \right) \text{-}100$$

2. Perf (J) – represents the total amount of work done during all repetitions:

$$C.Perf = \sum_{30}^{1} x$$

3. BR (J) – represent the largest amount of work done during a single contraction:

$$BR = \max x$$

Statistical analyses

All data were analysed using JASP statistical analysis software and R analytics. All data were checked for normality using the Shapiro-Wilk test. A repeated measures ANOVA with paired group comparison was used to compare the 3 parameters (n=160) for: 1) differences between arm position (45° vs 90°); 2) differences between arm dominance (Dom vs Non-Dom); and 3) muscle group differences (IR vs ER). In addition, a repeated measures ANOVA with independent group comparison was used to compare the 3 parameters (n=20) between the gender (Male vs. Female). The results are presented as the mean ± the standard deviation throughout the text unless otherwise stated. The alpha level of significance was set at 5% and values of “0.000” given by the statistics package are shown here as $P < 0.0005$ [24]. The Bonferroni correction was used for the repeated measures ANOVA to increase the significance.

Results

Position

There was a significant difference in angle between 45° and 90° of abduction (Table 1). There was a significant difference in angle, with higher values observed in 90° of abduction compared to 45° of abduction for C.Perf by 6% (mean difference = 445.2 J, $F_{1, 19} = 122.868$; $P < 0.0005$) and 7% for BR (mean difference = 34.8 J, $F_{1, 19} = 27.263$; $P < 0.0005$) in the ER. There was no significant difference for any of the parameters in the IR, or for IF in the ER ($P > 0.05$). No significant differences were observed in IF, C.Perf and BR between angle position (45° vs 90°) without differentiation between dominance and muscle group ($P > 0.05$).

Table 1
Mean ± SD values for IF (%), C.Perf (J) and BR (J) for differences between arm positions (45° vs. 90°) considering the influence of gender, muscle groups and arm dominance. ** highlights differences between 45° and 90° angles (P < 0.0005).*

			IR		ER	
			45°	**90°**	**45°**	**90°**
Females	**Non-Dom**	**IF (%)**	-40.11 ± 16.55	-40.35 ± 14.35	-46.71 ± 12.15	-43.82 ± 16.63
		C.Perf (J)	722.81 ± 160.60	745.09 ± 184.2	455.20 ± 128.98	489.94 ± 113.80*
		BR (J)	32.82 ± 6.81	33.85 ± 7.40)	21.38 ± 4.88	23.23 ± 5.18*
	Dom	**IF (%)**	31.65 ± 11.15	32.84 11.20	-41.09 ± 9.72	43.00 ± 9.89
		C.Perf (J)	688.18 ± 238.90	709.93 ± 239.10	531.60 ± 120.47	578.11 ± 116.10*
		BR (J)	31.65 ± 11.15	32.84 11.20	23.82 ± 4.94	27.08 ± 5.56*
Males	**Non-Dom**	**IF (%)**	-41.80 ± 13.67	-39.09 ± 10.68	-45.77 ± 7.86	-46.94 ± 8.29
		C.Perf (J)	1453.28 ± 453.50	1494.37 ± 443.90	951.70 ± 201.35	1061.61 ± 231.2*
		BR (J)	63.72 ± 20.15	65.07 ± 19.73	43.71 ± 9.72	49.86 ± 11.32*
	Dom	**IF (%)**	-39.60 ± 11.62	-38.716 ± 9.06	-41.62 ± 11.31	-46.69 ± 8.55
		C.Perf (J)	1532.84 ± 354.97	1532.76 ± 357.40	1063.27 ± 189.16	1107.71 ± 189.80*
		BR (J)	67.31 ± 16.27	66.07 ± 14.01	48.13 ± 9.76	51.38 ± 9.61*

Dominance

There was a significant difference in dominance between the dominant and non-dominant arms (Table 2). The dominant arm was significantly higher than the non-dominant arm for C.Perf with higher values of 9.7% at 90° of abduction compared to 45° of abduction ($F_{1,19}$ = 6.888; P = 0.017) and BR with higher values of 4.2% at 90° of abduction compared to 45° of abduction ($F_{1,19}$ = 19.693; P < 0.0005) in the ER in males. There was a trend for statistical significance for IF in the ER (in males, with higher values of 5.6% at 90° of abduction compared to 45° of abduction ($F_{1,19}$ = 3.643; P = 0.072). There was no significant difference for any of the values in the IR for dominance (P > 0.05). No significant differences were observed in IF, C.Perf and BR between arm dominance (dominant vs non-dominant) without differentiation between position and muscle group ($P > 0.05$).

Table 2
Mean ± SD values for IF (%), C.Perf (J) and BR (J) for differences between arm dominance (dominant vs non-dominant) considering the influence of position, muscle group and gender.. ** highlights statistical differences between dominant and non-dominant arm (P < 0.05).*

			45°		90°	
			Dom	**Non-Dom**	**Dom**	**Non-Dom**
Females	**IR**	**IF (%)**	-39.82 ± 13.03	-40.11 ± 16.55	-39.60 ± 16.35	-40.35 ± 14.35
		C.Perf (J)	688.18 ± 238.93	722.81 ± 160.59	709.93 ± 239.08	745.09 ± 184.15
		BR (J)	31.65 ± 11.15	32.82 ± 6.81	32.84 ± 11.20	33.85 ± 7.49
	ER	**IF (%)**	-41.09 ± 9.72	-46.71 ± 12.15	-43.00 ± 9.89	-43.82 ± 16.63
		C.Perf (J)	531.64 ± 120.47*	455.17 ± 128.98	578.11 ± 116.07*	489.94 ± 113.81
		BR (J)	23.82 ± 4.94*	21.38 ± 4.88*	27.08 ± 5.26*	23.23 ± 5.18
Males	**IR**	**IF (%)**	-39.60 ± 11.62	-41.80 ± 13.67	-38.71 ± 9.06	-39.09 ± 10.68
		C.Perf (J)	1532.84 ± 352.65	1435.28 ± 453.45	1532.76 ± 357.44	1494.37 ± 443.87
		BR (J)	63.31 ± 16.27	63.71 ± 20.15	66.07 ± 14.01	65.07 ± 19.73
	ER	**IF (%)**	-41.62 ± 11.31	-45.77 ± 7.86	-46.69 ± 8.55	-46.94 ± 8.29
		C.Perf (J)	1063.27 ± 189.16*	951.69 ± 201.35	1107.70 ± 189.77	1061.61 ± 231.16
		BR (J)	48.13 ± 9.76*	43.71 ± 9.72	51.38 ± 9.61	49.86 ± 11.32

Muscle Group

There was a significant difference in muscle group between the ER and IR (Table 3). There was a significant difference in muscle group, with higher values observed in the IR for C.Perf (88.2%; $F_{1, 19}$ = 1312.957; $P < 0.0005$), BR (22.5%; $F_{1, 19}$ = 1055.151; $P < 0.0005$) and IF (36.9%; $F_{1, 19}$ = 775.270; $P < 0.0005$) at 90 of abduction compared to 45 of abduction in males. Significantly higher values were observed for C.Perf in females between the dominant and non-dominant arm for the IR and ER ($F_{1, 19}$ = 648.627; $P < 0.0005$). No significant differences were observed in IF, C.Perf and BR between muscle group for IR without differentiation between dominance and position ($P > 0.05$) for males and females.

Table 3
Mean ± SD values for IF (%), C.Perf (J) and BR (J) for differences between muscle groups (ER vs IR) considering the influence of position, dominance and gender.* *highlights differences between IR and ER (P < 0.05).*

			45°		90°	
			IR	**ER**	**IR**	**ER**
Females	**Non-dom**	**IF (%)**	-40.11 ± 16.55	-46.71 ± 12.15*	-43.82 ± 16.63	-40.53 ± 14.35
		C.Perf (J)	722.81 ± 160.59	455.17 ± 129.00*	745.09 ± 184.15	489.94 ± 113.80*
		BR (J)	32.82 ± 6.81	21.38 ± 4.88*	33.85 ± 7.49	23.23 ± 5.18*
	Dom	**IF (%)**	-39.82 ± 13.03	-41.09 ± 9.72	-39.60 ± 16.35	-43.00 ± 9.89
		C.Perf (J)	688.18 ± 238.93	531.64 ± 120.50*	709.93 ± 239.08	578.11 ± 116.10*
		BR (J)	31.65 ± 11.15	23.82 ± 4.94*	32.84 ± 11.20	27.08 ± 5.56*
Males	**Non-dom**	**IF (%)**	-41.80 ± 13.67	-45.77 ± 7.86	-39.09 ± 10.68	-46.94 ± 8.29*
		C.Perf (J)	1435.28 ± 319.71	951.69 ± 201.40*	1494.40 ± 443.87	1442.61 ± 105.10*
		BR (J)	63.72 ± 20.15	43.71 ± 9.72*	65.07 ± 19.73	49.86 ± 11.32*
	Dom	**IF (%)**	-39.60 ± 11.62	-41.62 ± 11.31	-38.71 ± 9.06	-46.69 ± 8.55*
		C.Perf (J)	1063.27 ± 189.16	1532.84 ± 352.7*	1532.80 ± 357.44	1107.70 ± 189.80*
		BR (J)	67.31 ± 16.27	48.13 ± 9.76*	66.07 ± 14.01	51.38 ± 9.61*

Gender

There was a significant difference observed between three performance parameters in males compared females (Table 4). The females showed significantly lower values for C.Perf (47.74–55.10%) and BR (47.30-53.41%) in both muscle groups, both testing positions and in both limbs, when compared to males (P < 0.05). There were no significant differences between males and females in the levels of fatigue considering both muscle groups, both positions, and dominance (P > 0.05; Table 4). We can observe a significant difference between the ER and IR with higher values of 9% in C.Perf (mean difference = 217.04 J, P < 0.0005) and 11% in BR (mean difference = 104.72 J, P < 0.0005) in males compared to females at

90° of abduction compared to 45° of abduction, respectively. There were no differences in the ER and IR between genders for the IF (P > 0.05).

Values for BR in the non-dominant arm in the ER showed a trend for significance in males, with higher values of 13% at 90° of abduction compared to 45° of abduction (mean difference = 4.47 J, P = 0.073). Values of C.Perf in ER showed a significant difference between dominance, with higher values of 20.7% in the dominant arm compared to the non-dominant arm, in females (mean difference = 80.1 J, P < 0.0005), with no other values showing significant differences (P > 0.05).

Table 4
Mean ± SD values for IF (%), C.perf (J) and BR (J) for differences between gender (male vs female) considering both muscle groups (ER and IR), the influence of position, and dominance. ** highlights statistical differences between both males and females (P < 0.05).*

			IR		ER	
			Male	**Female**	**Male**	**Female**
	Dom	**IF (%)**	-39.60 ± 11.62	-39.82 ± 13.03	-41.62 ± 11.31	-41.27 ± 9.55
		C.perf (J)	1532.84 ± 352.70	688.18 ± 238.90*	1063.27 ± 189.16	537.94 ± 126.92*
		BR (J)	67.31 ± 16.27	31.65 ± 11.15*	48.13 ± 9.76	23.82 ± 4.94*
45°						
	Non-Dom	**IF (%)**	-41.80 ± 13.67	-49.11 ± 16.55	-45.77 ± 7.86	-46.71 ± 12.15
		C.perf (J)	1435.28 ± 453.50	722.81 ± 160.60*	951.69 ± 201.35	455.17 ± 129.00*
		BR (J)	63.72 ± 29.15	32.82 ± 6.81*	43.71 ± 9.72	21.38 ± 4.88*
	Dom	**IF (%)**	-38.71 ± 9.06	-39.60 ± 16.35	-46.69 ± 8.55	-42.51 ± 9.89
		C.perf (J)	1532.76 ± 357.40	709.83 ± 239.10*	1106.25 ± 5.49	578.11 ± 116.10*
		BR (J)	66.07 ± 14.01	32.84 ± 11.20*	51.38 ± 9.61	27.08 ± 5.56*
90°						
	Non-Dom	**IF (%)**	-39.09 ± 10.68	-40.35 ± 14.35	-46.90 ± 8.29	43.82 ± 16.63
		C.perf (J)	1494.37 ± 443.90	745.09 ± 184.20*	1059.56 ± 228.89	489.94 ± 113.90*
		BR (J)	65.07 ± 19.73	33.85 ± 7.49*	49.86 ± 11.32	23.23 ± 5.18*

Discussion

The main findings of this study display major differences between males and females in shoulder performance fatiguability with arm position, dominance and muscle group playing an important role. It has previously been established that the arm spatial orientation affects muscle activation and strength of the shoulder muscles [17, 25]. In overhead athletes it has been found that these individuals are at a higher risk of shoulder related injuries, with the ligaments around the shoulder weakened due to the overload and repetitive stress [26, 27] produced by reduction in the subacromial, with the higher angles of abduction [7], especially when the rotator cuff muscles are in a fatigued state [28]. Therefore, it is important to use a test which demonstrates high levels of reproducibility, in order to be able to detect any worthwhile changes when individuals are fatigued (a major factor which affects shoulder performance and functional dynamic stability). Horobeanu et al. [14] previously assessed the reliability of two isokinetic set-ups: lying supine with arm abducted at 45° and at 90° in frontal plane, for assessing shoulder rotators fatigability properties and found both set-ups demonstrating very high reliability. Further, it has also been established that lying in a supine position is not only comfortable for the individual, but it provides the best support base. Assessing the degree of variation for isokinetic strength Forthomme et al. [17] reported a “good” coefficient of variation below 12 %. The largest advantage of this position is that the gravitational forces are evenly distributed either side of zero (vertical) when testing the shoulder IR and ER muscles. Therefore, the results are not influenced by unquantified forces (such as gravity) especially during fatigue resistance assessment of a population which are not involved in “upper limb” sport participation. In addition, the specificity of the testing position is suitable for testing sport activities in overhead athletes.

The most notable finding of our study was that all measures related to performance were statistically and clinically different between IR and ER shoulder muscles in both males and females. It was found that the IR muscles were more fatigue resistant (IF: 8.19%), able to perform higher amounts of work over 30 repetitions (C.Perf: 45%) and able to develop more work during a single repetition (BR: 39.23%) compared to the ER muscles. Many studies have established differences in several performance variables between the IR and ER shoulder muscles. The IR muscles have always been found to be significantly stronger than the ER muscles [16, 29]. These observed differences are due to the muscle-size differences between both muscle groups, where the IR muscles can produce a larger amount of force due to the larger cross-sectional area. In addition, the IR muscles have a larger lever arm than the ER muscles, meaning more force can be produced [16]. In addition, there are differences from a biomechanical perspective between IR and ER shoulder muscles in relation to size and volume which further accentuates the significant differences found in favour of the IR muscles. The results of our study also found similar results to previous reports related to ER:IR ratios which seems to be between ~ 1:2 and 9:10 [16, 30, 31], for pain-free sedentary individuals.

Another finding of the current study was that no differences in performance (IF, C.Perf, BR) were present between supine position with the arm abducted to 90° angle and a supine position with the arm abducted to a 45° angle when considering only the arm position without differentiation of other possible interactions. In addition, arm dominance also showed no variation between the dominant and non-dominant arm. Therefore, considering previous literature findings related to changes in IR and ER muscle performance between different abduction angles, it was important to further investigate possible interaction of gender and dominance. Looking at whether possible interactions between arm position, dominance, muscle group and gender on muscle performance during 30 reciprocal maximal contractions at 180°/s will further explain findings between these. Our data suggests than increasing the abduction angle to 90° as opposed to 45° positively impacts only the work of ER regarding BR in both males and females and in both the dominant and non-dominant arm while there is no influence on IR. These results contradict the findings of Golebiewska et al. [19] who observed a decrease in muscular strength from 45° to 90° of abduction in frontal plane for both muscle groups. It must be noted that their performance measure was peak torque, while we considered the induced fatigue, work done over all repetitions and the best repetition. Peak torque looks at only one point of the movement, the highest one on the angular curve, while the work represents the whole area under the curve [32], which explains potential differences between these studies. Peak torque is not necessarily the etalon of all other torques developed through the entire range of movement, having a consistent occurrence between certain degrees of movement. However, the work accounts for the overall modification of the curve, not only its peak [1]. In addition, considering that their participants performed the test in a seated position, could further explain the disagreement. Regarding fatigue resistance, IR were deemed to be less fatigued than ERs after 30 repetitions in both the dominant arm (-38.71% vs. -46.69%) and non-dominant arm (-39.09% vs. -46.94%) for males at the 90° position while the females were less fatigued on non-dominant side and only at 45° (-40.11%vs. -46.71%). Similar profiles have previously been found in the literature with IR displaying more fatigue resistance than ER in a study performed by Ellenbecker & Roetert, [33] looking at young tennis players. Differences in fatigue rates between IR and ER have a clinical relevance due to ER functioning as a humeral head stabilizer [33] especially for the athletic population where it has been shown to alter performance [6] and be a potential shoulder injury risk factor. Differences in shoulder position affect the muscle activation around the shoulder and its rotational strength [26, 34]. Studies on a larger population and from variate age groups are necessary to explore their influences and possible implications for different rehabilitation programs of non-athletic populations.

Finally, it is well known that males are stronger than females when comparing different muscles groups [35–38]. Gender differences have previously been found for knee antagonist muscles, quadriceps and hamstrings, with males performing between 25–40% more work compared to their female counterparts [36, 37] during maximal concentric reciprocal contractions. Our study observed shoulder rotator muscles in males to be significantly stronger than females ($P < 0.05$) by 50%, for both arms and at both angles of shoulder abduction. The amount of difference between genders should be viewed from the perspective of raw data, without normalisation to body weight. The choice of comparing raw values has been agreed in order to make possible comparisons with other findings in the literature. However, there was no gender influence on fatigue resistance of the shoulder rotator muscles, showing both genders having a similar reduction in performance, ranging from 38–47%, after 30 reciprocal concentric contractions, respectively. Present results are in line with findings established by Senefeld et al. [38], who reported no significant gender difference but in contradiction with previous findings by Avin et al. [35], who showed females were more fatigue resistant than men. However, in their study the subjects were tested for their isometric sustained capabilities at elbow level, as opposed to the shoulder. Therefore, we support the affirmation of Hunter [21] that the gender differences in regard to fatigue resistance is task specific because different neuromuscular sites will be stressed when the requirements of the task are altered, and the stress on these sites can differ for men and women. Task variables that can alter the gender difference in fatigue resistance include but are not limited to the type, intensity and speed of contraction, the muscle group assessed, and the environmental conditions. In addition, it is also important to understand the impact of menstrual cycle phase on the effect of study design and potential outcomes, with different phases showing different fluctuations in performance levels [39, 40]. In order to gain a better understanding, monitoring females during different stages of the menstrual cycle will provide a clearer picture. Nevertheless, differences between males and females are apparent, but explanations for these differences remain unanswered and more research is required in order to supplement the literature.

Conclusion

The results of this study showed that when assessing muscular performance of the shoulder rotators in a sedentary population, choosing between the amount of shoulder abduction, 45° or 90° in frontal plane, does not influence the muscular fatigue. Therefore, it is suggested that either of these two positions can be considered to assess functional dynamic stability in sedentary individuals. When considering shoulder muscle strength, a change in the arm position, from 45° to 90° of abduction, significantly affects the ER muscles are in favour of the 90° angle, while the IR muscles are not affected. And, besides the known fact that males are in general stronger that females in performance measures related to work done (C.Perf and BR), there seems to be no fatigue difference between genders on any of the upper limbs. These findings are useful for clinicians working with sedentary people when monitoring the progression and outcome of their rehabilitation programs after certain shoulder injuries and provides us a better understanding of future shoulder joint assessments clinical interpretation.

Abbreviations

ER: External Rotator muscles; IR: Internal Rotator muscles; IF: Induced Fatigue; C.Perf: Cumulated Performance; BR: Best Repetition; Dom: Dominant arm; Non-Dom: Non-Dominant arm; ES: Effect Size; SWD: Small Worth-while Difference.

Declarations

Ethics approval and consent to participate

"Verbal explanation of the experimental procedure was provided to each individual; this included the aims of the study, the possible risks associated with participation and the experimental procedures to be utilized. Any questions were answered. Individuals then provided written, informed consent before participating in the study. The experimental procedures were approved by the Human Ethics Committee at the Faculté de Médecine, Université de Liège. The study was conducted in accordance with the ethical standards of the journal and complied with the Declaration of Helsinki."

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are included in this published article and more detailed data is available from the corresponding author on reasonable request.

Competing interests

"The authors declare that they have no competing interests"

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Authors' contributions

C.H., S.P., F.W. and C.S. wrote the main manuscript text. J.P. and A.S. conducted the statistical analysis and results of the manuscript text. C.H., B.F and JL.C. were involved with the set-up of the research and the acquiring of the data. C.H., S.P., F.W. and C.S. prepared all tables for the text. All authors reviewed the manuscript. All authors read and approved the final manuscript.

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