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Sex Differences and Physical Activity Status on the Hamstring: Quadriceps Ratio, Activities of Daily Living, and Functional Movement in Older Adults

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ABSTRACT

International Journal of Exercise Science 16(4): 1228-1243, 2023. The study aimed to investigate sex differences and the effect of physical activity on the hamstring:quadriceps (H:Q) ratio, activities of daily living (ADLs), and the *F*unctional Movement Screen (*F*MS) in older adults. Thirty older adults (72.56 + 6.22) completed maximal voluntary isometric contractions (MVICs), ADLs, the *F*MS, and three closed-kinetic chain exercises (CKCs); front lunge (*F*L), side lunge (SL), and bilateral squat (BLSQ). Electromyography was recorded from the biceps femoris (B*F*) and vastus lateralis (VL) on the dominant and non-dominant limbs during the MVICs and CKCs. Raw EMG recordings were normalized to MVICs and analyzed for root mean square (RMS). The H:Q ratio was calculated using RMS as B*F*/VL. It was determined that males had significantly higher H:Q ratios during the *F*L (p = 0.002), SL (p = 0.012) and BLSQ (p = 0.023), as well as higher RMS of the B*F* during the *F*L (p = 0.031), SL (p = 0.01), and BLSQ (p = 0.042). *F*emales scored higher on the ADLs and *F*MS. A significant positive correlation was observed between ADLs and RMS of the VL ($p < 0.05$, $r > 0.40$), whereas a negative correlation was observed between ADLs and RMS of the BF ($p < 0.05$, $r < -0.5$). The results suggest that males may activate their hamstrings more effectively than females and that females may tend to remain quadriceps dominant. High motor unit recruitment of the hamstring muscles may coincide with reduced functional ability, whereas high motor unit recruitment of the quadriceps may coincide with enhanced functional ability.

KEY WORDS: Electromyography, motor unit recruitment, aging, independence

INTRODUCTION

The hamstring:quadriceps (H:Q) ratio is often used to assess knee joint stabilization (28, 63) as the net balance of muscle strength around the knee may be indicative of muscle function (20). Closed kinetic chain (CKC) exercises, or exercises performed with the foot fixed against a stationary or moving resistance, are commonly used to promote muscular coactivation (19, 48) providing knee-joint stability (2). Muscular contraction is dependent on neural stimulation of the muscle and can be measured via electromyography (EMG) (17). EMG amplitude or root mean square (RMS) reflects motor unit recruitment and/or an increased firing rate (10, 47) and can be used to calculate the H:Q ratio, specifically during CKCs (19), which may provide insight on imbalances in muscle activation between the hamstring and quadriceps muscles. It has been suggested that quadriceps dominant activation has been associated with increased lower extremity injury (21), whereas greater hamstring relative to quadriceps activation may be a limiting factor in functional performance (18, 20).

Changes in force-generating capacity and neuromuscular activation patterns have been demonstrated with age (31), with reduced lower limb strength associated with deficits in movement capability in older individuals (7, 24, 35, 43). The age-related decrease in muscle mass and strength has also been associated with functional decline (13), with a decreased physical capacity to perform activities of daily living (ADLs) independently and without unusual fatigue (39). The age-related changes in muscle function can differ between muscle groups which may cause imbalances in the comparative force that can be generated in the lower limbs (37). The redistribution of force which may occur to compensate for differences in muscle weakness may decrease stability in older adults (7, 35). Hamstring and quadriceps muscle strength are critical for ADLs, including rising from a chair, walking, maintaining postural stability, and going up and down the stairs (4, 23). However, age-related strength deficits in these muscle groups have been demonstrated to reduce functional independence and the ability to perform ADLs (23). While age-related declines in strength have been observed for the the hamstring and quadriceps, greater deficits may occur in the quadriceps compared to the hamstring (46, 51, 54), which may be a significant predictor of decreases in functional ability in older adults (20). Additionally, higher H:Q ratios, and greater hamstring relative to quadriceps strength, are related to a decreased ability to generate muscle power (29) and may be a limiting factor in functional performance (18, 20). Furthermore, age-related declines in muscle strength and muscular coactivation around the knee joint may be sex-specific, with a previous study demonstrating that men lose almost twice as much strength as women (15). Additionally, greater hamstring activation and H:Q ratio in males (19, 62, 64), as well as greater quadriceps activation in females compared to males (64), have been observed in younger populations.

Due to the age-related decrease in physical activity and the negative impacts of inactivity, low functional performance and inability to perform ADLs are more common among older individuals who live a sedentary lifestyle (25, 53). While the level of daily activities and functional ability decreases with age (8, 50), physical activity is an important factor in maintaining independence and quality of life, as exercise may attenuate the negative consequences of aging on body composition and functional ability (30, 56). Specifically, physical activity has been shown to increase muscle strength and power, improving physical performance, ability to perform ADLs (14), and functional independence (36). Additionally, low levels of physical activity, dependence in ADLs, and obesity commonly coexist in older adults (25, 53). Inactivity is associated with increased body fat percentage, which has been reported as a likely cause of age-related changes in functional abilities (44) Specifically, it has been suggested that obesity and inactivity are associated with decreased ability to perform ADLs such as walking, stair-climbing, and ability to rise from a chair, reducing their overall quality of life (58).

The age-related declines in hamstring and quadriceps strength can drastically impact functional performance and the ability to perform ADLs, and may differ between males and females and those who are physically active versus sedentary. To our knowledge, little research has been done to investigate the differences between sex and physical activity level in the H:Q ratio in relation to ADLs and functional performance in the older population. Additionally, little research has been to determine a relationship between motor unit recruitment of the hamstring and quadriceps and functional performance. Therefore, this investigation aimed to examine sex differences and the effects of physical activity on the H:Q ratio, functional performance, and ability to perform ADLs in older adults. A second purpose of the study was to investigate the relationship between motor unit recruitment of the hamstring and quadriceps and functional performance.

METHODS

Participants

Twenty-nine older adults (72.6 + 6.2yrs, 171.52 + 10.63cm, 76.80 + 18.12 kg, 31.45 + 10.46% body fat) above the age of 65 volunteered for the study (female, n = 13; male, n = 16). Individuals with any contraindications to exercise, including cardiovascular disease, stroke, acute or ongoing neuromuscular disease, or musculoskeletal injuries determined by a medical history questionnaire, were excluded from this study. Participants were classified as physically active if they participated in 30 minutes of moderate-intensity exercise three days per week for at least three months (physically active, n = 15; sedentary, n = 14). Each participant provided their informed written consent prior to participating in this study, which adhered to the ethical policies of the International Journal of Exercise Science (45). The research protocol was approved by the Institutional Review Board of the University.

Protocol

Participants reported to the Exercise Science Laboratory on two separate occasions. During the first session, participants were assessed for anthropometric data, including height, weight, and body composition. Participants then completed maximal voluntary isometric contractions (MVICs) and closed-kinetic chain exercises (CKCs). During the second session, participants completed a functional movement screening (FMS) and a series of ADLs. During each trial, participants were asked to complete a 10-minute treadmill warm-up at a self-selected pace. Prior to the first session, participants were asked to refrain from eating, drinking, or exercising three hours before testing to ensure the accuracy of body composition assessment. Prior to the second session, participants were asked to abstain from exercise, alcohol, and smoking for at least 72 hours. Upon completion of the body composition measurement during session one and for the duration of session two, participants were allowed to drink ad libitum.

Body Composition: Body composition was measured using whole-body air-displacement plethysmography via the BodPod (COSMED USA, Inc.). Briefly, participants were asked to wear form-fitting clothing, wear a swim cap and refrain from eating, drinking, or exercising three hours prior to testing. The BodPod was calibrated before each trial and standardized procedures (40) were followed to ensure accuracy and reliability (12, 57).

EMG: Surface EMG was recorded from the biceps femoris (BF) and vastus lateralis (VL) from both the dominant and non-dominant lower limbs (MP160; Biopac System, Santa Barbara, CA, USA). Before electrodes were placed, the skin area was shaved, abraded, and cleaned with an isopropyl alcohol pad to reduce skin impedance and increase the signal-to-noise ratio. Bipolar surface EMG electrodes were placed over the muscle belly of each muscle with an interelectrode distance of 20 mm and aligned parallel with the expected muscle fiber orientation. Electrodes were placed at 2/3 of the distance between the anterior superior iliac spine and the lateral superior border of the patella for the VL and 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia for the BF according to SENIAM recommendations. In addition, ground electrodes were positioned on the lateral side of both knees. Raw EMG recordings were sampled at 1,000Hz, and the EMG signals were bandpass filtered at 10-500Hz.

The data from EMG was rectified based on the RMS. The same technician applied all EMG electrodes and analyzed all EMG signals using Acknowledge 5 software (Biopac System). (ICC 3,1 : RMS = 0.89).

MVICs: Prior to performing the MVICs, participants completed a 10-minute treadmill warm-up at a self-selected pace. Participants were then seated in an upright position in a leg extension or leg extension machine loaded with an immovable mass. Participants were then asked to perform two five-second MVICs separated by 3-minute rest intervals on both the dominant and non-dominant limbs. Participants were instructed to produce force as fast and hard as possible, to maintain the force for five seconds, and then relax as fast as possible. This procedure was completed on both the dominant and non-dominant limbs. RMS for the biceps femoris and vastus lateralis was determined on both limbs for the five-second epoch. Rectified EMG values were made relative to the MVIC (% MVIC). MVICs were performed similar to methods previously used in studies that analyzed the H:Q ratio via EMG during lower-limb exercises (9) and the same technician performed the equipment set-up and limb measurement for all participants.

CKCs: Participants performed a series of three exercises on a stable surface, including a forward lunge (FL), side lunge (SL), and bilateral squat (BLSQ). The front and side lunges were performed on the dominant and non-dominant limbs. All testing procedures were explained prior to testing, and each participant was given a 5-repetition trial to familiarize themselves with the movements and joint angle. When performing the forward and side lunge, participants performed a front or side step with their dominant or nondominant leg. During the exercises, the knee angle was set at 60 degrees of flexion while the trunk remained in an upright position. Participants were instructed to keep their knees over the toes and to place as much weight as possible on the leg being analyzed. Participants were asked to maintain their balance on both limbs for the bilateral squat with the knee joint angle set at 45 degrees flexion. A digital goniometer (Baseline, Aurora, IL, USA) was used to determine the knee-joint angle before and during the CKC exercises. Participants were instructed to hold the knee position at the preferred knee-joint angle for 15 seconds, with a two-minute rest interval between exercises. RMS of the middle five seconds for each exercise was normalized to the MVICs. The average of three trials expressed as % MVIC was used for data analysis. The hamstring:quadriceps (H:Q) ratio was calculated using RMS as BF/VL. CKCs were performed following the methods of previous studies (19)and the same technician performed lower-limb measurements on all participants.

FMS: Prior to performing the FMS (FunctionalMovementSystems, Chatham, VA), participants completed a 10-minute walking warm-up on a treadmill at a self-selected pace. While the FMS consists of 7 movements, only lower-body movements were included for the purpose of the study: deep squat, hurdle step, and in-line lunge (42). The same researchers scored all FMS tests. Participants were given three attempts to perform the movement as the researcher described it, and the best of the three attempts was used for analysis. Each of the three movements were scored from 0-3. A score of three indicates successful completion of the movement as described without any compensation. A score of two indicates that compensation is present, whereas a score of 1 was given when the participant was unable to perform the movement. If any pain was associated with the movement, a score of zero was given.

ADLs: Participants completed three ADLs: sit-to-stand (STS), ascending and descending stairs (STAIRS), and a step-over. Each ADL was scored, and a total ADL score was calculated by adding the scores of the three tasks.

STS: Participants performed three 30-second STS evaluations on a standardized armless chair. On a verbal cue, participants performed as many STS repetitions as possible, beginning in a seated position with their buttocks touching the chair and moving to a fully standing position with arms crossed over the chest. The number of fully-completed STS repetitions was counted and recorded (STS completed). The STS test was also scored on a scale of 0-3, similar to the FMS, with a score of 3 given if the participant could perform the movement as described with no compensation, a score of 2 if the compensation was present, a score of 1 if the participant could not perform the movement, and a score of 0 if any pain was present (STS ability).

STAIRS: Participants performed the Step Test Evaluation of Performance on Stairs (STEPS) (33). The test was performed on a standard set of eight stairs with one handrail. Participants were instructed to climb the stairs as they normally would, avoiding using the handrail if possible. Once participants reached the top of the stairs, they were asked to turn around, face the steps, and come down as they normally would (33). The STEPs evaluation tool consists of 8 items, and each is scored during the ascent and descent, which are scored on a scale ranging from 0-1 or 0-2, with a maximum possible score of 20 (33).

Step over: Participants were asked to step over a hurdle the height of their tibial tuberosity and then return to the starting position, leading with each foot three times. Participants were timed for the duration required to complete the task and their ability to complete it on a scale of 0-3 based on the scale previously established for the FMS.

Statistical Analysis

Prior to data analysis, all data were assessed via the Shapiro-Wilk test for normal distribution, homogeneity of variance, and sphericity. If the assumption of sphericity was violated, a Greenhouse-Geisser correction was applied. In order to examine the primary purpose, independent samples t-tests were used to determine differences in the H:Q ratio, motor unit recruitment, ADLs, and FMS between groups (sex; physical activity status). Paired samples t-tests were used to determine differences in the H:Q ratio and motor unit recruitment between the dominant and non-dominant limbs. To examine the secondary purpose, Pearson's product correlation (r = 0.4-0.59, moderate correlation; 0.6-0.79 = moderately high correlation; > 0.8 = high correlation) was used to determine associations between motor unit recruitment and performance on the ADLs and FMS, as well as between body fat percentage and performance on the ADLs and FMS. An alpha level of $p < 0.05$ was used to determine statistical significance. All data are reported as mean + SD. Effect size was reported as Hedge's g (0.2 = small effect size, 0.5 = medium effect, 0.8 = large effect). Data were analyzed using SPSS v28 software (SPSS v.28.0, IBM, Somers, NY).

RESULTS

CKC H:Q Ratio: H:Q ratios were significantly greater in males compared to females during the front lunge on the dominant limb (t (27) = 3.213, p = 0.002, g = 4.725) and non-dominant limb (t (27) = 3.312, p = 0.002, g = 1.94), the side lunge on the dominant limb (t (27) = 2.79, p = 0.012, g = 1.249) and non-dominant limb (t (27) = 2.34, p = 0.020, g = 3.47) and during the bilateral squat on the dominant (t (27) = 2.28, p = 0.023, g = 3.368) non-dominant limb (t (27) = 2.275, p = 0.023, g = 3.436) (Table 1).

Significant differences were observed in H:Q ratios between the dominant and non-dominant limbs. Specifically, the H:Q ratio was greater on the non-dominant limb compared to the dominant limb during the *FL* (t (28) = 2.123, p = 0.043, g = 2.34), SL (t (28) = 4.612, p = 0.041, g = 2.605) and BLSQ (t (26) = 2.061, p = 0.049, g = 2.635) (Table 3).

No significant differences between physically active and sedentary individuals were observed for the H:Q ratio during the CKC exercises (p > 0.05).

Table 1. H:Q ratio during CKCs for males and females on dominant and non-dominant limb.

	Dominant		Non-Dominant	
	Males	Females	Males	Females
Front Lunge	0.534 ± 0.07*	0.27 ± 0.03	0.90 ± 0.165*	0.27 ± 0.45
Side Lunge	0.40 ± 0.06*	0.24 ± 0.18	0.74 ± 0.19*	0.24 ± 0.04
Bilateral Squat	0.48 ± 0.08*	0.26 ± 0.04	0.89 ± 0.22*	0.31 ± 0.06

*Significantly greater H:Q ratio in males compared to females

CKC Motor Unit Recruitment: Significantly greater RMS of the B*F* was observed in males compared to females during the *F*L in the dominant (t (25) = 2.289, p = 0.031, g = 7.389) and non-dominant (t (27) = 3.378, p = 0.002, g = 5.489) limb, during the SL in the non-dominant limb (t (26) = 2.737, p = 0.010, g = 4.371), and during the bilateral squat in the dominant (t (26) = 2.07, p = 0.042, g = 7.976) non-dominant (t (25) = 2.522, p = 0.020, g = 3.923) limb. No significant difference was observed between males and females for RMS of the B*F* in the dominant limb during the side lunge (p > 0.05). *F*urthermore, no significant differences were observed in RMS of the VL between males and females during any of the CKCs (p > 0.05) (Table 2).

Interestingly, females had greater RMS of the VL compared to the B*F* on the dominant limb during the *F*L (t (12) = 7.548, p < 0.001, g = 9.475), SL (t (12) = 15.805, p < 0.001, g = 8.116), and bilateral squat (t (12) = 6.468, p < 0.001, g = 6.356), as well as the non-dominant limb during the *F*L (t (12) = 6.543, p < 0.001, g = 6.55), SL (t (12) = 7.75, p < 0.001, g = 10.07), and bilateral squat (t (12) = 4.66, p < 0.001, g = 6.092), whereas, males only had greater RMS of the VL compared to the B*F* during the SL on the dominant limb (t (15) = 4.262, p < 0.001, g = 6.519). (Table 2).

RMS of the B*F* was significantly greater in the non-dominant limb compared to the dominant limb during the *F*L (t (26) = 1.746, p = 0.036, g = 1.806), SL (t (27) = 2.137, p = 0.042, g = 2.124), and BLSQ (t (26) = 2.037, p = 0.043, g = 2.364). No significant differences were observed in the RMS of the VL between the dominant and non-dominant limbs during any of the CKCs (p > 0.05) (Table 3).

No significant differences were observed between physically active and sedentary individuals for RMS during CKC exercises (p > 0.05).

Table 2. Motor unit recruitment of the B*F* and VL during CKCs.

		Dominant			Non-Dominant		
		Front Lunge	Side Lunge	Bilateral Squat	Front Lunge	Side Lunge	Bilateral Squat
RMS:BF	Males	31.74 ± 3.61*	19.64 ± 3.98	25.05 ± 2.96*	34.27 ± 5.68*	33.12 ± 7.01*	26.28 ± 6.58*
	Females	12.75 ± 1.21	11.85± 1.55	8.16 ± 1.03	12.08 ± 1.9	12.07 ± 1.56	8.759 ± 1.13
RMS:VL	Males	39.43 ± 5.32	53.10 ± 6.07^	31.94 ± 5.62	43.63± 6.65	49.40 ± 6.17	31.28 ± 3.77
	Females	43.84 ± 4.48^	52.9 ± 3.79^	35.62 ± 4.36^	49.49 ± 5.76^	57.43 ± 6.17^	35.23 ± 6.04^

*Significantly greater RMS of B*F* in males compared to females, ^Significantly greater RMS of VL compared to B*F*

ADLs: A significant difference between males and females was observed for the STS completed (t (27) = 2.192, p = 0.028, g = 5.541), step-over (t (27) = 2.525, p = 0.013, g = 5.25), STAIRS (t (27) = 1.801, p < 0.001, g = 16.396) and total ADL score (t (27) = 3.719, p = 0.026, g = 6.005), with significantly greater scores observed in females compared to males. No significant difference was observed for STS ability (p = 0.073) (Table 4).

Table 3. Differences in H:Q ratio and motor unit recruitment (RMS) of the B*F* and VL between dominant and non-dominant limbs regardless of sex.

	H:Q Ratio		RMS:BF		RMS:VL	
	Dominant	Non-Dominant	Dominant	Non-Dominant	Dominant	Non-Dominant
Front Lunge	0.42 ± 0.05	0.62 ± 0.11*	17.41 ± 2.11	23.22 ± 4.03*	42.51 ± 3.506	46.26 ± 4.44
Side Lunge	0.31 ± 0.03	0.52 ± 0.11*	16.02 ± 2.33	23.26 ± 4.22*	52.55 ± 3.8	53.13 ± 4.36
Bilateral Squat	0.38 ± 0.06	0.63 ± 0.12*	10.95 ± 1.57	17.84 ± 3.81*	35.04 ± 3.35	33.04 ± 3.35

*Significantly greater in non-dominant limb compared to dominant limb

Significantly greater scores were observed in those who were physically active compared to the sedentary grou*p* during the step-over (t (27) = 2.671, p = 0.039, g = 3.436), STAIRS (t (27) = 2.678, p = 0.032, g = 4.927), and total ADL score (t (27) = 3.676, p = 0.004, g = 5.029). No significant difference was observed for the number of STS completed (p = 0.419) or STS ability (p = 0.624). (Table 4).

Table 4. Differences in ADL performance between sex and physical activity status.

	STS Completed	Step-Over	STAIRS	STS Ability	Total ADL Score
Male	15.13 ± 1.09	13.13 ± 0.99	14.56 ± 0.39	2.37 ± 0.05	47.69 ± 0.76
Female	21.22 ± 1.11*	17.08 ± 0.39*	19.54 ± 0.18*	3.0 ± 0	38.88 ± 2.03*
Physically Active	15.81 ± 1.16	16.38 ± 0.63^	19.69 ± 0.12^	2.69 ± 0.21	46.75 ± 0.78^
Sedentary	15.0 ± 1.12	13.31 ± 1.14	15.92 ± 1.14	2.62 ± 0.21	38.0 ± 2.46

*Significantly greater in females compared to males, ^Significantly greater in physically active compared to sedentary

FMS: Significantly greater *F*MS scores were observed in females compared to males for *F*MS squat (t (27) = 1.376, p = 0.017, g = 7.946) and hurdle-ste*p* (t (27) = 2.294, p = 0.040, g = 5.087). No significant difference was observed between males and females for in-line lunge (p = 0.481) (Table 5).

Significantly greater scores were observed in those who were physically active compared to those who were sedentary during the *F*MS squat (t (27) = 5.328, $p < 0.001$, g = 6.801), hurdle-ste*p* (t (27) = 5.534, $p < 0.001$, g = 4.709) and in-line lunge (t (27) = 5.337, $p < 0.001$, g = 6.846) (Table 5).

Correlations: Moderate to moderately high positive correlations were observed between STS completed and RMS of the VL during the BLSQ on the dominant (p = 0.032, r = 0.405) and non-dominant limbs (p = 0.040, r = 0.682), respectively. Additionally, moderately high positive correlations were observed between RMS of the VL during the *F*L on the dominant (p = 0.028, r = 0.612) and non-dominant limbs (p = 0.021, r = 0.653). Moderate negative correlations were observed between STAIRS and RMS of the B*F* during the *F*L on the dominant (p = 0.038, r = -0.502) and non-dominant limbs (p = 0.35, r = -0.582).

Table 5. Differences in *F*MS performance between sex and physical activity status.

	Squat	Hurdle-Step	In-line Lunge
Male	1.15 ± 0.21	1.75 ± 0.23	2.08 ± 0.24
Female	2.75 ± 0.19*	2.92 ± 0.21*	1.94 ± 0.23
Physically Active	2.44 ± 0.157^	2.25 ± 0.214^	2.56 ± 0.16^
Sedentary	1.30 ± 0.18	1.31 ± 0.18	1.30 ± 0.21

*Significantly greater in females compared to males, ^Significantly greater in physically active compared to sedentary

Moderate negative correlations were observed between body fat percentage and total *F*MS score (p = 0.009, r = -0.474), *F*MS squat (p < 0.001, r = -0.598), *F*MS hurdle-ste*p* (p = 0.029, r = -0.406) and *F*MS in-line lunge (p = 0.005, r = -0.511). No significant correlations were observed between body fat percentage STS ability (p = 0.724, r = 0.069), STAIRS (p = 0.099, r = -0.312), step-over (p = 0.681, r = -0.080), STS completed (p = 0.665, r = 0.084), or total ADL score (p = 0.072, r = -0.339).

Body Composition: Those who were sedentary had significantly greater body composition compared to physically active individuals (p < 0.001, F = 0.486; 39.68 + 2.5, 28.04 + 2.0).

DISCUSSION

The results of the present study indicate that the H:Q ratios and motor unit recruitment of the hamstring muscle are greater in males compared to females, with no differences in motor unit recruitment of the quadricep muscle during the CKCs. H:Q ratios and motor unit recruitment of the hamstring muscle also appear to differ between the dominant and non-dominant limbs, with greater H:Q ratios and motor unit recruitment of the BF in the non-dominant limb during all CKC exercises, with no differences observed in VL motor unit recruitment between limbs. Greater ADL scores and performance on the FMS were also observed in females, which may be attributed to the greater H:Q ratio and motor unit recruitment of the hamstrings observed in males compared to females. Specifically, higher motor unit recruitment of the hamstring muscle may coincide with reduced functional ability, whereas increased activation of the quadriceps muscle may be related to enhanced functional performance. Additionally, physical inactivity and increased body composition resulted in decreased performance on the FMS and ADLs.

The H:Q ratio is often used to assess the net balance of muscle strength around the knee joint and may be indicative of muscle function (20). Previous studies have investigated sex differences in neuromuscular function and have suggested that imbalances in the H:Q ratio or magnitude of muscle activity may limit functional performance (19, 21). In the present study, greater H:Q ratios were observed in males compared to females on both the dominant and non-dominant limbs during CKC exercises. The results of the present study are in agreement with previous studies demonstrating that the H:Q ratio during a single-leg squat performed at 45 degrees of knee flexion was smaller in females compared to males between the ages of 22 and 31 years of age (62), as well as during a side-lunge exercise at 60 degrees of flexion (19). Additionally, the present study determined that motor unit recruitment of the biceps femoris was significantly greater in males than females, which likely resulted in the higher H:Q ratio in males. It has previously been determined that men display greater EMG activity in their hamstrings than women during a single-leg squat (62), whereas females generate more activity in their quadriceps femoris (62, 64), suggesting that men activate their hamstrings more effectively than women (62). While the present study only observed sex differences in the EMG activity of hamstring muscles, with no sex differences in EMG activity of the quadriceps muscles, interestingly, females had greater motor unit recruitment of the vastus lateralis compared to the biceps femoris on both legs, during all CKC exercises. In contrast, males only displayed greater EMG activity of the VL compared to BF during one CKC on the dominant limb, with no differences observed in the non-dominant limb. The results of the present study, in combination with previous findings (19, 62, 64), may suggest that females remain quadriceps dominant, exhibiting less activation of the hamstring muscle, which may lead to greater functional performance in females (18, 20).

Greater ADL and FMS scores were observed in females compared to males. Previous authors have suggested that greater hamstring strength relative to the quadriceps muscle may be a limiting factor in the performance of functional-related activities (18, 20) and that higher H:Q ratios in older adults may lead to a decreased ability to generate muscle power (29). While no significant correlations were observed between the H:Q ratios and ADLs or FMS scores, the significant negative correlations between STAIRs and RMS of the BF suggest that increases in motor unit recruitment of the hamstring muscle may coincide with reduced ADL ability. Additionally, the significant positive correlation between STS completed and RMS of the VL suggests that increased quadriceps activation may coincide with enhanced ADL ability. Therefore, the sex differences observed in the ADLs may be attributed to the greater H:Q ratio and motor unit recruitment of the hamstrings observed in males compared to females, leading to decrements in functional performance in male participants (18, 20, 29). Additionally, while age-related declines in maximal strength have been reported for these muscle groups, several studies have shown greater strength deficits in the leg extensors than flexors (46, 51, 54) which have been suggested to be a significant predictor of the functional decline observed in older adults (20). While no sex differences were observed in motor unit recruitment of the quadriceps, it was determined that females had greater motor unit recruitment of the vastus lateralis than the biceps femoris on both legs during all CKC exercises. Therefore, greater quadriceps activation in females may be related to increased performance on ADLs.

Bilateral differences in the H:Q ratio were observed during the CKC movements, with higher H:Q ratios in the non-dominant limb compared to the dominant limb, regardless of sex. The higher H:Q ratio observed in the present study can be attributed to greater motor unit recruitment of the hamstring in the non-dominant limb, which may be the result of compensation via the hamstring muscles due to weaker quadricep muscles in the non-dominant limb (1) These results, however, are in disagreement with previous studies, which observed no difference in the H:Q ratio between the left and right legs (3, 61). The discrepancy may be due to leg dominance, physical activity status, and age, as the study by Camels et al. (1997) did not account for leg dominance and participants were recruited from professional, sporting, or social groups, and the study by Yoon et al. (1991) involved untrained participants with a mean age of 27. When leg dominance is taken into account, bilateral differences in the H:Q ratio have been observed in male and female soccer players, with higher H:Q ratios observed on the non-dominant limb in females (22), whereas in contrast to the present study, higher H:Q ratios have been observed in the dominant limb in males (11, 34, 60). While these studies and the results of the present investigation raise the question of whether sex influences bilateral differences in the H:Q ratio, discrepancies may be due to age and physical activity status. Nonetheless, while Kong and Burns (2010) were in disagreement with the present study, observing higher H:Q ratios in the dominant limb, the higher H:Q ratios were attributed to stronger hamstrings, which is in agreement with the results of the present study. Cheung et al (2012) also observed bilateral differences in the hamstring with no differences in the quadriceps muscle, however, weaker hamstrings were observed in the dominant compared to the non-dominant leg (6). The results of Cheung et al. (2012) are in agreement with the present study, which determined that motor unit recruitment of the biceps femoris was greater in the non-dominant compared to the dominant limb, with no differences observed in motor unit recruitment of the vastus lateralis between limbs. The results of the present study, in combination with the findings of Cheung et al. (2012), highlight the importance of the hamstring muscles in providing joint stabilization, suggesting an increased need for stabilization by the hamstring muscle (38) in the non-dominant limb and/or increased relative activation of the quadriceps muscle in the dominant limb (22). It is important to note, however, that sex, age, and physical activity level may influence the H:Q ratio.

Decrements in physical performance, independence, and functional ability may be exacerbated by obesity and physical inactivity (16, 26, 27). Lower ADL and FMS scores were observed in those who were sedentary versus those who were physically active. Additionally, the significant negative correlations between body fat percentage and FMS scores suggest that an increase in body fat percentage may coincide with reduced functional ability, particularly in movements involving the lower limbs, with sedentary individuals exhibiting significantly greater body fat percentages. A study by Milanovic et al. (2013) demonstrated that physical activity level was associated with 8-foot up-and-go, 30-second chair stand-up, and arm curl, suggesting that the age-related decline in physical activity leads to a decrease in functional fitness (41), likely due to age-related reductions in strength, endurance, agility and flexibility (8, 41, 50). These age-related declines can be further exacerbated by inactivity, with a sedentary lifestyle leading to the development of dependence for daily activities in older adults (47, 52). Age-related changes in body composition, including decreased muscle mass and increased fat mass, may lead to increased disability and reduced capacity for ADLs (5, 49). It has previously been determined that inactive individuals with a higher body fat percentage were more functionally impaired, particularly in activities that emphasize lower limb function (5,16), suggesting that obesity exacerbates the age-related decline in physical function (26, 27, 50, 59) Results of the present study, in agreement with the results of previous investigations, highlight the importance of physical activity as an effective means to improve physical condition, functional capacity (55), and body composition (32), as those with high physical activity levels often obtain better levels of functional ability and autonomy, resulting in greater independence (47).

This study is not without limitations. One of the limitations of this investigation is that conclusions are based on EMG of the vastus lateralis and biceps femoris only and may not reflect neuromuscular responses of lateral and medial hamstring and quadriceps muscles. Additionally, while joint angle and trunk position were monitored throughout the CKC exercises, slight changes may have altered the muscle activation. The study consisted of individuals who were free from all ongoing neuromuscular disease, musculoskeletal injuries, and cardiovascular conditions, therefore, the results of the study cannot be generalized to the general aging population. Furthermore, the study did not directly measure muscular strength or lean body mass and could not determine a direct relationship between muscle mass and strength and functional abilities.

The results of the study demonstrate that males have greater H:Q ratios and greater motor unit recruitment of the hamstrings compared to females during CKC exercises, suggesting that males activate their hamstrings more effectively than females and that females may tend to remain quadriceps dominant, with females exhibiting greater activation of VL compared to the BF on both limbs, during all CKC exercises. Greater ADL and FMS scores were observed in females compared to males, which may be attributed to the greater H:Q ratio and motor unit recruitment of the hamstrings observed in males compared to females. Specifically, high motor unit recruitment of the hamstring muscles may coincide with reduced functional ability. Additionally, greater H:Q ratios and motor unit recruitment of the hamstring muscle were observed in the non-dominant limb, suggesting a possible increased need for stabilization via the hamstring muscle, highlighting the importance of the hamstring muscles in providing knee joint stabilization as well as the role of agonist/antagonist coactivation in functional performance. Finally, physical inactivity and increased body fat percentage negatively impact functional performance and the ability to perform ADLs, particularly in movements involving the lower extremities. Future research may aim to compare the older population to younger adults to better understand age-specific changes that occur relative to the H:Q ratio and motor unit recruitment of the leg extensors and flexors. Furthermore, future directions for research should focus on muscular coactivation and effective weight management interventions targeting issues related to functional decline in the aging population.

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