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Original Research

Effects of a Quadricep-Dominant vs. Functional Training Program on Activities of Daily Living, Functional Performance, and Motor Unit Recruitment in Older Adults

Brittany Followay[‡], Tamera Holland[*#], Larissa Rowley[*#]

Department of Exercise Science, Ripon College, Ripon, WI, USA

*Denotes student investigator, ‡Denotes established investigator, #indicates contributed equally

Abstract

International Journal of Exercise Science 18(8): 1096-1113, 2025. https://doi.org/10.70252/YHYC9630 The study investigated the effects of a quadriceps-dominant (QD) versus functional (FX) training program on the Functional Movement Screen (FMS), activities of daily living (ADLs), and motor unit (MU) recruitment of the vastus lateralis (VL) and biceps femoris (BF). Twenty-six older adults (68.9 $\pm$ 5.1yrs) were randomly assigned to a 6-week QD or FX training program. Participants completed ADLs, FMS, and three closed-kinetic chain exercises (CKCs): front lunge (FL), side lunge (SL), and bilateral squat (BLSQ), pre and post-intervention. Electromyography was recorded from the VL and BF during maximal voluntary isometric contractions (MVICs) and CKCs. Raw EMG recordings during CKCs were normalized to MVICs, and analyzed for root mean square (RMS). The QD program resulted in improved FMS performance during a deep-squat ($p = 0.003$), in-line lunge ($p = 0.013$), and hurdle step ($p = 0.034$), as well as improved ADL sit-to-stand (STS) and STAIRS ($P < 0.05$). Furthermore, the QD program resulted in greater RMS of the VL during CKCs ($p < 0.05$). Lastly, a positive correlation was observed between ADLs and RMS of the VL ($p < 0.05$, $r > 0.6$), whereas negative correlations were observed between FMS movements and RMS of the BF ($p < 0.05$, $r < -0.6$). The results suggest that a QD program may lead to greater improvements in functional movements, ADLs, and VL MU recruitment compared to a FX program. Additionally, MU recruitment of the VL is essential for functional ability, whereas high MU recruitment of the BF may coincide with reduced functional ability. The results of this study suggest that QD training may improve functional abilities in older adults.

Keywords: Functional movement screen, motor unit recruitment, closed-kinetic-chain, leg extensor strength

Introduction

Age-related declines in muscular strength and neuromuscular function are often accompanied by functional decline, increased risk of falls, and loss of independence.[1,2] Muscle strength of the leg extensors and flexors is essential for functional movement and maintaining independence when performing activities of daily living (ADLs).[1] However, previous studies have shown greater age-related strength decreases in the leg extensors than flexors,[1] which may significantly predict functional decline.[3] Furthermore, research has identified decreased quadriceps strength as a factor contributing to falls among older individuals,[4] with positive relationships observed between leg extensor strength and ADL performance.[5] Additionally, Wearing et al,[6] investigated the relationship between dependence in ADLs and muscle strength and physical function, demonstrating a relationship between low quadriceps strength and dependence in ADL performance. Additionally, researchers concluded that quadriceps strength was significantly greater in participants who could independently perform ADLs than in those dependent during ADLs.[6] These previous studies demonstrate the importance of quadriceps strength for performing ADLs, including sitting down, rising from a chair, and climbing stairs.[1,2,7]

Declines in physical activity that occur with age are associated with decreased muscle strength and an inability to perform ADLs, placing sedentary individuals at an increased risk for lower functional ability and increased ADL dependence.[6] Age-related decrements in muscular strength and functional capacity are modifiable risk factors to prevent falls in older individuals, with previous research demonstrating that properly prescribed exercise interventions can be effective in slowing the loss of muscle strength and improving functional movement ability.[8–10] Additionally, due to the decline in quadriceps muscle strength that occurs with aging and the importance of quadriceps strength in maintaining functional independence, it has been suggested that interventions to improve functional ability and reduce the risk of falls should focus on strengthening the quadriceps muscles.[1,11] While several studies outline the importance of implementing traditional strength training that emphasizes increased strength of the leg extensor musculature to improve functional capacity,[1,11,12] others suggest that functional movement training may be imperative in improving functional performance.[13] Functional movement training is aimed explicitly toward improved function when performing everyday tasks and therefore focuses on the performance of an action and is designed to mimic ADLs, by targeting multiple muscle and joint activities during movements, and increasing overall strength, balance, and mobility.[14] The Functional Movement Screen (FMS) consists of seven tests to evaluate mobility, stability, and balance. The FMS allows for the observation of neuromuscular impairments and weaknesses, and provides the basis for corrective exercises to improve functional performance,[15] which have been implemented into functional training programs by previous authors.[16] Traditional training, on the other hand, isolates specific muscles to effectively increase strength without regard to training movements related to ADLs, and often limits range of motion and requires less stabilization and balance compared to functional training.[14] As previously mentioned, while previous research has demonstrated the importance of traditional training that emphasizes the leg extensor muscle group,[1,11,12] other investigations have shown the importance of training programs being task-specific and focusing on ADLs as a fundamental outcome if improved functional performance and ability are the training goals.[17] Despite conflicting results, age-related declines in muscle strength, which can significantly impair functional performance and the ability to perform ADLs, may be mitigated by appropriately prescribed exercise intervention.

Initial increases in strength can be largely attributed to increased motor unit activation of the trained musculature.[18] Previous research has suggested that strength gains in older adults may be primarily due to improvements in neuromuscular activity, specifically enhanced neural recruitment patterns, rather than muscle hypertrophy.[19] Specifically, strength training has resulted in significant strength gains due to neural adaptations, such as increased maximal motor unit recruitment.[20] Electromyography (EMG) amplitude or root mean square (RMS) reflects motor unit (MU) recruitment, which can be assessed during closed-kinetic-chain (CKC) exercises, commonly used to promote coactivation of the hamstring and quadriceps muscle groups.[21,22] Additionally, CKC exercises are closely related to functional movements and ADLs, with positive correlations observed between functional performance and CKC performance.[23] Previous research has suggested that decreased MU recruitment, a key contributor to reduced muscle strength, is linked to impaired physical function in older adults.[19] Additionally, reduced muscle strength may be due to changes in neural mechanisms, including decreased activation of agonist muscles and increased co-activation of antagonistic muscle groups.[24] It has been demonstrated that MU recruitment, specifically of the vastus lateralis, may be associated with increased strength of the leg extensors.[18] Additionally, greater MU recruitment of the VL assessed during CKCs has been linked to improved performance in ADLs and functional movements, including sit-to-stand and stair-climbing.[24] In contrast, high MU recruitment of the antagonist biceps femoris (BF) muscle may coincide with reduced functional ability.[24]

While previous studies have highlighted both the importance of quadricep strength and functional movement training in improving functional ability in older adults, to our knowledge, little research has been conducted to investigate the effects of a traditional quadriceps-dominant (QD) training program on functional performance in older adults, or to compare a QD versus a functional (FX) training program on ADL performance and functional movement ability. Therefore, the primary purpose of this investigation was to examine the effects of six-week QD and FX training programs on ADL performance, functional movement ability, and MU recruitment of the leg extensor and flexor muscles. A secondary purpose was to investigate the relationship between MU recruitment and functional performance. Researchers hypothesize the following: 1) a QD training program will result in greater improvements in functional movements, 2) a QD dominant training program will result in greater improvements in ADLS, 3) a positive relationship will exist between motor unit recruitment of the VL and functional movements, and 4) a positive relationship will exist between motor unit recruitment of the VL and ADLs.

Methods

Participants

Twenty-eight older adults volunteered for the study; however, two participants dropped out due to time constraints. Therefore, twenty-six older adults (68.9 $\pm$ 5.1yrs, 167.12 $\pm$ 9.2cm, 74.1 $\pm$ 19.6 kg) completed the study, randomly assigned to either a QD (n = 12) or FX (n = 14) training program. 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. 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*.[25] The Institutional Review Board of Ripon

College approved the research protocol in accordance with the ethical standards set by the Helsinki Declaration.

Protocol

Participants reported to the Exercise Science Laboratory for their initial session, during which participants were assessed for anthropometric data, including height, weight, and body composition. Participants then completed baseline (PRE) maximal voluntary isometric contractions (MVICs), closed-kinetic chain exercises (CKCs), activities of daily living (ADLs), and the Functional Movement Screening (FMS). Following baseline data collection, participants were randomly assigned to a quadricep-dominant (QD) or functional (FX) training program and reported to the resistance training facility three times per week for six weeks. MVICs, ADLs, CKCs, and FMS were completed again at the end of six weeks (POST).

Intervention.

All training sessions were facilitated by two certified trainers. Participants reported to the resistance training facility three times a week for six weeks, with each session lasting one hour, with at least 48 hours in between. Participants were asked to refrain from other forms of training or exercise during the six weeks. All training sessions included a 10-minute warm-up at a self-selected pace and intensity, 40 minutes of intervention training (QD or FX), and a 10-minute cool-down of either cycling and static stretching (QD group) or FMS corrective exercises (FX group). All training sessions were individualized, followed the principle of progressive overload, and were equalized for each group regarding the volume of exercises performed. While both training protocols emphasized lower-body movements, they both included upper-body exercises to minimize the effects of lower-body fatigue. Upper-body exercises in the FX protocol were designed to mimic activities of daily living (ADLs) as closely as possible. In contrast, the QD protocol implemented traditional upper-body strength training exercises. Before beginning the six-week training protocol, both groups underwent a one-week, three-session familiarization period to learn the movement techniques demonstrated by the researchers. The Borg Rating of Perceived Exertion (RPE) Scale was used to gauge intensity. Participants were asked to exercise at an RPE between 13 and 14 (somewhat hard). RPE was recorded following each exercise to control the target intensity of the different training programs.

QD Intervention.

Participants completed a 10-minute cycling warm-up at a self-selected pace and intensity. Participants then underwent 40 minutes of intervention training, performing seven exercises, for two sets of 12-15 repetitions for the first three weeks. During sessions one and three of each week, the seven exercises comprised all QD lower-body exercises. During the second session of each week, the seven exercises comprised three QD lower-body exercises and four traditional upper-body machine exercises to minimize lower-body fatigue effects. During the last three weeks, participants completed six exercises for three sets of 12-15 repetitions, which were all QD lower-body exercises during sessions one and three of each week. During the second session of each week, three traditional upper-body machine exercises were performed in place of three QD lower-body exercises. The session ended with a 10-minute cool-down, which included five minutes of cycling and five minutes of static stretching. Exercises that were implemented during training sessions to emphasize loading of the leg extensors included the following: machine leg extension, machine isometric quadricep holds on leg extension machine, seated cable knee extension, machine narrow-stance leg press, machine low-stance leg press, seated quad sets, machine narrow-stance hack squats, machine lower-stance hack squats. Upper body exercises included traditional machine-based exercises, including chest press, triceps cable extensions, lat pull-downs, seated rows, cable bicep curls, and chest fly. The load for each exercise was determined during the familiarization period and based on the participant's ability to perform 12-15 repetitions for two or three sets [8] at an RPE of 13 to 14. When the individual could perform two additional repetitions for two consecutive sets, the load was increased by 2.5 lb for upper body exercises and 5 lb for lower body exercises for the next training session.[26]

FX Intervention.

Participants completed a 10-minute treadmill warm-up at a self-selected pace before each FX training session. Participants then underwent 40 minutes of intervention training, performing seven exercises, for two sets of 12-15 repetitions or 45 seconds (farmers walk, step-ups) for the first three weeks. During sessions one and three each week, the seven exercises comprised all FX lower-body exercises. During the second session of each week, the seven exercises comprised three FX lower-body exercises and four FX upper-body exercises to minimize lower-body fatigue effects. During the last three weeks, participants completed six exercises for three sets of 12-15 repetitions or 60 seconds, which were all FX lower-body exercises during sessions one and three of each week. During the second session of each week, three FX upper-body exercises were performed instead of three FX lower-body exercises. FX lower-body exercises that were implemented during training sessions to mimic ADLs included the following: kettlebell deadlifts, step-ups, kettlebell high pull, med ball push press, floor transfers, kettlebell half squat, high-knee dynamic marching, and TRX assisted split squats. Wall support was provided if needed during step-ups and high-knee dynamic marching. Upper body exercises were selected to mimic ADLs more closely and included the following: standing bent-over rows, standing overhead press, push-ups with wall or knee modifications if needed, farmer's walk, standing dumbbell bicep curls, and upright rows. The load for each FX exercise followed the same protocol as the QD program discussed above. The session concluded with a 10-minute cool-down, during which participants performed corrective exercises aimed at addressing areas of deficiency identified during the FMS PRE testing. Therefore, corrective exercises were individualized for each participant and differed for each FMS movement. All corrective exercises followed the three approaches to correction of movement deficiencies outlined in the FMS assessment,[14] and included assisted exercises, reactive neuromuscular training, and resisted exercises.[14]

EMG.

Surface EMG was recorded from the biceps femoris (BF) and vastus lateralis (VL) from the dominant limb (MP160; Biopac System, Santa Barbara, CA, USA). The electrode sites were shaved, abraded, and cleaned with an isopropyl alcohol pad to reduce skin impedance and increase the signal-to-noise ratio. Bipolar surface EMG placement followed SENIAM recommendations and was placed over the muscle belly of each muscle, with an interelectrode distance of 20 mm and aligned parallel with the expected muscle fiber orientation, and was performed by the same technician for all participants and sessions. For the VL, electrodes were placed at 2/3 of the distance between the anterior superior iliac spine and the lateral superior border of the patella, and 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia for the BF. EMG recordings were sampled at 1,000 Hz, and the EMG signals were bandpass filtered at 10- 500 Hz. The data from EMG was rectified based on the RMS. EMG signals were analyzed using Acknowledge 5 software (Biopac System).

MVICs.

Prior to performing the MVICs, participants completed a 10-minute cycling warm-up at a self-selected speed and intensity. MVICs were performed against an immovable mass on the dominant limb. Participants were given verbal encouragement, and were instructor to produce maximal force as quickly as possible, to maintain consistent force throughout the 5-second contraction, and to then relax as fast as possible. MVICs were separated by 3-minute rest intervals. RMS for the biceps femoris and vastus lateralis was determined for the five-second epoch. Rectified EMG values were made relative to the MVIC (% MVIC).[24]

CKCs.

Participants performed a series of three exercises on a stable surface, including a forward lunge (FL), side lunge (SL), and bilateral squat (BLSQ), and followed the methodology of previous studies. [21,24]The same researcher administered the CKC protocols throughout the study and explained and demonstrated the CKC procedures before testing. Participants were also asked to perform three trial repetitions to familiarize themselves with the movements and joint angles. When performing the FL and SL, participants performed a front or side step with their dominant leg, with the knee angle set at 60 degrees of flexion. Participants were instructed to keep their knees over the toes and to place as much weight as possible on the dominant limb. Participants were asked to maintain their balance on both limbs for the bilateral squat with the knee joint angle set at 45 degrees of 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 each position for 15 seconds and a two-minute rest period was provided between exercises. RMS was normalized to the MVICs for the middle five seconds of each movement. The average of three trials expressed as % MVIC was used for data analysis.[24]

FMS.

While the FMS (Functional Movement Systems, Chatham, VA) consists of 7 movements, only FMS movements emphasizing the lower limbs were completed and included the deep squat, hurdle step, in-line lunge, and active straight leg raise. 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 was scored from 0-3. A score of three indicates successful completion of the movement as described without any compensation. If compensation was present, a score of 2 was given, whereas if the participant could not perform the movement, a score of 1 was given. A score of zero was given if any pain was associated with the movement.

ADLs.

Participants completed three ADLs: sit-to-stand (STS), ascending and descending stairs (STAIRS), and a step-over.

STS.

Participants performed three 30-second STS tests on an armless chair. When instructed, participants began in a seated position and moved to a fully standing position with their arms crossed over their chest, as many times as possible within a timed 30 seconds. The number of fully completed STS repetitions was counted and recorded. 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).[24]

STAIRS.

Participants performed the Step Test Evaluation of Performance on Stairs (STEPS).[27] The test was performed on a standard set of eight stairs with one handrail. Participants were instructed to climb the stairs using the same gait pattern as they normally would, without use of the handrail if possible. Participants were then instructed to return to the bottom of the stairs, again with the use of the handrail and using the same gait pattern they normally would.[27] 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.[24,27]

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.[24]

BESS Test.

Participants performed three dynamic balance stance tests, including a double-leg stance (DLS) with hands on hips and feet together, a single-leg stance (SLS) standing on the non-dominant limb with hands on hips, and a tandem stance (TS) with the non-dominant foot behind the dominant foot in heel-to-toe position. Each stance was completed twice on a firm surface and twice on a foam surface with the eyes closed. For each test, participants were asked to hold the stance for twenty seconds, with the timer starting as soon as they closed their eyes. Each of the stances was scored by counting the number of errors, with each error given 1 point. Therefore, lower scores indicate less errors and better balance. Errors included the following: open eyes, lifting hands off of iliac crest, stumbling/falling, stepping down to regain balance, lifting forefoot or heel, abducting or flexing hip greater than 30 degrees, and failing to return to the test position within 5 seconds.

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. Sample size was calculated utilizing G*Power software (version 3.1.9.3) and a study by Pinto et al.[12] For a mixed-design repeated measures ANOVA, a minimum sample size of 23 across two groups was determined, given a desired study power of 80%, an effect size of 0.80, and a Type I error of 0.05. Thus, the obtained sample size of N = 26 is adequate to test the study hypothesis.

In order to examine the primary purpose, repeated measures mixed design ANOVAs (two time-point, PRE, and POST) were used to analyze differences in FMS, ADLs, and the BESS test between training groups. Significant interactions were further analyzed by a two-timepoint repeated measures ANOVA, splitting the data file by group (QD, FX). Significant main effects for time were further analyzed with post hoc pairwise comparisons using a least significant difference (LSD) correction.

Additionally, Pearson's product correlation (r = 0.4-0.59, moderate correlation; 0.6-0.79 = moderately high correlation; $\geq$ 0.8 = high correlation) was used to determine associations between motor unit recruitment 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 $\pm$ SD. Effect size was reported as partial eta squared (η^2). Data were analyzed using SPSS v28 software (SPSS v.28.0, IBM, Somers, NY).

Results

FMS

Deep Squat.

A time x group interaction was observed for the deep squat average (F = 28.224, p < 0.001, η^2 = 0.777). Post-hoc analysis indicated a main effect of time for the QD group (F = 30.0, p = 0.003, η^2 = 0.857), with a significantly greater score at POST (2.5 $\pm$ 0.22) compared to PRE (0.5 $\pm$ 0.22). No main effect of time was observed for the FX group (F = 6.818, p = 0.080, η^2 = 0.694).

Hurdle-Step.

No significant interaction (F = 0.170, p = 0.691, η^2 = 0.021) was observed for hurdle-step non-dominant or dominant (F = 2.971, p = 0.123, η^2 = 0.271). However, a main effect of time (F = 16.897, p = 0.003, η^2 = 0.679) was observed for hurdle-step nondominant, with a significantly greater score at POST (2.167 + 0.160) compared to PRE (1.521 + 0.256) regardless of the training group. Additionally, a main effect of time was observed for hurdle-step dominant (F = 3.602, p = 0.034, η^2 = 0.310), with a significantly greater score at POST (2.59 ± 0.241) compared to PRE (0.5 ± .322)

In-Line Lunge.

A time x group interaction was observed for the in-line lunge non-dominant (F = 7.396, p = 0.026, η^2 = 0.480), with a main effect of time for the QD group (F = 28.26, p = 0.041, η^2 = 0.857) and a significantly greater score at POST (2.3 ± 0.24) compared to PRE (1.56 ± 0.16). No main effect of time (F = 1.752, p = 0.058, η^2 = 0.388) was observed for the FX training group. A time x group interaction was also observed for the in-line lunge dominant (F = 9.437, p = 0.015, η^2 = 0.541). Post-hoc analysis indicated a main effect of time for the QD group (F = 14.412, p = 0.013, η^2 = 0.742), with a significantly greater score at POST (2.6 ± 0.20) compared to PRE (1.42 ± 0.10). No main effect of time was observed for the FX group (F = 0.60, p = 0.495, η^2 = 0.167).

Active Straight-Leg Raise.

No significant interaction (F = 0.032, p = 0.863, η^2 = 0.004) or main effect of time (F = 0.032, p = 0.863, η^2 = 0.100) was observed for the active straight leg raise left.

Table 1. FMS Scores at PRE and POST Following QD or FX Training

	Deep Squat		Hurdle Step Nondominant		Hurdle Step Dominant		In-Line Lunge Nondominant		In-Line Lunge Dominant	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
QD	0.5 ± 0.22	2.5 ± 0.22*	1.44 ± 0.16	2.0 ± 0.8	0.5 ± 0.21	2.44 ± 0.16	1.56 ± 0.16	2.3 ± 0.24*	1.42 ± 0.10	2.6 ± 0.20*
FX	0.5 ± .5	0.66 ± 0.8	1.56 ± 0.18	2.25 ± 0.21	0.67 ± 0.19	2.92 ± 0.23	1.75 ± 0.18	1.8 ± 0.24	1.3 ± 0.18	1.33 ± 0.20

*Significantly greater at POST compared to PRE. Results are presented as mean ± SD. QD = Quad-dominant training, FX = Functional training.

ADLs

STS.

A time x group interaction was observed for STS completed (F = 13.474, p = 0.004, η^2 = 0.574). Post-hoc analysis indicated a main effect of time (F = 25.423, p = 0.004, η^2 = 0.836) for the QD group, with a significantly greater score at POST (18.67 ± 1.02) compared to PRE (12.33 ± 0.84). No main effect of time (F = 1.875, p = 0.229, η^2 = 0.273) was observed for the FX group.

Stepping-Over.

A time x group interaction was observed for stepping over nondominant (F = 10.946, p = 0.008, η^2 = 0.523). Post-hoc analysis indicated a main effect of time (F = 62.50, p < 0.001, η^2 = 0.926) for the FX group, with a significantly greater score at POST (3.0 ± 0.0) compared to PRE (1.33 ± 0.21). No main effect of time (F = 0.172, p = 0.695, η^2 = 0.033) was observed for the QD group. A time x group interaction was observed for stepping over dominant (F = 12.448, p = 0.005, η^2 = 0.555).

Post-hoc analysis indicated a main effect of time ($F = 49.828$, $p < 0.001$, $\eta^2 = 0.909$) for the FX group, with a significantly greater score at POST (3.0 ± 0.0) compared to PRE (1.58 ± 0.2). No main effect of time ($F = 0.172$, $p = 0.695$, $\eta^2 = 0.033$) was observed for the QD group.

STAIRS.

A time x group interaction was observed for STAIRS ($F = 5.293$, $p = 0.044$, $\eta^2 = 0.346$). Post-hoc analysis indicated a main effect of time ($F = 10.435$, $p = 0.023$, $\eta^2 = 0.676$) for the QD group, with a significantly greater score at POST (19.0 ± 0.63) compared to PRE (15.0 ± 0.68). No main effect of time ($F = 1.923$, $p = 0.224$, $\eta^2 = 0.278$) was observed for the FX group.

Table 2. ADL performance at PRE and POST following QD and FX Training Programs

	STS		Stepping-Over Nondominant		Stepping-Over Dominant		STAIRS	
	PRE	**POST**	**PRE**	**POST**	**PRE**	**POST**	**PRE**	**POST**
QD	12.33 ± 0.84	18.67 ± 1.02*	1.30 ± 0.39	1.31 ± 0.19	1.5 ± 0.214	1.58 ± 0.16	15.0 ± 0.68	19.0 ± 0.63*
FX	11.13 ± 1.09	13.33 ± 1.11	1.33 ± 0.21	3.0 ± 0.0*	1.58 ± 0.2	3.0 ± 0.0*	14.65 ± 0.8	15.1 ± 1.14

Significantly greater ADL performance at POST compared to PRE. Results are presented as mean ± SD; QD = Quad-dominant training, FX = Functional training, STS = sit-to-stand

CKC Motor Unit Recruitment

A time x group interaction was observed for RMS of the VL during a BLSQ ($F = 15.172$, $p = 0.006$, $\eta^2 = 0.684$). Post-hoc analysis indicated a main effect of time ($F = 37.5$, $p = 0.004$, $\eta^2 = 0.904$) for the QD group with significantly greater RMS at POST (91.47 ± 25.09) compared to PRE (77.08 ± 23.12). No main effect of time ($F = 3.003$, $p = 0.182$, $\eta^2 = 0.500$) was observed for the FX group. No significant interaction or main effect of time was observed for RMS of the BF during the BLSQ ($P > 0.05$).

Table 3. RMS during CKCs at PRE and POST following QD and FX Training Programs.

	BLSQ		FL		SL	
	PRE	**POST**	**PRE**	**POST**	**PRE**	**POST**
QD	77.08 ± 23.12	91.47 ± 25.09*	84.46 ± 23.55	105.1 ± 27.69*	82.66 ± 25.24	106.4 ± 27.25*
FX	75.12 ± 19.87	78 ± 23.57	86.48 ± 21.06	88.38 ± 19.32	85.39 ± 21.09	83.99 ± 18.76

*Significantly greater RMS at POST compared to PRE. Results are presented as mean ± SD; QD = Quad-dominant training, FX = Functional training, BLSQ = bilateral squat; FL = front lunge; SL = side lunge

A time x group interaction was also observed for RMS of the VL during a FL ($F = 10.498$, $p = 0.037$, $\eta^2 = 0.663$). A main effect of time ($F = 9.196$, $p = 0.039$, $\eta^2 = 0.697$) was observed for the QD group with significantly greater RMS at POST (105.1 ± 27.69) compared to PRE (84.46 ± 23.55). No main effect of time ($F = 0.043$, $p = 0.85$, $\eta^2 = 0.014$) was observed for the FX group. No significant interaction or main effect of time was observed for RMS of the BF during the FL ($P > 0.05$).

A time x group interaction was also observed for RMS of the VL during a SL ($F = 5.869$, $p = 0.046$, $\eta^2 = 0.456$). A main effect of time ($F = 16.97$, $p = 0.015$, $\eta^2 = 0.809$) was observed for the QD group with significantly greater RMS at POST (106.4 $\pm$ 27.25) compared to PRE (82.66 $\pm$ 25.24). No main effect of time ($F = 0.135$, $p = 0.738$, $\eta^2 = 0.043$) was observed for the FX group. No significant interaction or main effect of time was observed for RMS of the BF during the SL ($P > 0.05$).

BESS

DLS.

No significant interaction ($F = 3.462$, $p = 0.092$, $\eta^2 = 0.257$) or main effect of time ($F = 0.385$, $p = 0.549$, $\eta^2 = 0.037$) was observed for DLS firm. No significant interaction ($F = 0.526$, $p = 0.485$, $\eta^2 = 0.050$) or main effect of time ($F = 2.105$, $p = 0.177$, $\eta^2 = 0.174$) was observed for DLS foam.

SLS.

A significant time x group interaction ($F = 22.857$, $p < 0.001$, $\eta^2 = 0.696$) was observed for SLS firm. Post-hoc analysis indicated a main effect of time ($F = 45.0$, $p = 0.001$, $\eta^2 = 0.90$) for the FX group, with significantly fewer errors at POST (0.833 $\pm$ 0.307) compared to PRE (2.333 $\pm$ 0.333). No main effect of time ($F = 1.0$, $p = 0.363$, $\eta^2 = 0.167$) was observed for the QD group. A significant time x group interaction ($F = 8.421$, $p = 0.016$, $\eta^2 = 0.457$) was observed for SLS foam. Post-hoc analysis indicated a main effect of time ($F = 19.286$, $p = 0.007$, $\eta^2 = 0.794$) for the FX group, with significantly fewer errors at POST (0.667 $\pm$ 0.211) compared to PRE (2.167 $\pm$ 0.307). No main effect of time ($F = 0.294$, $p = 0.611$, $\eta^2 = 0.056$) was observed for the QD group.

TS.

A significant time x group interaction ($F = 9.80$, $p = 0.011$, $\eta^2 = 0.495$) was observed for TS firm. Post-hoc analysis indicated a main effect of time ($F = 16.0$, $p = 0.01$, $\eta^2 = 0.762$) for the FX group, with significantly fewer errors at POST (0.5 $\pm$ 0.224) compared to PRE (1.833 $\pm$ 0.401). No main effect of time ($F = 1.0$, $p = 0.363$, $\eta^2 = 0.167$) was observed for the QD group. A significant time x group interaction ($F = 7.353$, $p = 0.022$, $\eta^2 = 0.424$) was observed for TS foam. Post-hoc analysis indicated a main effect of time ($F = 40.0$, $p = 0.001$, $\eta^2 = 0.889$) for the FX group, with significantly fewer errors at POST (0.5 $\pm$ 0.224) compared to PRE (1.833 $\pm$ 0.401). No main effect of time ($F = 5.0$, $p = 0.076$, $\eta^2 = 0.50$) was observed for the QD group.

Correlations

Moderately high positive correlation was observed between STS and RMS of the VL during a FL ($p = 0.004$, $r = 0.787$), SL ($p = 0.010$, $r = 0.733$), and BLSQ ($p = 0.020$, $r = 0.685$). No correlations were observed between STS and RMS of the BF during any of the CKC exercises. Additionally, moderately high positive correlations were observed between STAIRS and RMS of the VL during a FL ($p = 0.006$, $r = 0.783$), SL ($p = 0.021$, $r = 0.687$), and BLSQ ($p = 0.011$, $r = 0.798$). No correlations were observed between STAIRS and RMS of the BF during any of the CKC exercises.

A moderately high negative correlation was observed between FMS deep-squat average and RMS of the BF during a SL ($p = 0.042$, $r = -0.620$). Furthermore, moderately high negative correlations were observed between FMS in-line lunge dominant and RMS of the BF during a FL ($p = 0.006$, $r = -0.765$), SL ($p = 0.004$, $r = -0.790$), and BLSQ ($p = 0.011$, $r = -0.726$).

Discussion

The development and implementation of effective exercise interventions for maintaining functional ability and independence in older individuals partially depends on the strength of specific musculature involved in the performance of common ADLs,[28] with previous research suggesting that the quadriceps are essential to everyday movements such as sitting down, rising from a chair, and stair-climbing.[29] The results of the present study indicate that a QD resistance training program improves performance in lower body functional movements, including the deep-squat, in-line lunge, and hurdle-step. Furthermore, a QD training program led to improvements in ADLs, including STS and STAIRS, with no changes in these ADLs observed following the FX training. Greater motor unit recruitment of the VL was observed following the QD training program, with no improvements following the FX training. Furthermore, results of the present study suggest that functional performance and ADLs may be attributed to motor unit recruitment of the hamstring and quadriceps muscles. Specifically, higher motor unit recruitment of the hamstring muscle may coincide with reduced functional ability, whereas increased activation of the quadriceps may be related to enhanced performance on ADLs.

Previous studies have demonstrated a positive relationship between strength and functional performance, and have suggested that the greater decline in leg extension strength associated with age[11] may be a major contributor to age-related decrements in functional performance.[3] In addition, previous studies have determined that large quadriceps strength deficits may negatively impact the performance of tasks such as walking and standing up from a chair[30] and that strength training programs emphasizing quadriceps musculature may be an effective preventative measure for older individuals who are at increased risk for functional decline.[11] In the present study, a QD training program resulted in more improvements in lower-body functional movements and ADLs compared to the FX training program. In contrast, Schlicht et al,[31] examined the effects of an eight-week, three-day per week intense lower-body strength training program on functional ability and found that strength training alone does not enhance STS performance in adults aged 61-87. In comparison to Schlicht et al,[31] other studies on older individuals used a slightly higher training stimulus[32] or a less intense intervention[33,34] and found no effect of strength training on STS or other functional movements. The contrasting results between the present study and those of these previous authors are likely due to differences in interventions, as while there was an emphasis on lower-body training, none of those above studies emphasized leg extensor strength specifically. Differences may also be due to training intensity, training volume, or the age and sex of the participants. Similar to the present study, a five-week isometric quadriceps training program showed beneficial effects on quadriceps strength and functional ability in individuals aged 40-65.[10] Additionally, Teixeria et al,[9] investigated the impact of an 18-week progressive muscular strength program on the muscle strength of the quadriceps and a timed up and go (TUG) test. The intervention group experienced significant improvements in the TUG test compared to a control group and an average increase of 76% in maximal dynamic strength of the quadriceps muscle. [9] The study suggests that progressive training for the quadricep group is effective in improving the performance of ADLs.[9] While very few studies have examined the effectiveness of a QD training program on functional performance in the older population, the results of the present study, in combination with the results of Anwer et al,[10] and Teixeria et al,[9] suggest that training interventions that substantially emphasize the leg extensor muscles may be effective in improving functional ability and ADL performance. However, due to limited research in this area, more studies are needed to validate these findings and further understand the impact of QD training on functional performance.

In the present study, the FX training did not significantly improve the FMS deep-squat, FMS in-line lunge, or ADLs, including STS and STAIRS. Similarly, a study investigating the effects of a 12-week functional training intervention in older females determined that the exercise program was insufficient to improve functional ability performance during a timed-up-and-go (TUG) and functional reach test.[35] Conversely, a study by De Matos et al,[13] investigated the effects of an eight-week functional training program on the autonomy of older females. It was demonstrated that 20 functional training sessions were sufficient in improving walking ability and sitting and rising from a chair.[13] The difference in results between the present study and De Matos et al,[13] is likely due to the training interventions used. The study by De Matos et al,[13] encompassed various motor and physical abilities, including endurance, balance, agility, strength, flexibility, coordination, and speed, which were not directly incorporated into the FX training program in the present study. Similar to De Matos et al[13], Kim et al,[36] investigated the effects of corrective exercises on functional movement and observed improvements in Selective Functional Movement Assessment (SFMA) scores and the deep squat movement.[36] These results are in contrast to the present study, which may be due to a difference in participants, as the study by Kim et al,[36] involved middle-aged women (40-59 yrs). Additionally, while the protocol utilized by Kim et al,[36] was only four weeks, and the study by De Matos et al,[13] included fewer sessions than the present study, participants in both studies completed more total corrective exercises during each training session. Therefore, the FX training program in the present study may have resulted in greater improvements in functional movement and ADLs if more time was spent on FMS corrective exercises. Similar to the present study, Oleksiak et al,[16] investigated the effects of corrective exercises on the FMS deep-squat and determined that a functional training program was insufficient to improve mobility during the deep-squat movement. However, the study observed improvements in the deep squat if the test was performed immediately after the corrective exercises, suggesting that corrective exercises result in short-term improvements. It is worth noting that while the FX training program in the present study did not result in improvements in STS or STAIRS ADLs or the FMS deep-squat or in-line lunge, the FX training did result in significant improvements in balance during a SLS and TS on both a firm and foam surface. In contrast, the QD training program did not improve balance. These findings are similar to the results of previous studies, which demonstrated improved balance in older individuals following eight-week[29] and 12-week,[37] three-times per week functional training programs. Additionally, Pacheco et al,[8] examined the effects of 24 functional vs. strength training sessions in older adults on the Y-Balance Test and determined that only the functional training program resulted in balance improvements. In the present study, the FX training program improved the FMS hurdle-step and the stepping over ADL. The FMS hurdle-step, similar to the stepping over ADL movement, assesses the body's ability to maintain balance in a single-leg stance while moving the other leg to step over a hurdle, and therefore, the improvements in these movements are likely due to the increased balance that resulted from the

FX training program, compared to the QD program. It has been suggested that improvement in functional performance tends to coincide with greater balance. Additionally, balance disorders are one of the leading causes of falls in older adults and often lead to loss of independence.[31] Therefore, it may be beneficial to incorporate corrective functional movements to mitigate fall risk, which is frequently associated with difficulties in maintaining balance and postural control while performing ADLs.[38]

Previous studies have observed significant strength gains in older adults following strength training programs,[39] and it has been suggested that these strength improvements are largely due to neural adaptations, such as enhanced motor unit recruitment.[20] Additionally, a link between motor unit recruitment and muscle strength has been demonstrated, with previous researchers observing a significant increase in motor unit recruitment of the VL following a six-month strength training program in middle-aged adults that was associated with increased strength of the leg extensors.[18] A positive relationship exists between muscle strength and functional performance, as observed by Pinto et al,[12] who demonstrated a positive relationship between quadriceps strength and performance on a 30-second sit-to-stand test following a six-week strength training program in older adults. Similarly, there is a relationship between low quadriceps strength and dependence in ADL performance.[6] Greater motor unit recruitment of the VL was observed during CKC exercises following the QD training program, with no increases observed following the FX training program. Given these results, in combination with the improvements in ADLs and functional movement following the QD training program, it is reasonable to suspect that increases in motor unit recruitment of the leg extensor musculature and improvements in functional performance may be linked. Furthermore, the significant positive correlations between STS and RMS of the VL and STAIRS and RMS of the VL suggest that increased quadricep activation may coincide with enhanced ADL ability. Additionally, the significant negative correlations between functional movements and motor unit recruitment of the BF suggest that increases in motor unit recruitment of the hamstrings may coincide with reduced ADL ability. The hamstring: quadriceps ratio (H:Q), used to assess the net balance of muscles around the knee joint, is indicative of muscle function. While the present study did not analyze the H:Q ratio, the present results are in agreement with previous authors who have suggested that greater H:Q ratios in order adults, specifically, greater hamstring strength relative to the quadriceps muscle may be a limiting factor in the performance of functional movements and corresponding activities of daily living.[3,40,41] Similarly, a previous study investigating the relationship between the H:Q ratio and ADLs and functional movements in older adults demonstrated similar relationships between the motor unit recruitment of the quadriceps, hamstrings, and ADL performance. Specifically, high motor unit recruitment of the hamstring muscle coincided with reduced functional ability in males, and high MU recruitment of the vastus lateralis coincided with enhanced functional ability in females.[24] Results of the present study, in combination with previous literature, demonstrate the importance of motor unit recruitment of the quadriceps musculature in the successful performance of ADLs.

This study is not without limitations. One limitation is that data was only collected on participants with no contraindications to exercise, including cardiovascular disease, stroke, acute or ongoing neuromuscular disease, or musculoskeletal injuries; therefore, results may not be applied to the general aging population. Furthermore, diet was not controlled throughout the duration of the study, which may have influenced muscle adaptations. Additionally, no follow-up assessment was completed after the post-testing, so it is unclear whether participants continued to adhere to the training program or if improvements in ADL performance and functional ability were sustained over time. Furthermore, conclusions may not reflect neuromuscular responses of lateral and medial hamstring and quadriceps muscles, as only EMG of the vastus lateralis and biceps femoris was considered. Additionally, while joint angle and trunk position were monitored throughout the CKC exercises, slight changes may have altered the muscle activation. Lastly, the study did not directly measure muscular strength or muscle mass, and therefore, could not demonstrate a direct relationship between these variables and functional performance.

The results of the present study demonstrate that a QD training program results in greater functional movement ability, increased performance in ADLs, and increased MU recruitment of the VL compared to a FX training program. These results, combined with those of previous studies, highlight the importance of implementing training programs in the older population that substantially emphasize leg extensor muscle strength. The present study also demonstrated a positive relationship between RMS of the VL and FMS and ADL performance, whereas increased RMS of the BF was negatively associated with FMS performance. These findings suggest that enhanced MU recruitment of the leg extensor muscles coincides with enhanced functional capabilities, whereas increased MU recruitment of the leg flexors may coincide with decrements in functional ability. While the QD training program resulted in more improvements in functional movement, ADLs, and MU recruitment, the FX training program resulted in improved balance, which was likely responsible for the improvements observed in the FMS hurdle-step and ADL stepping-over movement, which both assess the ability to maintain balance during movement. Considering that poor balance is associated with increased risks of falls when performing ADLs, the effects of a FX training program should be considered. While the study did not examine a combination training program, including both QD and FX movements, it is reasonable to conclude that training programs that emphasize both the quadriceps musculature and incorporate functional corrective exercises may be the most effective in improving ADLs and preventing functional decline in the older population. Therefore, future research may investigate the effectiveness of QD and FX combination training on functional performance ability. Additionally, future research may investigate the effects of QD training on quadriceps cross-sectional area and the associated strength improvements, in relation to functional movements and ADLs.

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Corresponding author: Brittany Followay; followayb@ripon.edu