Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Medicine and Health Sciences
Department of Neuromedicine and Movement Science

Manish Kumar Dawadi

Knee antagonist muscle activity during open and closed kinetic chain exercises among healthy individuals and gender differences.

Master's thesis in Physical Activity and Health
Supervisor: Ann-Katrin Stensdotter
Co-supervisor: Karin Roeleveld
January 2022

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Kunnskap for en bedre verden

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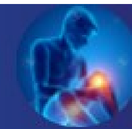
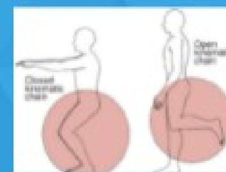
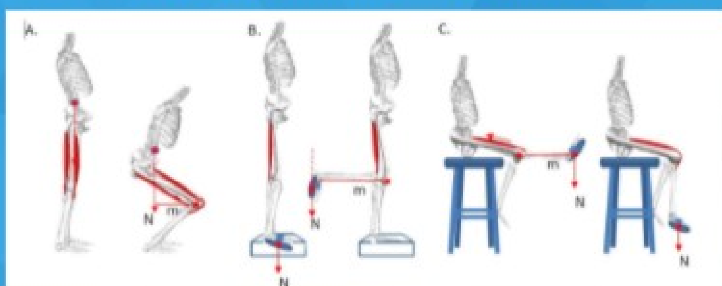
Does our knee muscles behave differently during different exercises?



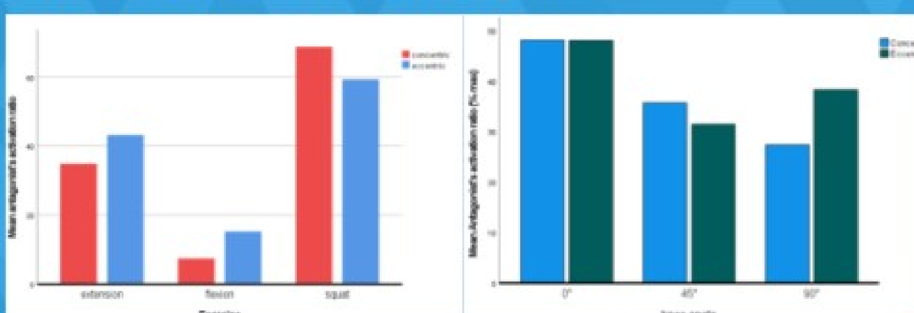
Knee is a complex joint so more understanding is required to know about antagonist activity during open and closed kinetic chain exercises. Antagonist activity changes to provide dynamic stability to the joint depending upon the movement.



Eighteen active students involved in regular sports performed three exercises: **Single leg extension, Single leg flexion and Bilateral squat.**



To access how quadriceps and hamstrings behave differently during these exercises, antagonist activity ratio was calculated and analysed across exercises and gender.



Antagonist activity changes depending upon open and closed kinetic chain activities but does not differ among gender significantly.

This knowledge can be utilized in designing exercises in sports, post knee injury and post surgery rehabilitation.

Abstract

Background: Investigating the antagonists knee muscle activity during open and closed kinetic chain exercises and among gender is not only important to understand knee mechanics among healthy but also its importance in designing effective exercises for sports, post injury and post-surgical rehabilitation of the knee.

Aim: The aim of this study was to investigate the antagonist activity during different open kinetic chain and closed kinetic chain exercises and compare the differences between males and females.

Study Design: Cross sectional study

Methods: 18 healthy and active participants, males (n=9, mean ± SD; age 25.4±2.24 years, height 183.2±7.02 cm, and weight 79.5±8.68 kg) and females (n=9, mean ± SD; age 24.4±2 years, height 167.2±10.9 cm and weight 65.4±10.2 kg) who are involved in regular sports were recruited in the study. Each participant performed seated single leg extension, standing single leg flexion and bilateral knee squat in a movement lab. EMG data obtained were analyzed using MATLAB and repeated measure of analysis of variance to compare antagonist activity ratio across all exercises and groups.

Results: No significant differences were found for antagonist ratio between males and females across all exercises ($F_{3,32}$=1.372, p=0.269, η^2=0.114). The result of analysis of variance between group effect indicated a significant exercises effect, Wilks's Lambda= 0.065, $F_{(6,12)}$ = 28.804, p <0.001, η^2=0.94.

Conclusion: The result of this study confirmed that the antagonist activity is different across different open and closed kinetic chain exercises. However, there was no significant difference between difference between males and females. This knowledge can be used to design both open and closed kinetic exercises among healthy and knee injured individuals.

Acknowledgements

Foremost, I would like to express my sincere thanks of gratitude to my supervisor Prof. Ann-Katrin Stensdotter for the continuous support of my master thesis project, for always being positive, encouraging and supportive through all the time. Her guidance helped me throughout research and writing of this thesis. I could not have imagined having a better advisor for my project. Besides my supervisor, I would also like to express my gratitude toward Prof. Karin Roeleveld for her support and insightful comments, which helped me with analysis of this project.

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I would also like to thank my wife Rejina, who supported and stayed with me through all the ups and downs and always encouraging me to work harder and refreshing the journey. Finally, I would like to praise and thank my family and God, the Almighty for showering blessing and love during difficult moment of my life and guiding me towards better health and this day.

Manish Kumar Dawadi, January 2022

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List of abbreviations

ACL	Anterior cruciate ligament
EMG	Electromyography
OKC	Open kinetic chain
CKC	Closed kinetic chain
SLE	Single leg extension
SLF	Single leg flexion
BS	Bilateral squat
BMI	Body mass index
NTNU	Norwegian University of Science and Technology
REC	Regional Ethical Committee
DPIA	Data Protection Impact Assessment
GDPR	General Data Protection Regulation
SD	Standard Deviation

1.Introduction

In sports, 10-25% of all injuries occur to the knee. It has increased the economic burden of surgical treatment and extensive rehabilitation. In developing countries, limitations related to effective strategies of treatment and access to high level care leads to long term disability and impedes participation in sports and other recreational activities [1]. Knowledge of the knee joint and control of the same is essential in sports training, rehabilitation, and surgery. Knee joint mechanics are not only dependent on the bony structures and ligamentous stability, but how also the activity of the muscles that crosses the knee controls the articulation between joint surfaces. This muscle activity is also dependent on the environment as well as the task and how interaction occurs with the nervous system that triggers muscle activation. Although numerous studies have investigated the agonist and antagonist muscle co-activity that provides dynamic stability to the knee joint [2, 3], knowledge of its interaction during different type of movements are still scarce. There is no clear understanding how different the antagonists act relative to the agonists during different types and modes of exercises in normal healthy young individuals or in males versus females.

1.1 Knee: Overview and Mechanics

The knee is a complex joint with non-uniform articular surfaces of tibia and femur. This asymmetric structure does not allow simple movement as a hinge joint but rather a polycentric motion [4]. While flexion-extension is the primary motion in the knee joint, secondarily motions like anterior-posterior translation, internal-external rotation and abduction-adduction occurs within the joint to fulfil primary function. These secondary motions couples with flexion and extension during the movement in the knee joint and are affected by weight bearing or non-weight bearing activities [5] and so does the muscle activity. Being a complex joint, the knee has multiple muscles acting on it at the same time during joint motion. The quadriceps is a group of muscle that lies anterior to the knee and are prime agonists for knee extension and rectus femoris being secondary hip flexors [6], while the hamstrings are the group of muscles that lies posterior to the knee and works primarily as agonists for knee flexion and secondarily to support hip extension. Apart from their primary role in knee motion these muscles along with all other muscles surrounding knee joint work as secondary stabilizers to the ligaments and the joint capsule of the knee during active knee movement [7]. The motor control of the knee depends on the type of activity, amount of load acting on it [8], and the joint specific response based on afferent input [9]. Females have different motor control strategies than males [10] that alters the knee motion pattern [11] and demonstrate higher level of co-activation. It is essential to assess the amount of contraction in the antagonist of the knee during extension exercises and measure if it differs depending upon the type of activity and gender. The extensional forces across the knee of the quadriceps pulls the tibia anteriorly while the anterior cruciate ligament (ACL) resists the motions of anterior tibial translation and internal tibial rotation and provides rotational stability of the knee. The hamstring in contrast works medially and laterally restricting anterior translation [12]. The complex interaction of these structures allows the knee to withstand a tremendous complex six degrees of freedom of motion [4, 13]. This complexity is one of the reasons motivating evaluating and understanding of the knee joint.

1.2 Open vs Closed Exercises

During open kinetic chain (OKC) exercises also called non weight bearing movements, the distal end of the segments is moving while the proximal segments are stabilized. Similarly, proximal segments moves while distal segments are fixed during closed kinetic chain (CKC) exercises or weight bearing movements [3]. Due to this, OKC allows for single segments to move, or isolated joint movement like in unilateral single knee flexion in standing or seated knee extension. In contrast, in a task such as (bilateral) squat, more than one segment must move as single joint movement is not possible in CKC. The role of the hamstring is contradictory during open and closed chain activities as reported by previous research [3]. There has been a long debate among practices either to use open or closed kinetic chain exercises during rehabilitation after ACL injury [3]. In previous practices, closed kinetic chain exercise had been accepted more widely as being safer and more popular for knee rehabilitation over open kinetic chain exercises [14]. A randomized control trial conducted among ACL deficient individuals found open chain exercise being superior to improve quadriceps strength [15], while other studies found a combination of both being more effective for earlier return to sport [14, 16]. Meanwhile, the role of the hamstrings has been questioned. However, most of these studies on knee joint stability have been conducted either concerning rehabilitation post ACL reconstructive surgery with focus on quadriceps activity or increased anterior tibial translation following ACL injury [15, 17, 18]. There is limited knowledge whether and how the activation pattern of these muscles' changes after knee injury, in particular for the ACL which plays an important role in knee joint stability. Furthermore, there is also scarce knowledge of how these muscles behave in OKC and CKC tasks in the intact knee. Such information could be used to design exercise in sports, post-injury and post-surgical rehabilitation.

1.3 Antagonists Activity and Motor Control

The simultaneous muscle activity in agonists and antagonists' groups that occurs while contracting voluntarily in static or dynamic state is mentioned as antagonist muscle co-activity [19]. Antagonistic activity is regulated by central spinal and peripheral neuronal mechanisms [20]. Co-contraction of agonists and antagonists during active knee movements have been reported in both OKC and CKC exercises contributing to active joint stabilization [20-22]. The relationship between thigh muscle agonists and antagonists, their coactivations and role in knee stability in ACL deficient knees, has been documented

multiple times electromyographically (EMG) [23-25]. An EMG study [17] found that larger muscle co-activation was found in a weight bearing position (squats) than in a non-weight bearing position, while anterior tibial translation due to increased anterior shear forces was greater in active extension of the knee in non-weight bearing position. They also reported low levels of muscle activation seen in the hamstrings during active knee extension exercises. The role of hamstrings seems to alter depending upon weightbearing or non-weight bearing tasks [22]. Reports on the ratio of agonist-antagonist co-activation in open chain exercises are contradictory. Some studies have documented co-activation seen during OKC while other have demonstrated the opposite. Most of the studies done before looking into closed and open chain has been done using a Biodex or other isokinetic instruments [21, 26]. However, no study has been conducted so far to compare the level of antagonistic activity during open and closed chain exercise just using only body weight that represents more of regular and practical setting and compared within and between the different modes of activity and between gender.
Other factors that affect the role of the quadriceps and hamstrings are one joint movement or two joint movement and movement velocity. A study found that the higher the velocity, lower the amplitude of surface EMG of quadriceps and hamstring and vice-versa [27]. To keep it constant, this present study used just one movement velocity throughout all test and all participants.

To understand the agonist and antagonist activity depending upon different types of exercises and across gender it is of importance to develop an understanding of joint mechanics and apply the knowledge onto general healthy as well as persons with knee injury or pathology. Therefore, this present study investigated the agonist-antagonistic activity of hamstrings and quadriceps. The objective was to uncover if and how it differed depending on the type of OKC and CKC exercises, and secondarily if there was any difference between male and female. Our hypothesis was that the role of antagonist activity changes depending upon the closed or open chain activities, and secondarily there would be differences between males and females.

2.Methods

2.1 Participants

Information about the study was advertised through word of mouth among students studying at the master's program physical activity and health at the Norwegian University of Science and Technology (NTNU), by posters and through social media. Twenty-one healthy individuals (11 males and 10 females) between 21-29 years of age involved in regular sport or exercise activity and without history of knee injury were recruited into the study (Table 1). Participants with dominant right leg and able to perform the test protocol exercises were included. Exclusion criteria were lower limb surgery, history of meniscal injury, injury to the anterior or posterior cruciate ligament, severe pain, musculoskeletal or neurological conditions interfering with performance of the knee movement testing protocol. Two males and one female were excluded from the study as they did not meet the inclusion criteria or unsatisfactory data quality. The flowchart (Figure 1) shows the participants' inclusion and exclusion from the study.

Table 1. *Mean and standard deviation (SD) of demographic and anthropometric measures among the healthy participants.*

Demographic	**Male (n=9)**	**Female (n=9)**	**p-value**
Age (years)	25.44 (2.24)	24.44 (2.007)	0.334
Height (cm)	183.21 (7.02)	167.24 (10.99)	0.002
Weight (kg)	79.53 (8.68)	65.44 (10.28)	0.006
BMI	23.66 (1.59)	23.38 (3.14)	0.813

n is number of participants. BMI- Body mass index.

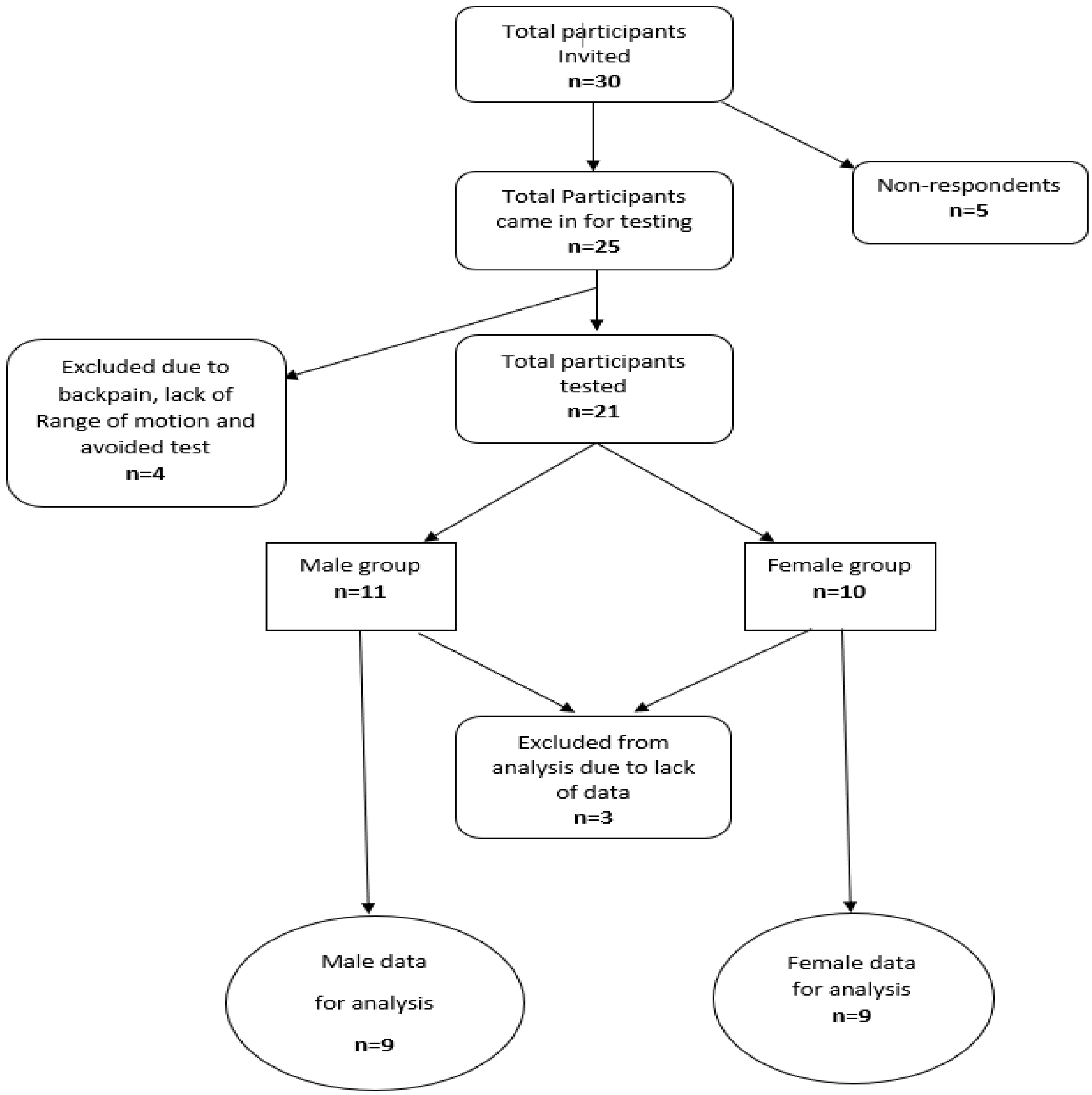


Figure 1. Flowchart of included participants

2.2 Ethics

All the information regarding the study was explained to the subjects and a signed written consent was obtained from each participant before the lab session. The study was approved by the Regional Ethical Committee (REC 169385), registered in Data Protection Impact Assessment (DPIA) for General Data Protection Regulation (GDPR) and conducted in accordance with the Helsinki Declaration (1964). Special COVID-19 regulations were followed according to NTNU safety regulations in the lab during the session. A list of safety checks regarding COVID-19 was followed to make sure that the participants had no symptoms related to COVID-19 or had been exposed to any affected persons recently. Participants signed a declaration and supplied their mobile number for tracking if needed.

2.3 Testing Procedures

The participants were invited to the Next Move movement lab for a single lab session. Once participants came in, the COVID-19 checklist form and the consent form were given to the participant and the test leader explained the procedures of the session. Participants' body height, weight and the stance width between feet were measured. Before the actual testing the participants were familiarized with the three different tasks they had to perform. This study was a part of a larger project also investigating the helical axis of the knee joint. A single lab session was performed to obtain both kinetic and kinematic data, and data for muscle activity for the present part of the project. Muscle activity was registered by surface EMG (Noraxon, USA). Before electrode placement, skin preparation was done rubbing the skin with alcohol. Some participants needed shaving of the hairs around the electrode placement area, and it was done with the consent from the participants. One participant who volunteered for the study refused to shave the hairs and was discontinued for a lab session. Disposable Ag–AgCl surface EMG electrodes (Ambu® Blue Sensor N) were placed, following the Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM) guidelines [28], over the muscle belly of the rectus femoris, vastus medialis, vastus lateralis, biceps femoris, and semitendinosus on the right leg. The electrodes were attached in a bipolar arrangement along the direction of the muscle fibers with an inter-electrode distance of 20 mm between the centers of the electrodes. Surface EMG was recorded from the muscles by using a wireless data acquisition system (Noraxon TeleMyo DTS).

2.4 Testing Protocol

Three exercises were designed to create different loading conditions across the tibio-femoral joint, with emphasis on shear, traction, and compressive forces. These three exercises demonstrated CKC bilateral squats imposing compressive forces in knee joint and muscle co-contraction and open kinetic chain OKC unilateral standing knee flexion with hamstring being prime agonists and unilateral seated knee extension with quadriceps primarily being agonists.

Ten repetitions of each dynamic exercises were performed ranging 0-90° (0°= full extension) along the paced auditory signal generated at 30 beats per minute, (Fine Metronome 3.4 software, Fine Software Inc, USA) to achieve a standard angular velocity, approximately 45°/s and a brief hold at each end of the movement. All exercises were performed without shoes and arms across the shoulder. All three exercises were performed in the same order of squat, single leg standing knee flexion, and seated unilateral knee extension. For open chain exercises, a 2 kg weight was applied around the foot to increase the load of the shank to amplify the effect of the shearing and traction forces.

A. Bilateral Squat (BS)

For closed kinetic chain exercise, bilateral squats (BS) were performed with the feet at shoulder width apart and feet pointing straight forward. Wood blocks of one centimeter height were placed at under the hind foot allowing heel raise to enable individuals to keep their torso upright while squatting in order to standardize performance. Elastic thread was placed behind the participants where they stood for testing to give them a cue to reach 90° knee flexion. The 90° range was pre-measured using plastic 360° goniometer (Chattanooga ©).

B. Single Leg Flexion (SLF)

For open kinetic chain exercise, single leg flexion (SLF) in standing was performed with the stance leg on a step-up wooden plat form (approx. 7 cm) to allow the testing leg to hang freely in full extension in order to minimize torque at the knee in 0° and increase joint traction. During the flexion, thighs were kept parallel to prevent flexion at the hip joint (Figure 2). Verbal cues were given and an elastic thread barrier was kept behind to limit the flexion to approximately 90° after goniometric measurement.

C. Single Leg Extension (SLE)

For another open kinetic chain exercise seated single leg extension (SLE) was performed with participants sitting in a highchair while the thigh was supported with a cushion to secure the femur in a horizontal position and shank at vertical position at 90° knee flexion for maximum versus minimum torque across the knee joint. Verbal cues were given to extend the knee as possible to reach approximately 0° extension.

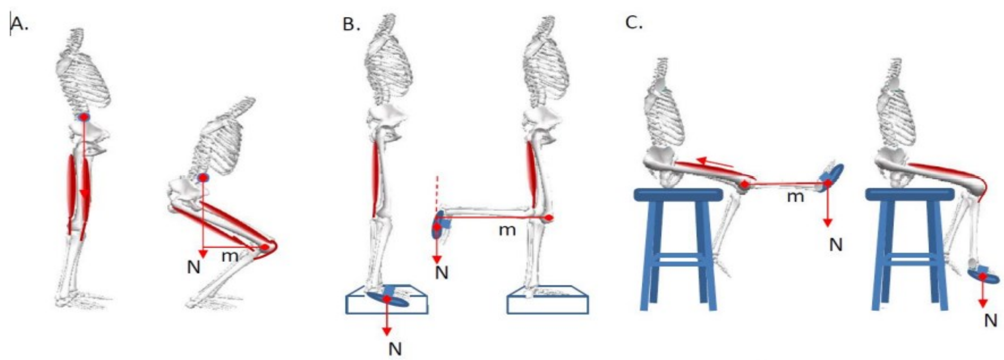


Figure 2.Schematic illustrations of tasks. A. Closed chain bilateral squat (BS): First figure shows knee at approximately 0° where minimal moment across the knee and second picture with knee at approx. 90° maximal moment. Compressive forces in the tibiofemoral joint are created and co-contraction of muscles expected. B. Open chain single leg flexion (SLF): First figure shows knee at approximately 0° where minimal moment across the knee joint where the leg hangs freely to create traction across the joint and second with knee at approx. 90° shows maximal moment where posterior shear forces are expected when the hamstrings as prime knee flexors pull at the tibia. C. Open chain seated leg extension (SLE): First figure with knee at approx. 0° shows the maximal moment across the knee joint where quadriceps pulls the knee into extension as prime extensors and second figure where knee is at approx. 90° shows minimal moment across knee when leg hangs freely.

In order to get a baseline graph of EMG, participants were asked to step on the testing platform once the test began and hold steady for an initial 10 seconds after finding the correct starting position. After repeating 10 movements along the beat, participants stayed still for 5 more seconds and then came to ease. Manual inspection of EMG activity was checked to make sure the EMG data collected were smooth and clean, asking participants to contract each muscle then be at rest.

2.5 Data analysis

For the EMG analysis out of 21 sets of data obtained, two males and one female were discarded as either they were missing data or the MATLAB analysis script failed to read it. Hence, a total of 9 males and 9 females' data were used for data analysis. The raw EMG obtained from the activities were full wave rectified and smoothed, as the signal becomes qualitatively reliable to the muscle activity [29]. All EMG signals were filtered with high pass filter at 5 Hz and low pass filter at 200 Hz and finally smoothened by moving RMS average. To make an easier analysis different component of hamstrings and quadriceps were averaged and collectively termed as agonists and antagonists here after in the study. The muscle activity in this study would be collectively representative of hamstring and quadriceps. Each hamstrings and quadriceps EMG were normalized individually against the activity of relative muscles at its maximal activity across all exercise and subjects. This is based on the effort required by individual muscles to perform the test based on each exercise with a load of shank and 2 kg weight tied to the foot, or squat with body weight. This value is assigned as 100 % and all other values were expressed as a % max for each muscle. From the 10 repetitions of each set, the first and last repetition was discarded as it is known to be not equally representative as the rest of the repetition in the set [30]. Each repetition was divided into concentric and eccentric phase and each phase into 20 points of total phase range. Mean of first three points were used to represent 0° where leg is at starting position, mean of middle four as 45° where leg is at middle and mean of last three points as a representative of 90° where leg is at end of the phase for standing SLE and BS. For the seated SLE the opposite applies as the knee is in 90° at the start, and 0° at the end phase.

The agonist-antagonist ratio was calculated as antagonist / agonist x 100. For the BS and SLE exercises the quadriceps are agonists and the hamstrings antagonists. For SLF the opposite is true.

2.6 Statistics

Repeated-measure multi-level ANOVA was used to calculate the effects of within- and between factors for each antagonistic ratio variables. "Group" (male and female) and Phase (concentric and eccentric) was set as between group factor and "exercise" (Extension, flexion and squat) and range (0°, 45° and 90°) was set as a within group factor. The mean of all these factors were used in statistical analysis. Pairwise comparison of all the exercises were done across gender, different phases and knee angles. The level of significance was set at 0.05.

3. Results

3.1 Antagonist muscle activity

The degree of antagonist's activity was always higher in CKC BS than in any other exercises (Table 2 and Figure 3 shows the illustrative details). OKC exercises such as SLE and SLF produced relatively lower % max. antagonist's activity across all knee angles. Overall hamstrings antagonist activity was 3.4 to 4.5 % of relative maximal hamstring activity during single leg extension which was the lowest among all the exercises. The highest antagonist's activity was seen during 90° knee flexion of CKC BS.

Table 2. Measured % max. activity of agonists and antagonists relative to its muscle activity obtained during open and closed kinetic chain exercises across averaged initial (0°), middle (45°) and end (90°) knee angle. (Mean of % max activity ±SEM)

	Single leg extension		Single leg flexion		Bilateral Squats	
Averaged	Quadriceps agonists	Hamstrings antagonists	Quadriceps antagonists	Hamstrings agonists	Quadriceps agonists	Hamstrings antagonists
knee angle	% max activity	% max activity	% max activity	% max activity	% max activity	% max activity
0°	48.3±3.4	16.4±2	4.5±0.9	29.9±2.8	24±2.8	17.4±1.8
45°	23.1±1.4	6.9±3.5	3.4±0.2	59.9±3.2	38.3±1.7	22.8±1.9
90°	9.5±1	3.6±0.4	4.3±0.3	67.7±3.4	66.6±2.4	26.8±2.8

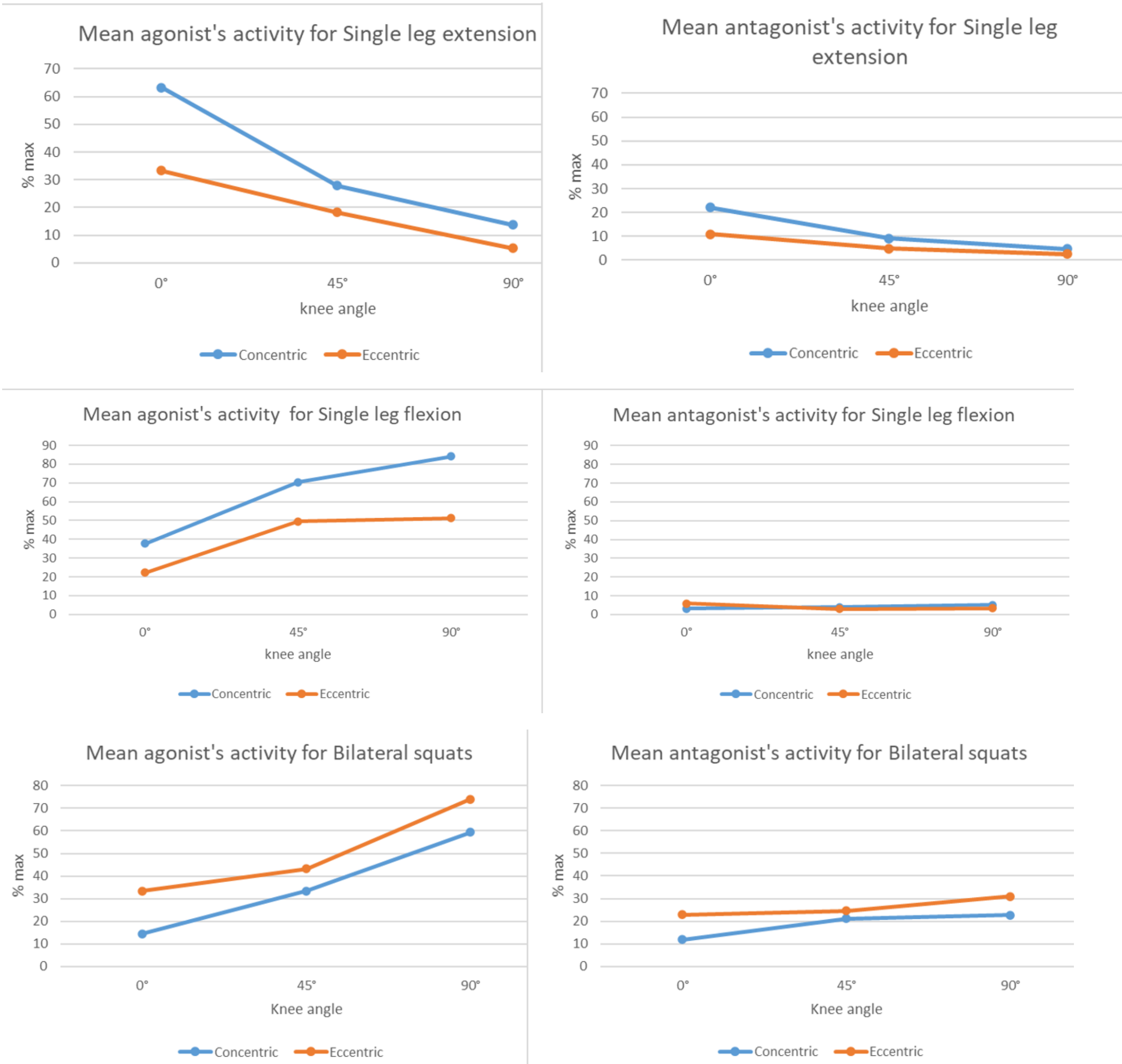


Figure 3. Mean % max agonists and antagonists muscle activity during concentric and eccentric phases of all three open and closed kinetic chain exercises across averaged three knee angles, averaged for all subjects (n=18). Blue lines represent the concentric phase while orange lines represent the eccentric phase of the agonists and antagonist contraction.

3.2 Difference between the gender groups

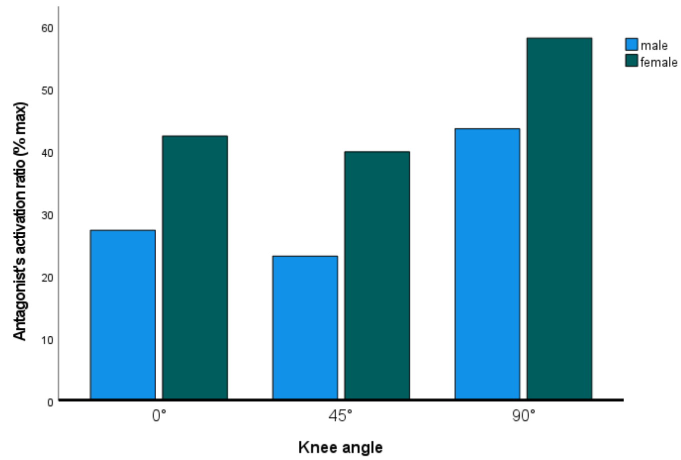
A repeated measures ANOVA was performed to compare the effect of exercises on antagonistic ratios between males and females. There was no statistically significant difference in antagonist activation ratio between male and female across the three exercises ($F_{3,32}$=1.372, p=0.269, η^2=0.114). Similarly, pairwise comparisons for each of the three exercise sets showed no significant differences between males and females. A detailed outcome of pairwise differences across all three exercises between males and females is explained in Table 3.

Table 3. Outcome variable values for three different exercise movements based on gender and its significance with 95% confidence interval. (N=18)

Exercises	Gender	Mean Antagonist's Ratio (in %)	Std. Error	95% Confidence Interval[d] Lower Bound	Upper Bound	Sig.[d](p-value)
SLE[a]	M	31.299	7.87	-31.44	.53	0.580
	F	46.755		-.53	31.44	
SLF[b]	M	11.174	3.36	-7.21	6.44	0.909
	F	11.560		-6.44	7.21	
BS[c]	M	60.450	10.98	-29.42	15.28	0.522
	F	67.552		-15.28	29.42	

Pairwise comparisons based on marginal means.
where, 'M' is male, 'F' female. 'N' is total number of participants.
[a]Seated leg extension
[b]Single leg flexion
[c]Bilateral squat
[d]Adjustment for multiple comparisons: Bonferroni.

However, females tend to have higher antagonist's activity compared to males in most of the cases. Gender differences during all the three exercises at three different knee angles are presented in figure 4.



4A. Marginal means for seated leg extension.

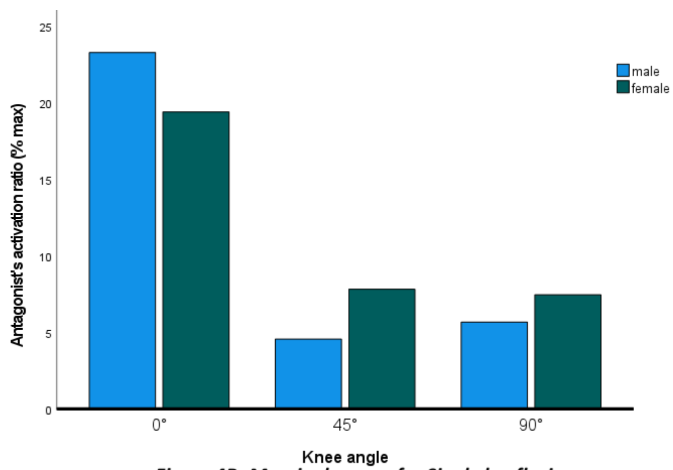


Figure 4B. Marginal means for Single leg flexion

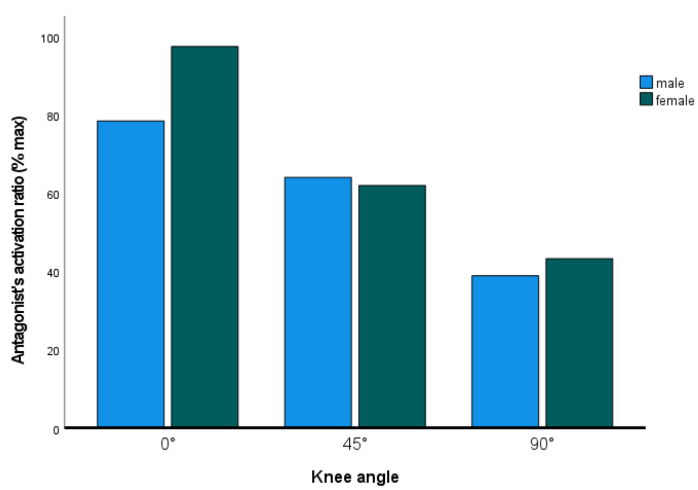


Figure 4C. Marginal means for Bilateral squat

Figure 4. Mean antagonist's activation ratios for mean three knee angles (0°,45° and 90°) for all three exercises tested; 4A. SLE, 4B. SLF and 4C. BS based on the gender differences.

3.3 Differences between the Exercises

Analysis of different exercises showed that the assumption of statistical sphericity was violated for all three sets of exercises tested. A detailed outcome of concentric and eccentric phases of different exercises are presented in Table 4 and Figure 5. The adjusted repeated ANOVA between group effect indicated a significant exercises effect on antagonist ratio across concentric and eccentric phases of exercises, Wilks's Lambda= 0.065, $F_{(6,12)}$ = 28.804, $p < 0.001$, $\eta^2 = 0.94$. However, the adjusted repeated measures ANOVA revealed that the difference in antagonist's activation ratio was not significantly different between the total range of concentric phase of SLE ($F_{1.5,24.7} = 0.664$, $p = 0.477$, $\eta^2 = 0.038$).

Table 4. Mean antagonist's ratio across all three ranges of concentric and eccentric phases of the three exercises with its mean and SD along with differences and its significance value.

	Range	0°	45°	90°		
	Phase	Mean (SD)	Mean (SD)	Mean (SD)	F value	Sig. (p-value)
SLE[a]	Concentric	35.08(21.99)	33.44(20.98)	36.11(25.13)	0.664	0.477
	Eccentric	34.54(21.90)	29.50(23.55)	65.47(44.81)	15.376	<0.001
SLF[b]	Concentric	10.54(10.36)	5.74(2.08)	6.12(2.04)	4.514	<0.047
	Eccentric	32.12(34.57)	6.64(4.14)	7.01(3.01)	10.014	0.006
BS[c]	Concentric	98.52(61.33)	67.88(41.99)	39.81(22.11)	16.234	<0.001
	Eccentric	77.30(43.17)	58.07(28.44)	42.39(20.15)	15.004	<0.001

Values are represented in means, standard deviation (SD), with its differences (F value) and significance (p-value) with alpha set to <0.05.

[a] Single leg extension

[b]Single leg flexion

[c]Bilateral squat

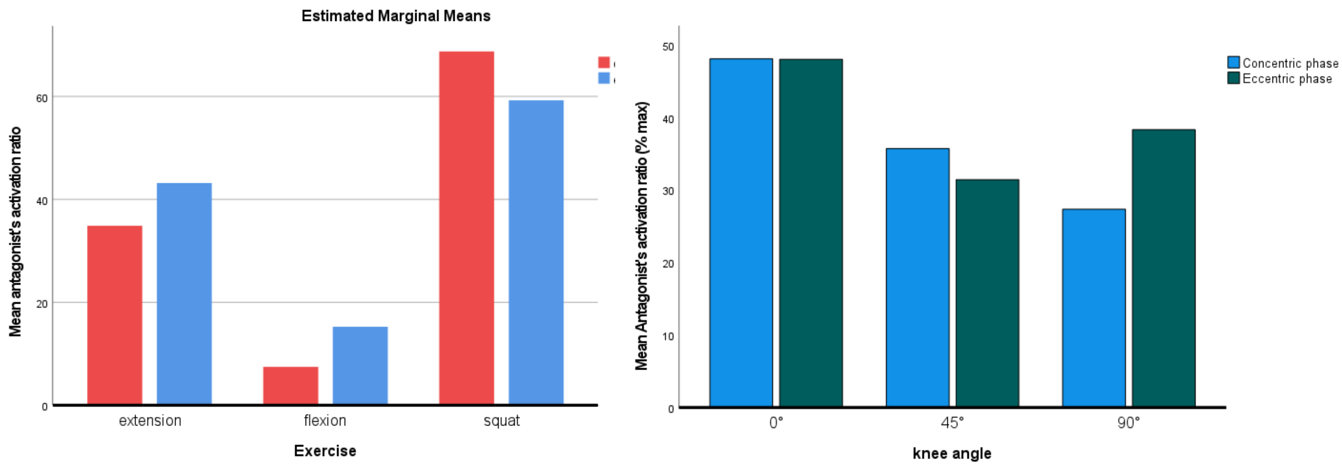


Figure 5. Mean antagonist ratio across concentric and eccentric phases of all three exercises i.e., SLE, SLF and BS and at knee angle of 0°, 45° and 90° averaged across all exercises.

Mean antagonist's activation ratio was reported to be highest during CKC BS and lowest during the open chain unilateral flexion in standing. Also, another distinct finding is that during OKC movement, antagonist's activation ratio was higher in eccentric phase of the movement. In contrast for CKC, the concentric phase generated higher antagonist's activation ratio than the eccentric during closed chain bilateral squat. In terms of the knee angle, manual observation of Figure 5 shows that, at the 0° the antagonist's activation ratio was highest and at same level between concentric and eccentric phase of the exercises irrespective of open or closed chain movement.

4. Discussion

The main purpose of this study was to investigate antagonist's activity relative to the agonist during different OKC and CKC exercises. In addition, the effect of different knee joint angles and phases of knee movements based on quadriceps and hamstring as agonists and antagonists respectively was investigated. This study secondarily also investigated the antagonist's activity during different types of exercises based on the gender. This is the first study to investigate the antagonist's activity of young healthy active individuals without using any type of isokinetic dynamometry but just body weight which is more representative of daily activities.

4.1 Antagonists muscle activity and normalization

Significant amount of hamstring antagonists and quadriceps antagonist's activity were observed throughout the range of knee joint motion (Table 2, Figure 3), as also reported by numerous other similar studies that investigated knee coactivation and hamstring co-activity [21, 26, 31]. Highest antagonist's activity was recorded during CKC BS than in any other OKC exercises. Increased hamstrings antagonist activation was seen during the eccentric phase of BS slightly higher around 90° than around 0°, as also reported by several other studies [3, 31]. In contrast, higher hamstring antagonist activation was recorded during the concentric phase of SLE.

To compare the antagonist's activity, agonist and antagonist muscle activity was normalized relative to individual's maximal activity and presented as percentage maximum. Most previous studies have normalized relative antagonist's activity to its agonist activity [32, 33]. Study on quantification of antagonists activity [34] suggested use of the same muscle's maximal voluntary effort makes it easier to make comparisons between different participants. However, it also stressed to consider the eccentric and concentric phases of antagonist's contraction. Hence, normalization of muscle activity relative to its maximal activity per individuals and task would give more reliable antagonist's activation interpretation in this study.

4.2 Gender differences

The present study found no significant difference comparing the effect of exercises on antagonist activation ratio between the male and female group as illustrated in Table3 and Figure 4. This is in line with one previous study [35] which reported that both muscle activity and ratios were not significantly different between male and female groups. However, that comparison was based on isometric squat. Another study [2] reported significant exercise to gender interaction for quadriceps to hamstring ratio ($F_{3,48}$ =6.63, p=0.001) but only during side-lunge exercise In such activities individual strategies and agility comes into play. In the present study, exercises were designed to minimize personal strategies by standardizing positions, range of motion, and movement velocity. Most of other studies reported females having lower hamstrings to quadriceps ratio [36] with contrast from female handball and football players who have shown relatively higher hamstrings to quadriceps ratios in the dominant leg [37]. A study on neuromuscular adaptation at the knee joint [38] reported that females tend to take longer to generate hamstring torque during isokinetic testing which could be similar to our present study where females demonstrated lower antagonists activation ratio during the beginning (0°) of the OKC SLF which gradually became higher than in males as goes towards 90°. This could be the case in our findings as reported by another study quadriceps gets recruited prior to hamstrings in response to anterior tibial translation [38]. In the present study, females have shown similar antagonists activation ratio compared to males which could be due to the fact that all the females were healthy and involved in regular sports, professionally or as passionately as their male counterparts. Similarly, the test protocol was controlled and constrained to produce isolated knee movement for both male and female groups thus limiting any individual strategies to be adopted during different forms of the exercise testing.

4.3 Antagonist Activity during different Exercises

The primary objective of this study was to investigate the antagonist activity in different exercises and investigate how it changes depending upon OKC and CKC tasks. Several studies have examined the antagonist activity and coactivation based on isokinetic and isotonic knee extension [21, 26, 34, 39] and similar to their findings, this study found significant effects of different exercises on antagonist activation. During CKC, higher compressive force have been reported with higher co-contraction, while maximum shear force but lower compression and lesser co-contraction during OKC exercises [40]. This is in line with the present study where CKC BS showed higher antagonist activation ratio compared to other OKCs, that is, SLE and SLF. One study reported higher antagonist activation during isometric knee extension exercise than short arc knee extension and squat [34]. During OKC and CKC knee extension, the quadriceps create anterior shear force of the tibia, that stresses the ACL [41] and activates a neural reflex pathway that activates the hamstrings [42]. The hamstrings as an antagonist, counteracts agonists activity with co-activation providing stability to the knee joint. Then OKC activities that generates higher anterior shear during knee extension should also lead to increased neural reflex and increased antagonist activation. Another study reported that antagonistic activity is regulated by central, spinal and neuronal mechanisms [20]. This mechanism interacts and develops antagonist activity in both OKC and CKC exercises. This could explain differences in different exercises tested in present study where relatively higher antagonist activation ratio were observed.

Considering angular velocity of the movement tested, a study reported that change in angular velocity alters the antagonist co-activation level across exercises [27]. In the present study however, angular speed of approximately 45° per second was maintained with brief rest at each end points of the exercises. That would limit the present studies comparison as some studies reported that controlled isokinetic activity results in lower antagonist co-activation compared to those observed in CKC activities [34]. It is however difficult to compare different studies as they have different testing protocols and EMG normalization models. In terms of different phases of exercise, the present study revealed that antagonist activation ratio was not significant during concentric phase of SLE. It revealed higher antagonist activation ratio during eccentric phase of OKC than CKC corroborating a previous study that reported that during active knee extension exercises there was a higher anterior tibial translation during eccentric activity that in response increases antagonist activity [17]. Moreover, as eccentric agonist activity is expected to be higher than concentric, greater antagonist activity is expected during eccentric phases [34]. This contrasts with our preset study where CKC demonstrated higher antagonist activation ratio in the concentric phase. Several previous studies have reported that joint position alters the level of antagonist activity in young healthy adults [26, 32]. The present study showed higher antagonist activation ratio during the end of the movement and relatively higher during 0° CKC BS. A study reported increased external torques during CKC across 90°-45° knee flexion promoting antagonist coactivation [3, 31] which was not reflected in the present study result. Thus, it could be discussed that increased activity of both quadriceps as agonists and hamstrings as antagonists is resulting in low antagonist activation ratio. Also, the consideration must be taken how the isolated joint movement produces the agonists and antagonist activity.

4.4 EMG Cross talk

Antagonist muscles EMG signals collected in present study could have been contaminated by the EMG signals of agonists and adjacent muscles [43]. The present study did not perform EMG cross-correlation analysis but used various measures to limit the cross talk [34]. For instance, the surface electrode used had inter-distance of 20 mm, electrodes were placed between distal tendon and innervation zone for each muscle. All the participants recruited in the study were young and physically active having lean mass with minimal adipose tissue around the tested muscles. Skin preparation was done using rubbing alcohol and shaving the excess hair if present. Visual confirmation of EMG amplitude was done in each subject for respective muscle activity to avoid possible cross talk before testing.

4.5 Practical implication

There has been a long-standing debate on either OKC or CKC is superior for knee rehabilitation following injury, especially ACL injury. Our study showed and is in line with the balanced co-activation that that is beneficial for knee activity and ACL injury prevention [3, 39]. This study supports the concepts of OKC to promote knee extensor strength and similarly balanced co-activation that is safer during CKC for patients with knee joint laxity and ACL injury. Moreover, antagonist co-contraction is significant in all exercises shown in this study and this could contribute to the active joint stabilization as reported by various other studies [21, 31]. Such knowledge could be useful in sports, post-injury and post-surgical rehabilitation to design different forms of OKC and CKC type of concentric and eccentric exercises.

4.6 Limitation

This study could have numerous limitations. Firstly, the method of using only body weight in eliciting antagonist activity could give different results than movements against higher external resistance. Therefore, comparison with other studies which used isokinetic devices and external resistance to elicit antagonist coactivation may not be justifiable for comparison. Secondly, the present study had controlled lab testing protocol for each exercise for all participants to produce isolated knee joint movement which do not reflect natural human movement. Since some studies have reported that rapid segmental activity increases antagonist co-activation rather than isolated movement [34]. Third, the individual muscle activity was averaged and generalized to represent collective hamstring and quadriceps activity as an agonists and antagonists during different exercises. As some components of quadriceps (rectus femoris) and hamstrings (except short head of biceps femoris) are two-joint muscles, this may affect antagonist activation. All the participants were instructed to keep the hip joint as neutral as possible during the testing with verbal cues and support by a barrier, but the amount of hip joint motion was not studied and hence not reflected as a true neutral.

5. CONCLUSION

In summary, both OKC and CKC forms of exercises generated considerable amount of antagonist activity which were significant. The result showed that CKC BS developed higher co-activation ratio than OKC SLE and SLF. Higher antagonist activity ratio was found during eccentric phase of activity during both OKC exercises, whereas higher antagonist activity ratio was seen during concentric phase of CKC exercise. There was no significant interaction found when all forms of exercises were compared between male and female groups. However, females seem to have higher antagonist activity ratio than males during OKC single leg extension. The methodology in this study can be used to examine the role of antagonist activity in other clinical as well as practical settings and among ACL injured patients and generalize the findings to a greater population. The result has demonstrated all characteristic of antagonist activity that can be taken into consideration while designing different exercise protocols for sports, post-injury and post-surgical rehabilitation.

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7. Appendices

Appendix 1

REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region:	Saksbehandler:	Telefon:	Vår dato:	Vår referanse:
REK midt	Magnus Alm	73559949	07.10.2020	169385
			Deres referanse:	

Ann-Katrin Stensdotter

169385 Muskelaktivitet og kneleddets kinematikk etter korsbåndsskade.

Forskningsansvarlig: Norges teknisk-naturvitenskapelige universitet

Søker: Ann-Katrin Stensdotter

Søkers beskrivelse av formål:

Studien undersøker kneleddets «skruvaksel», dvs leddets rotasjon og glidning i 6 frihetsgrader samt aktiviteten i de muskler som krysser kneleddet etter fremre korsbåndsskade og hos kontrollpersoner uten kneskade. Det er kjent at kinmatikken i kneleddet og aktiviteten i musklene over kneleddet endres etter korsbåndsskade. Ingen har dog tidligere undersøkt hvordan skruvakselen oppfører seg under kontrollerte bevegelser som belaster ytterpunktene i bevegelsesbanene med traksjon, translasjon og kompresjon. Rasjonale for studien er at resultatene kan bidra til bedre og tryggere trening etter korsbåndsskade.
Studiedesign: eksplorativ tverrsnitt case-kontroll og er å betrakte som en pilot.
Til studien rekrutteres 20 idrettsaktive men og kvinner (50/50) mellom 18-28 år, som har diagnostiert ruptur av det fremre korsbåndet i løpet av de to siste årene men som ikke er operert for korsbåndsrekonstruksjon. Personene rekrutteres via annonsering på NTNU, fysioterapi klinikker og idrettskretser. Deltakere i studien må være klarert fra sin fysioterapeut for å utføre testøvelsene. Matchede kontrollpersoner rekrutteres fra masterstudiet, og venners venner.
Testprotokollen inneholder 3 lette øvelser med 10 repetisjoner / øvelse: knebøy, sittende kne ekstensjon og stående kne fleksjon. Data samles i bevegelseslabb med optisk kinematisk kamerasystem av under eks og trunkus, og elektromyografi av lår- og leggmuskler. Utfallsvariabler er rotasjonsvinkler og glidning i kneleddet, dvs skruvakselen, samt forholdet mellom agonist og antagonist muskler i de tre øvelsene. Øvelsene sammenlignes innom gruppe, og gruppene sammenlignes innfor hver øvelse. En subanalyse undersøker kjønnsforskjeller. Personopplysninger er alder, vekt, høyde, idrett og tid siden skade.

REKs vurdering

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK midt) i møtet 22.09.2020. Vurderingen er gjort med hjemmel i helseforskningsloven § 10.

REK midt **Telefon**:73 59 75 11 | **E-post**:rek-midt@mh.ntnu.no
Besøksadresse: Øya Helsehus, 3. etasje, Mauritz Hansens gate 2, Trondheim **Web**:https://rekportalen.no

Komiteens prosjektsammendrag: Formålet med denne studien er å undersøke hvordan skade i fremre korsbånd påvirker kneleddets rotasjon og glidning (dvs. skruvaksel), samt aktivitet i musklene som krysser kneleddet. Man skal undersøke hvordan kneleddets skruvaksel oppfører seg under kontrollerte bevegelser som belaster ytterpunktene i bevegelsesbanene med traksjon, translasjon og kompresjon. Utvalget skal bestå av 20 idrettsaktive menn og kvinner mellom 18-28 år som har fått diagnostisert ruptur av det fremre korsbåndet i løpet av de to siste årene. Deltakere må være klarert fra fysioterapeut for å utføre testøvelser som består av knebøy, sittende kne-ekstensjon, og stående kne-fleksjon. I tillegg skal det rekrutteres 10 matchede kontrollpersoner uten kneskade. Testing skal gjennomføres ved NTNUs NeXt Move lab, hvor data skal innhentes ved hjelp av et optisk kinematisk kamerasystem, og gjennom elektromyografi av lår- og leggmuskler. Studien er samtykkebasert. Prosjektet er en del av to mastergrader i fysisk aktivitet og helse ved NTNU. NTNU er oppført som forskningsansvarlig institusjon, og Umeå universitet er samarbeidende institusjon.

Forsvarlighet

Komiteen har vurdert søknad, forskningsprotokoll, målsetting og plan for gjennomføring. Komiteen har noen kommentarer til rekrutteringsprosedyren, forsikringsdekning og datadeling. I tillegg ber vi om noen endringer i informasjonsskrivene. Vi har ellers ingen forskningsetiske innvendinger til prosjektet. Under forutsetning av at vilkårene nedenfor tas til følge vurderer vi at prosjektet er forsvarlig, og at hensynet til deltakernes velferd og integritet er ivaretatt.

Rekrutteringsprosedyre

Du skriver at kontrolldeltakere skal rekrutteres fra masterstudiet og venners venner. Komiteen vurderer at rekruttering blant venners venner ikke er i tråd med prinsippet om frivillighet i forskning. Det kan være vanskelig å takke nei til en forespørsel som kommer fra noen man har en personlig relasjon til. Komiteen stiller derfor vilkår om at dere endrer rekrutteringsprosedyren slik at frivilligheten ivaretas, og at kontrolldeltakere rekrutteres på samme måte som pasienter.

Forsikring

I informasjonsskrivet oppgir du at deltakerne er dekket av pasientskadeloven, men det er uklart for komiteen om prosjektet har en tilstrekkelig tilknytning til helsetjenesten til at denne loven er gjeldende. For at forskningsdeltakere skal være dekket av pasientskadeloven må prosjektet enten ha en stedlig eller persontilknytning til helsetjenesten, dvs. forskningen må enten foregår ved en helseinstitusjon eller utføres av autorisert helsepersonell (se pasientskadeloven § 1).

Deltakerne må være forsikret, og vi ber om en bekreftelse på hvilken forsikring som er gjeldende i prosjektet. Komiteen anmerker at NTNU ofte er oppgitt som selvassurandør i forskningsprosjekter der de er involvert.

Datadeling

Du oppgir at forskningsdata skal legges ut på NTNU Open. Komiteen forutsetter at denne delingen begrenser seg til data som omhandler muskelaktivitet og kneleddets kinematikk, og at delingen ikke omfatter andre helseopplysninger fra deltakerne. Vi forutsetter at dataene som deles er reelt anonyme, og henviser til Datatilsynets veileder om anonymiseringsteknikker.

Endring av informasjonsskriv

Komiteen ber deg endre informasjonsskrivet i samsvar med følgende punkter:

1. Du må oversette informasjonsskrivene til norsk.
2. Du må oppgi riktig forsikring.
3. Du må sette inn en egen avkryssingsboks for datadelingen.

Merknad om prosjektperiode

Vi gjør oppmerksom på at prosjektet må ha en gyldig REK-godkjenning så lenge det er aktuelt å bruke personopplysninger (både direkte identifiserbare eller indirekte identifiserbare opplysninger om enkeltpersoner) i forskningsprosjektet, og inntil publiseringsprosessen er ferdig. Dersom det er aktuelt å forlenge prosjektperioden må du sende en søknad om prosjektendring *før* sluttdato for prosjektet har passert.

Vilkår for godkjenning

1. Du må sende inn reviderte informasjonsskriv via rekportalen.no. Du kan ikke ta skrivene i bruk før vi har bekreftet at de er endret i tråd med våre merknader.
2. Vi forutsetter at deltakerne er forsikret.
3. Komiteen forutsetter at ingen personidentifiserbare opplysninger kan framkomme ved publisering eller annen offentliggjøring.
4. Komiteen forutsetter at du og alle prosjektmedarbeiderne følger egen institusjons bestemmelser for å ivareta informasjonssikkerhet og personvern ved innsamling, bruk, oppbevaring, deling og utlevering av personopplysninger. Bestemmelsene må være i samsvar med REKs vilkår for godkjenning.
5. Av dokumentasjonshensyn skal opplysningene oppbevares i fem år etter prosjektslutt. Enhver tilgang til prosjektdataene skal da være knyttet til behovet for etterkontroll. Prosjektdata vil således ikke være tilgjengelig for prosjektet. Prosjektleder og forskningsansvarlig institusjon er ansvarlige for at opplysningene oppbevares indirekte personidentifiserbart i denne perioden, dvs. atskilt i en nøkkel- og en datafil.Etter denne femårsperioden skal opplysningene slettes eller anonymiseres. Komiteen gjør oppmerksom på at anonymisering er mer omfattende enn å kun slette koblingsnøkkelen, jf. Datatilsynets veileder om anonymiseringsteknikker.

Vedtak

Godkjent med vilkår

Med vennlig hilsen

Vibeke Videm
Professor dr. med. / Overlege
Leder, REK Midt

Magnus Alm
rådgiver, REK midt

Sluttmelding
Søker skal sende sluttmelding til REK midt på eget skjema senest seks måneder etter godkjenningsperioden er utløpt, jf. hfl. § 12. Dersom prosjektet ikke igangsettes eller gjennomføres skal prosjektleder også sende melding om dette via sluttmeldingsskjemaet.

Søknad om å foreta vesentlige endringer
Dersom man ønsker å foreta vesentlige endringer i forhold til formål, metode, tidsløp eller organisering, skal søknad sendes til den regionale komiteen for medisinsk og helsefaglig forskningsetikk som har gitt forhåndsgodkjenning. Søknaden skal beskrive hvilke endringer som ønskes foretatt og begrunnelsen for disse, jf. hfl. § 11.

Klageadgang
Du kan klage på komiteens vedtak, jf. forvaltningsloven § 28 flg. Klagen sendes til REK midt. Klagefristen er tre uker fra du mottar dette brevet. Dersom vedtaket opprettholdes av REK midt, sendes klagen videre til Den nasjonale forskningsetiske komité for medisin og helsefag (NEM) for endelig vurdering.

NTNU

Kunnskap for en bedre verden