A DATA CONSISTENCY OF STRENGTH TESTING ON AN ISOKINETIC DYNAMOMETER; AN INVESTIGATION INTO THE NUMBER OF REPETITIONS REQUIRED TO PEAK PERFORMANCE AND UNTIL FATIGUE

BEYZA TAYFUR
C1659529

Cardiff University
School of Healthcare Sciences

MSc Sport and Exercise Physiotherapy

Presented to Cardiff University in partial fulfilment of the requirements for the degree of Masters of

Sport and Exercise Physiotherapy.

Word Count: 19,360
Date of Submission: 05.01.2018

NOTICE OF SUBMISSION

School of Healthcare Sciences

NOTICE OF SUBMISSION: POSTGRADUATE TAUGHT DEGREES

SECTION A: TO BE COMPLETED BY THE CANDIDATE AND SUBMITTED WITH THE DISSERTATION

Student ID Number:	C1659529
Title:	Mrs
Surname:	TAYFUR
First Names:	BEYZA
School:	SCHOOL OF HEALTHCARE SCIENCES
Title of Degree:	MSc SPORT AND EXERCISE PHYSIOTHERAPY
Full Title of Dissertation submitted:	A DATA CONSISTENCY OF STRENGTH TESTING ON AN ISOKINETIC DYNAMOMETER; AN INVESTIGATION INTO THE NUMBER OF REPETITIONS REQUIRED TO PEAK PERFORMANCE AND UNTIL FATIGUE
Is this a resubmission?	Yes ☐ No X
Supervisor's Name:	MR TIMOTHY SHARP
Address for receipt of your Result Letter, Degree Certificate and Details of the Graduation Ceremony:	20 CLEPHANE ROAD LONDON Postcode: N1 2FZ
Please indicate whether you wish to attend the Degree Ceremony:	Yes X No ☐
Preferred Contact Telephone (with dialling code/s):	+44 7460 733 817 +90 541 918 98 68
Email/s:	beyzakap93@gmail.com TayfurB@cardiff.ac.uk

CANDIDATE'S SIGNATURE: ..... **DATE OF SUBMISSION:** 05/01/2018

School of Healthcare Sciences

SECTION B: TO BE COMPLETED BY THE SCHOOL

Please tick the appropriate box to confirm that the following documents have been completed by the candidate and deposited in the School.

Dissertation Summary Sheet:	**Yes** ☐	**No** ☐
Statements and Declaration:	**Yes** ☐	**No** ☐
A signed statement regarding availability of the Dissertation:	**Yes** ☐	**No** ☐
Where Candidate is resubmitting, School should attach cheque (or evidence that the fee has been paid):	**Yes** ☐	**No** ☐

SCHOOL'S SIGNATURE: ..... **DATE:** ..... / ..... / .....

POSITION: .....

DECLARATION

School of Healthcare Sciences

Declaration/Statements Form

Candidate ID Number	**C1659529**
Candidate Surname	**MRS TAYFUR**
Candidates Full Forenames	**BEYZA**

Declaration

This work has not been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree

Signed..... **(candidate)**

Date.....05/01/2018.....

Statement 1

This dissertation has been submitted in partial fulfilment of the requirements for the degree of MSc in SPORT AND EXERCISE PHYSIOTHERAPY

Signed..... **(candidate)**

Date.....05/01/2018.....

Statement 2

This dissertation is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A list of references is appended.

Signed..... **(candidate)**

Date.....05/01/2018.....

Statement 3:

I hereby give consent for my dissertation, if accepted, to be available for photocopying and for inter-library loan and for the title and summary to be made available to outside organisations, as well as electronic copies distributed where appropriate.

Signed..... **(candidate)**

Date.....05/01/2018.....

DEDICATION

This research is dedicated to my dear parents;

My mother, Gülgün Kap

and

My father, Recep Kap

Thank you for your love, support and encouragement my entire life.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Tim Sharp, for his guidance and advice he has provided throughout this research.

Special thanks to my personal tutor, Dr Valerie Sparkes, for her continuous support during my studies at Cardiff University.

I am grateful to Prof Nicola Phillips, for her professional guidance and support whenever I addressed her.

I must express my gratitude to my dearly beloved husband, Abdulhamit Tayfur. Without his loving support, this research would have not been possible.

Finally, I would like to thank the Turkish Ministry of National Education for providing the funding which allowed me to complete my studies at Cardiff University.

ABSTRACT

Background: Accurate measurement of strength is important for athletic performance, injury prevention and rehabilitation. Isokinetic dynamometer is the gold standard of strength assessment. However, the optimal repetition number during isokinetic strength testing to obtain the maximum performance has not been evaluated for different contraction types and speeds until now.

Objective: The main objective of the current study is to find out the required repetition number to achieve the consistent maximum performance during isokinetic strength testing of knee flexion and extension at two mostly used velocities of 60º/sec and 180º/sec for both concentric and eccentric contraction types.

Method: 32 healthy university students were assessed on 8 different testing sessions on the same day in a counter-balanced order of knee flexion and extension for concentric and eccentric contraction modes at 60º/sec and 180º/sec. Data were analysed by graphs, setting ranges from the maximum performance until obtaining three consecutive values. The repetition number to obtain the maximum value and its consistency were explored individually for each graph.

Results: The results of the current investigation indicated that the participants need only three repetitions to exert their maximum force during isokinetic strength testing at 60º/sec. For the tests at 180º/sec, more repetitions were required only for concentric knee extension test indicating that at least five repetitions should be performed until the maximum performance. The eccentric knee flexion tests were not found valid, indicating that a specific familiarization session may be required for this test.

Conclusion: Only three repetitions may be enough to obtain the maximum performance; however, at least five trials should be performed for concentric knee extension at higher speeds. More repetitions than these seem like unnecessary for healthy young populations. Differently for eccentric knee flexion test, a specific familiarization session may be needed to provide valid results.

Word Count: 289

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

º/sec	Degree/Seconds
VO_2	Volume Oxygen
ATP	Adenosine Triphosphate
PCr	Phosphocreatine
pH	Potential of Hydrogen
EMG	Electromyography
Kin-Com	Kinetic Communicator
RCCK	Research Centre for Clinical Kinesiology
CON	Concentric
ECC	Eccentric
SI Unit	the International System of Units
Nm	Newton Meter
SD	Standard Deviation
y	Years
cm	Centimetre
kg	Kilogram

1. INTRODUCTION

1.1. Background

Strength is a key component of athletic performance, injury prevention and rehabilitation. Within the field of research and rehabilitation, the best and most accurate way of assessing muscle strength is accepted as the use of isokinetic dynamometers. Isokinetic dynamometers can assess the amount of force produced at a single joint at a set speed. It can measure the static strength, shortening strength and lengthening strength of a muscle. Despite the wide use of isokinetic dynamometers, there is no consistency in testing protocols when assessing the maximum performance. Studies have used different familiarization sessions, warm-ups, repetitions, speed orders and rest periods.

Even the isokinetic dynamometers are accepted as the gold standard method for assessing strength, they are not very functional and only provide information on pure muscle force. Because of its difference from the functional movements, participants may need familiarization sessions or specific warm-up protocols on the isokinetic machine to understand the movement and exert their maximum force. While several reliability studies have investigated the use of familiarization sessions one or two weeks before the actual test; in clinical practice, an additional session is not so practical and costly. Therefore, understanding how many trials the participants need to understand the movement and achieve peak performance only on one testing session is important.

The repetition number to obtain the maximum performance is the main variable during isokinetic strength testing. While few trials may result in a lower value than the normal performance, too many trials may cause fatigue. Studies generally fail to report the reason behind their choice of specific trial numbers when assessing muscle performance. Also, the same repetition number is used for all contraction types and speeds. However, the physiological differences in these movements may require different repetition numbers. Therefore, standardizing the optimal repetition number for different testing modes, contraction types, movements and speeds are important for both clinical practice and research.

1.2. Aim of the Study

The main aim of this study is to find out the required repetition numbers to achieve the consistent maximum performance during isokinetic strength testing of knee flexion and extension at two mostly used velocities of 60°/sec and 180°/sec for both concentric and eccentric contraction types.

2. LITERATURE REVIEW

2.1. Introduction

The purpose of the literature review was to investigate and critically appraise the current research publications relevant to the research topic and then identify the gaps in the knowledge in the studied topic. The results of the found studies will be synthesised and summarised at the end of this section, while outlining the need for the current study.

2.2. Search Strategy

The literature review was conducted by searching the following electronic databases for research publications covering the last 10 years: PubMed, PEDro, Cochrane, Medline and Web of Science. The following terms were searched in all databases: Isokinetic Dynamometer, Isokinetic Strength, Isokinetic Test*, Kin-Com, Kinetic Communicator, Knee Strength Test*, Fatigue, Familiarization, Learning Effect, Performance, Warm* up. The selected articles were limited to those published in English, and available in full text. The studies related to knee muscles strength testing were identified. The references of the found articles were also searched for relevant studies; and relevant papers were included, regardless of their publication year as they may provide the core knowledge about the topic. Once identified the abstract was read for the relevance to the current study and studies not thought to be relevant were excluded.

2.3. Isokinetic Muscle Strength Testing

Muscle strength is a key component of athletic performance, injury prevention and functional recovery following an injury (Ozcakar et al. 2003; Mizner et al. 2005; Alentorn-Geli et al. 2009). It is defined as the ability of a muscle to exert force with or without changing the joint angle and muscle length (Haff and Triplett 2015). There are three basic types of muscle action; isometric, concentric and eccentric (Haff and Triplett 2015). Isometric action is when the contractile force and the resistive force are equal; therefore, there is no change in muscle length or joint angle (Haff and Triplett

2015). Concentric action is when the contractile force is greater than the resistive force; therefore, the muscle shortens (Haff and Triplett 2015). Finally, eccentric action is when the contractile force is less than the resistive force; therefore, the muscle lengthens (Haff and Triplett 2015). These isometric, concentric and eccentric actions of the muscle may result in different levels of strength. Therefore, each type of contraction needs to be assessed separately.

While there are various ways to measure muscle strength, isokinetic testing is defined as the gold standard method to objectively assess and document dynamic muscle strength and determine changes in muscle performance in both clinical and research environments (Wilhite et al. 1992; Drouin et al. 2004; Rahnama and Bambaeichi 2008; Tsiros et al. 2011). The isokinetic concept was first introduced by Perrine and Hislop in 1967 and has become a popular method following its introduction. Isokinetic dynamometers measure the amount of force produced at a single joint at a constant angular velocity for both concentric and eccentric contractions, while keeping the resistance of the dynamometer equal to the produced force by the tested muscle (Rahnama and Bambaeichi 2008). The angular velocity of the movement on the isokinetic device can be set by the user. Generally, the lower angular velocities from 15^{o}/sec to 60^{o}/sec, the medium angular velocities from 90^{o}/sec to 120^{o}/sec and higher angular velocities from 180^{o}/sec up to 450^{o}/sec have been used in the literature to assess the muscle performance (Undheim et al. 2015). When the velocity is not controlled, the results of the strength test may show an erroneous performance. For example, during the isotonic testing of knee flexion-extension movements, the mechanical advantage of the muscles is minimal at the limits of the range of motion. However, the mechanical load applied to the muscles by the free weight or the machine is maximal at these points. On the contrary, at the middle ranges, the applied load is not at its maximum and are not completely challenging the muscle where the muscle has a mechanical advantage. During the isokinetic testing, the applied load to the muscle is equal to the force generated by the muscle. Therefore, at the angles where the mechanical advantage of the muscle is maximum, the force production can be maximum as well (Perrine and Hislop 1967). Thus, isokinetic dynamometers provide optimal loading of the muscles with the same controlled velocity at all angles of the movement, giving the opportunity to the muscle to apply the maximum force at the angles where the mechanical advantage is maximum.

Isokinetic strength measures are generally reported as peak torque and/or total work. Peak torque is the maximum value reached at one specific point through the range of the movement (Baltzopoulos and Brodie 1989). It eliminates the submaximal values; therefore, it is a good measure of maximal strength (Gransberg and Knutsson 1983; Baltzopoulos and Brodie 1989). On the other hand, total work indicates all the work done by the muscle through the range of the movement, including all maximal and submaximal values. Therefore, total work is a good indicator of the endurance of the muscles (Baltzopoulos and Brodie 1989). Total work is generally used to assess the endurance of the muscles at higher velocities. However, different populations may require different muscle actions, therefore different testing protocols. For example, 180^{o}/sec was generally used to assess the endurance of muscles (Pincivero et al. 1997). However, when the physiological requirements of the tested population are different, the same velocity may be used to assess the peak torque, as in sprinters (Jonhagen et al. 1994). Therefore, the isokinetic test protocol should be suitable to the purpose of the test and focus on the physiological demands of the tested population. Both peak torque and total work have been reported to have high test-retest reliability for knee flexor and extensor muscles (Greenberger et al. 1994; Li et al. 1996; Sole et al. 2007).

Isokinetic knee flexion and extension tests are used in the literature to assess performance, determine injury risk, follow the recovery from an injury and create fatigue profile (Östenberg and Roos 2000; Baron 2001; Ozcakar et al. 2003; Mizner et al. 2005; Garrandes et al. 2007; Alentorn-Geli et al. 2009). Despite its wide range of use, there is no standardized protocol for the testing. Studies have used different velocities, repetitions, rest periods and warm-up sessions (Warren and Longwell 2010). Therefore, it is difficult to compare research findings. Researchers recently focused on the effects of different rest times between sets (Parcell et al. 2002; Celes et al. 2009; Warren and Longwell 2010; Blazquez et al. 2013; Bernard et al. 2016). However, all of them have used different familiarisation periods, velocities and repetitions. Also, these studies generally investigated more than five different velocities on the same testing session. In clinical practice, researchers generally used one lower velocity (generally 60^{o}/sec) and one higher velocity (generally 180^{o}/sec) for the strength testing (Sato et al. 2011; Koller et al. 2015; Undheim et al. 2015; Yeung

et al. 2016; Psatha et al. 2017). While the studies have focused on the rest periods between sets, the required repetition numbers to achieve the maximum performance was not addressed or discussed recently. The repetition numbers within sets ranged from 2 to 10 (Parcell et al. 2002). This inconsistency also resulted in different findings in terms of optimal rest period between sets. Also, these studies assessed only concentric contractions; however, in practice concentric and eccentric tests are mostly performed together (Overend et al. 2000; Askling et al. 2003; Undheim et al. 2015; Nickols-Richardson et al. 2007; Frisch et al. 2011). Therefore, the standardization of the test is important for both concentric and eccentric contraction types.

To understand the importance of standardised protocols, it is important to understand the physiology of the muscle strength testing. Therefore; energy supply of the muscle, fibre types and motor unit recruitment, learning effect, force-velocity relationship, and fatigue will be discussed specific to isokinetic strength testing in the following sessions.

2.3.1. Energy Systems

The energy supply during maximal exercise has been investigated and very-well documented by many studies including muscle biopsy reports and VO_2 max tests. The three energy suppliers of the body are the immediate energy system (Adenosine triphosphate and phosphocreatine), the short-term energy system (Glycolysis) and the long-term energy system (Aerobic). The Adenosine triphosphate (ATP) and phosphocreatine (PCr), and glycolysis are the anaerobic systems. All three systems provide energy during exercise; however, their contribution changes over time. It is well-known that the main energy during high intensity short-period exercise is provided by the phosphagenic (ATP-PCr) and glycolytic systems; firstly, using the intramuscular high energy phosphates ATP and PCr, and then the glycolytic system for ATP resynthesis which results in lactate production. During the first 15-s of the exercise the main provider of ATP was found to be the phosphagenic system; while during a 16 to 30-s exercise, the main provider becomes the glycolytic system (Serresse et al. 1988). The oxidative system increases its contribution between 61 to 75-s of the exercise (Serresse et al. 1988).

Studies have reported decreased performance with the onset of lactate accumulation

in blood, following the start of glycolysis (Hirvonen et al. 1992). At the beginning of muscle contraction, hydrolysis of creatine phosphate turns the muscle pH into alkaline, which promotes the glycolysis. Following the start of the glycolysis, the lactic acid accumulation decreases the pH (Trivedi and Danforth 1966). Also, the build-up of hydrogen ion within the muscle cells decreases the pH of the muscle and reduces the force production as a result with the other factors including fuel depletion and lactate accumulation (Hirvonen et al. 1992). Greater hydrogen ion concentration hinders the cross-bridge attachment of actin and myosin (Metzger and Moss 1987). These combined factors limit the force production during high-intensity exercise of the musculoskeletal muscle.

During the isokinetic strength testing, the duration of the maximal contractions depends on the velocity of the movement and the repetition numbers within the sets. The higher velocities mean faster movements; therefore, the same repetition number within sets may result in different demands on the energy systems for different velocities. Until now, the repetition numbers used within the sets were the same for every velocity, from 30^{o}/sec to 300^{0}/sec (Parcell et al. 2002; Celes et al. 2009; Warren and Longwell 2010; Blazquez et al. 2013; Bernard et al. 2016). However, when investigated from a physiological point of view, these repetitions were completed in different times, therefore, their use of energy may be different. While 10 continuous repetitions at 60^{o}/sec may take 18 seconds, the same repetition number at 300^{o}/sec may take only 6 seconds. These different contraction periods may result in different use of the energy systems. While a 6-second muscle action primarily uses the immediate energy (ATP-PCr) system, an 18-second action may mainly rely on the short-term energy system (Glycolysis). These differences indicate that the muscles may have different energy demands at different velocities if the same repetition number is performed for different speeds. This may denote that different repetition numbers may be required for different velocities to equate the energy demands of the tests and provide the best performance.

2.3.2. Fibre Types and Motor Unit Recruitment

It is apparent that the understanding of the energy supplementation of the muscle is important when testing the strength. However, without understanding the morphology

of the muscle that is using this provided energy, it is not possible to completely understand the physiology of muscle contraction and strength. It is therefore crucial to know the different fibre types within the muscle, as well as the recruitment of these fibres.

The basic functional unit of the skeletal muscle is the motor unit, including a moto-neuron and all the muscle fibres innervated by it (Raven et al. 2012). There are three main muscle fibre types in human skeletal muscle, classified based on the type of myosin heavy chain genes (Raven et al. 2012). Type I is classified as slow-twitch oxidative, the time to peak tension is longer when compared to fast-twitch types (Raven et al. 2012). Type IIa fast-twitch fibres have high oxidative capacities, and type IIb fast-twitch fibres have low oxidative capacities (Raven et al. 2012). These fibres constitute different proportions in different muscle groups (Johnson et al. 1973). The muscle groups that require more endurance (predominantly tonic) have more type I fibres when compared to the muscles that require more strength and speed (predominantly phasic muscles) (Johnson et al. 1973). Biopsy studies also found that type II fibres may have about three times greater strength of the specific strength of type I fibres (Young 1984).

During the muscle contraction, smaller motor units are recruited first and then the larger units are activated; this principle is defined as ‘the size principle’ first by Henneman et al. (1965). Slow-twitch fibres also tend to be in smaller motor units, while fast-twitch fibres tend to be in larger motor units (Wuerker et al. 1965). These early studies agreed that at the beginning of the movement, slower motor units are recruited first; after that, the faster motor units are recruited (Henneman et al. 1974). This recruitment pattern was accepted to ensure that the most fatigue resistant and slowest units are recruited first during a movement (Henneman and Olson 1965). Also, faster motor units, which are also larger and stronger, are providing greater force after their recruitment. This principle indicates that to obtain the maximum strength of a muscle, the recruitment of faster motor units should be ensured. In terms of isokinetic strength testing, the repetitions of the movements should be enough to provide the recruitment of the fast-twitch motor units to achieve the maximum performance.

The orderly recruitment of motor units may not be present in all movements. Numerous

studies observed different recruitment patterns during different force levels as well as different contraction types. Nardone et al. (1989) showed selective recruitment of fast motor units during eccentric contractions as opposed to concentric contractions. While findings of Howell et al. (1995) are supporting these results; many investigators have reported similar recruitment patterns during isometric, concentric and eccentric contractions (Søgaard et al. 1996; Bawa and Jones 1999; Stotz and Bawa 2001). There is also some evidence suggesting that contraction speed may affect the recruitment order of the motor units. Selective recruitment of fast motor units was observed by Moritani et al. (1991) in human muscles. Several EMG studies are supporting these findings while reporting selective activation of fast motor units within the same muscle at higher velocities (Citterio and Agostoni 1984; Moritani and Muro 1987). While some controversy exists regarding the recruitment pattern differences between different contraction types and speeds, it is evident that maximum voluntary motor unit recruitment should be ensured when testing the maximum muscle strength. Therefore, it is important to provide this recruitment during all different velocities and contraction types with optimal number of repetitions.

2.3.3. Learning Effect

Strength is not only related to muscle size and composition, but also the neural system. The motor system including nervous and muscle systems ensures the coordinated movement. Movements may not be considered as skills, as they may not always have a particular goal (Schmidt and Lee 2005). However, the force production at strength tests may be considered as a motor skill, as it requires an ability to bring an end result with maximum certainty, and minimum use of time and physiological, psychological and mental energy (Schmidt and Lee 2005). Therefore, the force production may be improved with practice. As any skill, force production requires deciding what to do and when to do it, as well as producing organized neural and muscular activity to generate movements (Schmidt and Lee 2005). It is suggested that practice is one of the most important factors for learning a skill (Schmidt and Lee 2005). Understanding the isokinetic strength test involves optimizing the required movement, at a certain time and velocity, and at the correct direction. The participants should be able to perform the task with a high degree of certainty.

It is shown that neuro-motor learning is an important factor in strength increase (Almåsbakk and Hoff 1996). Improved coordination of muscles with nervous adaptations and the learning of the movement provides greater force production (Almåsbakk and Hoff 1996). For these gains, the instructions given to the subjects to teach the movement are also important (Almåsbakk and Hoff 1996). Therefore, explaining the test and the movements to the subjects prior to isokinetic testing is crucial.

Previous studies have shown differences between each trial performed during the isokinetic testing, suggesting that the changes in strength may occur even with the test repetitions (Johnson and Siegel 1978; Mawdsley and Knapik 1982; Sawhill et al. 1982). The changes between trials are not due to morphological changes within the muscle but the neuro-motor coordination of the movement. These changes in the neuro-motor learning and control of the movement are important factors when designing the testing protocols. Previous research suggests that understanding eccentric movements requires more practice than concentric movements, especially at high angular velocities (Steiner et al. 1993). Also, reliability of eccentric isokinetic test protocols is generally found to be lower when compared to concentric (Wilhite et al. 1990, Deighan et al. 2003). A decrease in reliability with increasing angular velocity of the movement was also reported by Brown (1993). These lower reliabilities may indicate that for higher velocities and eccentric contraction types, different testing protocols may be needed to ensure high reliability of test results. However, until now, the same testing protocols were used for different contraction types and angular velocities. The test trials should be suitable to provide the motor-learning phase and increase the movement control for all contraction types and angular velocities; and this may need different test trials for different contraction types and angular velocities.

2.3.4. Force-Velocity Relationship

The effect of speed of muscle contraction on force production was first examined and described as ‘force-velocity relationship’ by Hill et al. (1938). The force output of the muscle is greatest at lower velocities and decreases as the velocity of the movement increases (Hill et al. 1938). Studies using the isokinetic dynamometer have also reported the same relationship between the speed of the movement and the produced

torque (Thorstensson et al. 1976; Barnes 1980). The dynamic torque of the muscle is increasing gradually with decreased speed of shortening (Thorstensson et al. 1976; Barnes 1980). Also, the motor-unit activity increases linearly as the contractile speed decreases during concentric contraction (Barnes 1980). Therefore, the reason of this force production increase is related to the greater activity of the motor units at slower velocities. Interestingly, the force-velocity relationship during the eccentric contractions is not the same as during the concentric contractions. The movement speed does not seem to affect the force production during lengthening as much as during shortening (Komi 1973; Colliander and Tesch 1989). Also, the electrical activity of the muscle is not the same during the concentric and eccentric contractions. In theory, the amount of electrical activity and the number of recruited muscle fibres are the same for all velocities and for all contraction types (isometric, concentric and eccentric) during maximal contractions (Raven et al. 2012). However, during the maximal voluntary contractions, the recruitment of the muscle fibres differs between different velocities and contraction types. Electromyography (EMG) studies have reported that the EMG activity of the muscles are greater during the concentric contraction when compared to eccentric contraction (Westing et al. 1991). During the eccentric contraction, electrical stimulating the already voluntarily contracted muscle was resulted in 24% increase in force production (Westing et al. 1990). Even the voluntary contraction always results in less muscle fibre activity when compared to maximal contraction, the activity in the eccentric contraction is lower than the concentric and isometric contractions (Gravel et al. 1987; Westing et al. 1990). Although the exact mechanism behind it is still unknown, a possible neural inhibition was suggested by the researchers to explain the less recruitment of muscle fibres during eccentric contraction despite the maximal effort of the participants (Westing et al. 1990; Aagaard et al. 2000). The possible explanation of this neural inhibition is the higher mechanical load during the eccentric contraction which may cause a greater amount of muscle damage and muscle soreness (Howell et al. 1993; Day et al. 1998). Also, fear of performing maximal eccentric contractions may be decreasing the motor-unit activity of the muscle. This neural inhibitory mechanism may help to maintain the muscle tension within safe limits to prevent any possible injury but may also inhibit the maintenance of the maximal eccentric force throughout the motion.

2.3.5. Fatigue

Fatigue has been defined as any reduction in the capacity of the total neuromuscular system to generate force; therefore, the failure to maintain a given exercise intensity (Bigland-Ritchie and Woods 1984; Brooks et al. 1996). In the current investigation, the definition of skeletal muscle fatigue will be used as the significant decrease in the peak torque values during an isokinetic strength test, in response to maximal concentric and eccentric contractions.

The fatigue mechanism most often depends on the specific task imposed, which has been defined as 'task specificity' (Enoka and Duchateau 2008). Therefore, in this chapter, fatigue specific to isokinetic knee strength testing will be discussed. The inability to maintain the achieved maximum performance represents fatigue, which results in submaximal contractions after the onset of muscle fatigue. It is therefore important to understand the onset of fatigue during the isokinetic tests and provide the tested subject enough time to rest. Fatigue leads to a decreased efficiency of muscle contractions; therefore, it can be identified before the phase that the tested subject is no longer able to continue the task. The tests should not necessarily continue until the tested subjects become exhausted or until the failure of the task.

The fatigue develops gradually after the beginning of a specific physical task, isokinetic knee muscle contractions in the current investigation. Fatigue was defined as 3 consecutive repetitions below 50% of the maximum peak torque in several studies (Salavati et al. 2007; Gear 2011). The study by Gear (2011) have also classified fatigue as mild (90% decrease), moderate (70% decrease) and maximum (50% decrease). These values may be reliable when testing the response of the muscle to a specific physical exercise protocol or trying to induce fatigue. However, when investigating the decrease of the maximum performance more specifically, these percentages are much greater than expected.

The muscle force production is a complex procedure involving neural and muscular systems, beginning at the molecular level and resulting in whole-body movements (Kent-Braun et al. 2012). Therefore, a reduction in this function may result from different points of these systems involving cortical, spinal and peripheral neural

structures as well as contractile tissues. Current evidence suggests that the main reason of muscular fatigue during repeated contractions is mainly within the muscle itself and generally does not involve the failure of the central nervous system or neuromuscular junction (Bigland-Ritchie et al. 1978; Fitts 1994). The fibre composition of the muscles involved in the movement as well as the contraction type affects the fatigue during exercise (Fitts 1994). During the isokinetic tests, the decline in the peak torque was generally attributed to metabolic by-products including hydrogen ions, potassium and inorganic phosphate; and/or the damage to the myofibrils, including dilated T-tubules, damage in plasma membrane and sarcomere derangement (Edwards 1981; Staublr 1989). While the fatigue during the concentric and isometric contractions are mainly related to the metabolic by-products, the main reason of fatigue during the eccentric contractions are mostly related to both metabolic by-products and myofibril damages (Edwards 1981; Staublr 1989). These different fatigue mechanisms may result in different onset times of fatigue during different isokinetic contraction types.

2.4. Number of Repetitions During Isokinetic Strength Testing

The number of repetitions required to achieve the peak torque within a set is an important factor when designing standardized isokinetic testing protocols. If too few repetitions are performed, the maximum value may not be achieved and then the results may show a sub-maximum value. On the other hand, too many trials may cause fatigue. Also, too many trials require more time; therefore, are costlier and more time consuming. While there are different variables in a testing session including the warm-up procedure, selected velocities, order of the velocities, contraction type, the repetition numbers within sets, the rest periods between sets and the set numbers; the repetition number within sets may affect the results mostly because of the previously explained reasons. Obviously, all variables are important factors and may affect the results of an isokinetic strength test. However, if the number of repetitions performed within a set is not sufficient to elicit the maximum performance, the other variables may not improve the validity and reliability of the test protocol, then the results of the test might be misleading. Even the recent studies have investigated different rest periods between sets at different velocities, the main problem of these protocols is the different repetition numbers within sets. It cannot be assumed that the peak

performance is achieved with two, three or more repetition numbers without empirically testing the subjects at different velocities and different contraction types. Physiological differences of the contraction types and velocities may indicate that there may be different repetition numbers for different contraction types and velocities to achieve the maximum consistent performance.

Recent research publications have cited the review by Baltzopoulos and Brodie (1989) for their choice of trial numbers within sets (Mikesky et al. 2000; Spurway et al. 2000; Câmara et al. 2010; Câmara et al. 2012; Blazquez et al. 2013; Owens et al. 2014; Vodička et al. 2014; Nugent et al. 2015). Mikesky et al. (2000) have used three to five maximal concentric and eccentric repetitions with a rest interval of 30 seconds between contractions at 90º/sec while testing the strength. They have also used a warm-up protocol which consists of three to five repetitions at the same speed with submaximal contractions. Spurway et al. (2000) have tested their participants at 30º/sec, 90º/sec, 150º/sec and 250º/sec, using a warm-up with three submaximal contractions at each speed prior to actual test. Three to six repetitions were performed by the participants for obtain the maximum value for each velocity. Also, a 5-second rest period between concentric and eccentric action of the muscle, a 30-second rest between successive concentric/eccentric action pairs and a 2-minute rest between each velocity was provided during the testing. Câmara et al. (2010; 2012) have used five repetitions for testing the concentric knee flexion and extension strength of their participants at 60º/sec in the reciprocal contraction mode. Three to five familiarization trials were allowed prior to testing. Blazquez et al. (2013) have investigated the optimal rest period between sets while testing concentric knee flexion and extension at 60º/sec, 180º/sec and 300º/sec. All velocities were tested with 5 repetitions. Owens et al. (2014) have used four maximal repetitions when testing maximal knee flexion and extension strength at 60º/sec and 180º/sec. Vodička et al. (2014) have assessed isokinetic strength at 30º/sec and 60º/sec with 5 repetitions for each velocity. A warm-up protocol consisting sub-maximal repetitions were used before the actual test. However, the repetition number was not reported. Nugent et al. (2015) have used 5 repetitions to assess the strength of knee flexion and extension at 60º/sec, 120º/sec, 180º/sec and 240º/sec.

Even all of these recent studies have used different repetition numbers, different

warm-up protocols, different contraction types and different velocities; they all have cited the study by Baltzopoulos and Brodie (1989) to justify their repetition numbers. To further understand why this old study is still being used in recent publications, the review was critically appraised. The review has suggested that the sufficient trial numbers to achieve the maximum performance should be from 2 to 6 maximal repetitions during the isokinetic testing. However, when investigated, the conclusion of the writers was grounded by only one piece of empirical research (Sawhill et al. 1982). There was one reliability study (Johnson and Siegel 1978) and other unsupported subjective choices of previous researchers, which the choice of the trial numbers have not been tested objectively (Jenkins et al. 1984; Dibrezzo et al. 1985; Appen and Duncan 1986; Baltzopoulos et al. 1988).

In the study by Sawhill et al. (1982), 5 males were tested for leg extension and flexion movements for the trial numbers to achieve the stable muscle performance at 200º/sec, 300º/sec and 400º/sec. The study defined stability as the event when the cumulative means were within 25% standard deviation of the grand mean. While the researchers tested only 5 repetitions, the order of speeds (ascending/descending) or test protocol (reciprocal/discrete) were not reported. In addition to this the contraction mode (concentric/eccentric) was not specified. The study suggested at least 4 repetitions to achieve the stable muscle performance during isokinetic testing, but there is no strong evidence to support this recommendation. Also, the sample size of the study was very small, only 5 subjects were included in the test. Another weakness of the study was the standard deviation percentage. 25% may present very high values; therefore, high degrees of variation in terms of strength. Thus, this variation range might not present a real ‘stable’ performance. Interestingly, the tested velocities were very high and are not commonly used in clinical practice. Therefore, these values may not provide a satisfactory level of evidence to decide the repetition numbers within the sets.

In the reliability study by Johnson and Siegel (1978), knee extensor muscle performance of 40 females were tested on three separate days with 6 repetitions on each day. Prior to maximal 6 repetitions, 3 submaximal warm-ups were performed by the participants. The velocity of the test was 180º/sec. The subjects were given 20 seconds of rest between trials without referencing a source for the choice of this time.

The researchers suggested 3 sub-maximal repetitions followed by 3 maximal repetitions were the essential warm-up for the stable measures at the given velocity of knee extension, based on the high reliability after eliminating the 3 submaximal and the first 3 maximal repetitions. Correlation coefficients of the test were as high as 0.99, when the reliability was calculated by comparing the means of the last three maximum contractions. This result indicates that this protocol is highly reliable and can detect the changes in the strength in clinical practice. However, the results of this study may not be suitable to conclude that 3 submaximal and 3 maximal repetitions were enough to get the maximum stable performance. The repetition numbers in the study were limited to 6. The high velocity (180^{o}/sec) of the test may indicate that more repetition numbers may be required to achieve the maximum values. When the provided data were examined, an increase can be seen in the mean values from the fourth trial to the sixth trial. Even if the results were reliable, it may be assumed that the means could continue to increase after the sixth trial. Six trials may not be enough to achieve the maximum performance, as the repetitions may not be enough for the recruitment of motor units within the muscle (Raven et al. 2012). Therefore, the values may be the submaximal performances of the participants. Also, an important point about the study was that they have used a 20-second rest period between each trial, which might affect the physiological changes within the muscle. It is shown that when a rest-period is provided after a contraction, the PCr recovery occurs up to 70% within 20-30 seconds while the ATP-PCr recovery occurs within the following 3-5 minutes (Harris et al. 1976). A rest period between each trial may provide recovery and result in a greater performance. Testing with a long rest period may give errors when the aim is to obtain the consistent maximum performance of the participant. Generally, the isokinetic tests are performed continuously in clinical practice with reciprocal contractions, which involves both agonist and antagonist muscles within the test; or with concentric and eccentric contraction of the agonist muscle consecutively. Also, the nature of many movements generally requires continuous repetitions without long rests. Therefore, providing a long rest period may change the physiological adaptations to the movement and affect the time to achieve the maximum performance. Additionally, it was not mentioned if the contraction mode was concentric or eccentric. The failure to report the contraction mode decreases the validity of this protocol for different contraction modes (concentric/eccentric). While the reliability is high, this protocol can be used to determine the performance changes of the muscle. However, it cannot be

assured that this protocol gives the maximum performance. Additionally, these results can be useful only for tested velocity and with the same rest period between the trials. Therefore, it cannot be assumed that these repetition numbers are suitable for the other velocities (such as lower velocities as 30º/sec, 60º/sec), as the contraction time is different for each velocity; as well as other protocols such as the tests involve reciprocal contractions. When compared to the study by Sawhill et al. (1982), these results provide much stronger evidence. The velocities used by the studies were comparable, as Sawhill et al. (1982) also used 200º/sec, which is close to 180º/sec chosen by Johnson and Siegel (1978). However, both studies have reported different trial numbers for their protocols. While Sawhill et al. (1982) suggests the use of the first four trials, Johnson and Siegel (1978) suggests almost the opposite by excluding the first 3 sub-maximal and 3 maximal repetitions. Even there are differences between test protocols; for example, the rest periods between the trials may not be the same (Sawhill et al. (1982) has not reported the rest times or contraction mode), the study by Johnson and Siegel (1978) provides a greater evidence as their protocol is proven to be reliable. The study by Sawhill et al. (1982) have not tested the reliability of their protocols and accepted 25% change in performance as stable, which gives a really high degree of variation in terms of muscle strength.

Li et al. (1996) have cited the studies by Sawhill et al. (1982) and Johnson and Siegel (1978) for their choice of trial numbers in their reliability study. Li et al. (1996) have also cited another study by Mawdsley and Knapik (1982) to justify their choice of trial numbers within sets. Mawdsley and Knapik (1982) have tested 16 participants in three sessions to find out if there is a change across sessions or trials in terms of mean peak torque. The study only investigated concentric knee extension at 30º/sec. The participants have performed 6 maximal contractions without any prior warm-up. During the test, a one-minute rest period was given between the trials without any reported reason. The testing sessions were completed in 6 weeks, with 2 weeks of rest between each test. There was no difference in terms of mean peak torque between three testing sessions. The researchers have also concluded that the participants should perform at least one maximal trial to ensure reproducible values if they are tested only at one session. The reason behind that was the difference between the values of the first trials of three sessions. While the first trial was the highest at the first session, it was the lowest at the second and third sessions. Also, the only statistical difference

between trials was between the first and the third trial of the first session. When the provided graphs were examined; it is seen that the maximum peak torque was performed at the first trial of the first test session; decreasing gradually until the third trial by less than 10%. The third trial was the lowest value throughout the first session. The second and third sessions showed the maximum values at fifth and fourth trials, respectively. Interestingly, the difference between the maximum value and the first trial was again less than %10 in the second and third sessions. Also, there was no difference between the maximum values between three sessions. The participants just reached the maximum value at different trial numbers. However, the range of the values were almost the same. When the first value of the first test session is excluded, the maximum peak torque would be different from the second and third testing sessions; therefore, may not result in the same high reliability as reported by the investigators. The reliability measurements were done by including the first trial of the first session. The writers also reported that in the first session, some participants have indicated that the movement was not comfortable and all the subjects reported that there was a difference in feeling. While these reports were not objectively presented, the researchers suggested that some inhibitory mechanism may have prevented the participants to perform better after the first trial. There was no objective data behind that assumption, and this may be the reason why the participants performed lower at the following trials after the first one at the first session. The willingness of the participants is an important factor during isokinetic testing, if the participants have not tried their best after the first trial, then the decrease in the value is normal and may not present the real maximal value. It is seen that the performance at the second and third testing sessions increases gradually from the first trial. The participants might have thought that they had 6 repetitions to perform their best and increased their force through the repetitions intentionally. This may also be the reason of the difference between the first and third trials at the first session. Participants might have experience hardness at the first trial and may not perform voluntary maximal at the second and third repetitions. The gradual decrease may be the result of the willingness of the participants.

As reported earlier, Sawhill et al. (1982) have used 25% to decide stability of the performance. In the study by Mawdsley and Knapik (1982), the range of almost 10% was not assumed enough for the ‘stable’ performance. There are no specified ranges

for the performance changes, also the difference between the tested velocities makes the comparison of the studies difficult. While Sawhill et al. (1982) have tested the participants at 200º/sec, 300º/sec and 400º/sec; Mawdsley and Knapik (1982) have used 30º/sec. The physiological demands of the muscles are not the same at different speeds. Another important difference was the rest time between each trial. The study by Sawhill et al. (1982) has not reported if the testing sessions included any rest period between each trial, but Mawdsley and Knapik (1982) have given a one-minute rest between each trial. As discussed earlier, different rest times provide the muscle different recovery times. Also, in clinical practice, the tests are generally performed without long rests between trials. These may decrease the validity of the results of these studies for clinically common test protocols.

Mawdsley and Croft (1982) have investigated if a 3 sub-maximal warm-up would affect the peak torque during isokinetic measure of knee extension strength. Twenty subjects were tested into two groups, one group with a prior 3 sub-maximal warm-ups and the other group without any warm-up, with six repetitions at 30º/sec. The study population were experienced with the isokinetic dynamometer test of knee. Subjects were told to increase the torque gradually during the warm-up. After the warm-up, subjects were rested for one minute. One minute rest was also provided between trials; which shows that the same protocol as Mawdsley and Knapik (1982) was used. The study has reported no differences in maximum peak torques between the groups. However, when the graphical result of the groups was observed, it is seen that the pattern of the mean peak torques were different. The results of the non-warm-up group were more consistent in the graphical representation, without any excessive changes within the given repetitions. Even it was not significant ($p < 0.051$), the difference between the first and second trial in the sub-maximal warm-up group was very close to a significant difference. One possible explanation of this difference may be that the sub-maximal trials may have affected the ability of the participants to give their maximum performance at the real testing session. The researchers concluded that the warm-up repetitions were adequate to prevent any discomfort during the testing; however, this conclusion was not driven from any objective data, it was just the subjective responses of some of the participants during the test as reported by the researchers. Overall, 3 submaximal warm-up trials have not affected the overall maximum peak torque for the specific testing protocol, even the patterns of the maximum values were different.

The main limitations of the studies by Mawdsley and Knapik (1982) and Mawdsley and Croft (1982) was the 1-minute rest period between each trial. This rest period is considered as a 'limitation', because recent investigators generally used the continuous mode for the testing, which is because of the continuous nature of movements in real life activities. When a long rest period is provided, a recovery occurs within the muscle (Harris et al. 1976). This may change the use of the energy systems at the following movement. Therefore, the recommendations of these studies may not be suitable for a continuous test protocol or a protocol with shorter rest times between each trial.

A study by Wyatt and Edwards (1981), have reported that during an isokinetic test of reciprocal muscle strength, the second and third repetitions are the peak torque values during extension. However, the findings were not reported as the aim of the study was not to find out the required repetition numbers to reach the maximum performance. The conclusion made by the researchers were not supported with any graphs or data. Also, when the testing protocol was observed, it was seen that their protocol was consisted of a practice exercise bout at 120^{o}/sec followed by 5 to 10 practice repetitions at each tested speed; including 60^{o}/sec, 180^{o}/sec and 300^{o}/sec. The researchers reported that the repetition numbers were limited to prevent fatigue; however, it was not proven that these 5 to 10 repetitions have not caused any decrease in the performance. Also, it was not mentioned if these repetitions were maximal or submaximal. The participants might have performed their maximum peak torques during these practice exercises. The participants were given a 2-minute rest period before the actual test; however, the selection of this rest period was not supported by the investigators. Considering these weaknesses of the study, the conclusion of the researchers about the repetition numbers to reach the maximum peak torque must be interpreted with caution.

Isokinetic tests were also performed without any certain repetition numbers, where the test continued until the subject was unable to increase the peak torque (Aagaard et al. 1995). However, in the clinical settings, some tests may be performed consecutively, generally on the same day. Testing the subjects until they are fatigued may result in a decreased performance on the following tests. Even there is only one test on one day,

the shortest and the most comfortable test protocol should be aimed and performed for the benefit of both the clinician and the tested subjects. Also, it should be noted that fatigue may result in an increased injury risk (Mclean and Samorezov 2009; Small et al. 2010). This is specifically important for the athletes, as they may be tested on one day and perform a training or match on the following day. Thus, deciding the required repetition numbers during the isokinetic testing may provide both shorter and safer testing protocols.

The studies by Johnson and Siegel (1978), Mawdsley and Knapik (1982) and Sawhill et al. (1982) were also discussed in book chapters to decide the trial numbers to achieve stable measurements (Osternig 1986). However, it is seen that the different populations in terms of gender and experience on the isokinetic dynamometry, different testing protocols (including different rest periods between trials, different velocities and different contraction types) and trial efforts (submaximal or maximal) have resulted in contradictory results. The recommendation paper by Brown and Weir (2001) have suggested the use of maximum 5 repetitions if the aim is to test the strength on the isokinetic dynamometer. However, no empirical study was referenced for this assumption. From a physiological point of view, this recommendation may be useful for lower velocities, as the ATP-PCr system is the main energy supplier during the first 15 seconds (Serresse et al. 1988). However, for higher velocities, the maximum strength may not be measured with just 5 repetitions. The subjects may need more repetitions to use the ATP-PCr system fully, as the contraction time at higher velocities is less than the contraction time at lower velocities. Also, this basic research knowledge should be transformed into applied research by testing the subjects with clinically useful machines, in this case the isokinetic dynamometer.

It is obvious that there is a gap in the literature to provide empirical evidence to decide the required repetition number to achieve the maximal consistent performance during the isokinetic strength testing. While too few trials may result in an unachieved maximum performance, too many trials may result in fatigue and risk the tested subjects, which is ethically not suitable. Therefore, the trial numbers until achieving the maximum stable performance is clinically important. As discussed in this section, studies into the optimum number of trials have rarely been undertaken before a considerably long time ago, and these studies have some methodological limitations.

The use of different velocities, contraction types, test orders and rest periods also makes it difficult to compare the findings of the studies and decide an optimal test protocol. The primary focus of the current study was the repetition numbers within the sets, to determine the trial numbers to achieve the consistent maximum performance. Following the findings of the current study, the primary variable of an isokinetic test, the repetition numbers within the sets, will be decided with an objective data. Without standardising the trial numbers within sets, other variables in the isokinetic test may not be meaningful, as too few trials within a set may cause the participants not to achieve their maximum performance or too many trials may cause fatigue and affect the following sets or other tests. Therefore, the current investigation aims to fill this gap by providing these repetition numbers for the most tested movement, knee flexion and extension at the mostly used velocities, 60º/sec and 180º/sec. The study will also investigate whether there is a difference between concentric and eccentric contraction types. Some studies have reported poorer reliability for eccentric testing when compared to concentric (McCrory et al. 1980; Tredinnick and Duncan 1988; Wessel et al. 1988). As the eccentric contraction type on the isokinetic machine is slightly different from the natural movement, when compared to the concentric mode and its nature, it might be expected that the tested subjects may need more repetitions to understand the movement and maximize their effort. It was also suggested by Wessel et al. (1988) to practice the test one week before the actual test date to increase the reliability, especially for the eccentric measures of knee extension. However, in most clinical settings, it is not practical to call the subjects twice and is also an additional expense that would be better to avoid. Thus, a testing protocol that would both provide the learning phase and getting used to the machine in the same session would be practically useful in most research and clinical settings.

2.5. Summary

Isokinetic strength testing provides valid and reliable data when objectively investigating the dynamic muscle strength and determine changes in muscle performance in both clinical and research environments. However, the researchers should control the different factors affecting the results of their investigations. These factors include the planning of the protocol in relation to the aim of the test, safety of the tested subjects, familiarization to the isokinetic machine, general and specific

warm-up procedures, proper stabilization and positioning. While some of these factors generally have been investigated in the literature, the testing protocol is still inconsistent, even in the studies with the same aim. It is shown that to obtain the maximum strength, the peak torque should be used as the quantification. While generally lower velocities have been used to assess the maximum strength, the physiological demands of the tested population sometimes require higher velocities to be tested during the strength measurements. It is known that different velocities results in different contraction times, therefore different physiological demands. However, in the literature, different velocities have been tested in the same session with the same procedure. The physiological differences may require different protocols during the testing, as shown in the studies investigating the rest period between sets proved that different velocities require different rest periods for recovery after the contraction. Another different point is the contraction type, concentric and eccentric contractions have different physiological processes, therefore may require different testing protocols. It is clear from the literature review that less attention has been paid to the repetition numbers within the sets until now. Some early studies have investigated the optimal number of trials to obtain a consistent data; however, all these studies have some methodological limitations as discussed earlier. Also, a distinction between velocities and contraction types has not been made with all isokinetic testing being seen as homogenous. While the repetition number within sets is inconsistent in the studies, generally maximum 5 repetitions were used by the investigators. This repetition number may seem reasonable from a physiological perspective at lower velocities, as the contraction time is suitable to assess the ATP-PCr and anaerobic glycolytic system. However, the higher velocities may require longer contraction times to use both anaerobic energy systems. Fibre types within the muscle was also shown to be affecting the force production. Therefore, different muscle groups may show different fibre recruitments during contraction. While most studies investigating suitable protocols have tested knee extensor muscles, knee flexor muscles are also commonly tested in the clinical practice. Therefore, standardization of the testing protocol for knee flexion is also important.

2.6. Aim of the Study

The main aim of this study is to find out the required repetition numbers to achieve the

consistent maximum performance during isokinetic strength testing of knee flexion and extension at two mostly used velocities of 60º/sec and 180º/sec for both concentric and eccentric contraction types.

2.7. Objectives of the Study

1- To find the required repetition numbers to achieve the consistent maximum performance during isokinetic concentric knee extension test at 60º/sec.

2- To find the required repetition numbers to achieve the consistent maximum performance during isokinetic eccentric knee extension test at 60º/sec.

3- To find the required repetition numbers to achieve the consistent maximum performance during isokinetic concentric knee flexion test at 60º/sec.

4- To find the required repetition numbers to achieve the consistent maximum performance during isokinetic eccentric knee flexion test at 60º/sec.

5- To find the required repetition numbers to achieve the consistent maximum performance during isokinetic concentric knee extension test at 180º/sec.

6- To find the required repetition numbers to achieve the consistent maximum performance during isokinetic eccentric knee extension test at 180º/sec.

7- To find the required repetition numbers to achieve the consistent maximum performance during isokinetic concentric knee flexion test at 180º/sec.

8- To find the required repetition numbers to achieve the consistent maximum performance during isokinetic eccentric knee flexion test at 180º/sec.

3. METHODOLOGY

3.1. Study Design

An observational study was undertaken using the Kin-Com 125E Isokinetic Dynamometer (*Kin-Com, Kinetic Communicator*, Chattecx Corporation, Chattanooga, Tennessee, USA) for repeated testing of muscle strength. This was to explore trial numbers to reach the maximum performance consistency and identify when the effects of fatigue are seen during the isokinetic testing of knee flexion and extension for both concentric and eccentric strength at 60^{o}/sec and 180^{o}/sec. The aim was collecting data prospectively from a group of participants and exploring the existing patterns of performance. The study did not aim to change or manipulate any of the data of participants by any intervention. There was no grouping, comparison or exploring the relationship between different variables. Therefore, a descriptive observational study design was chosen (Portney and Watkins 2014).

3.2. Sample Size

The study aimed to determine the clinical numbers for a testing protocol and inform the clinical practice. Therefore, firstly a convenience sample size of 30 participants was utilized for the graphical analysis of the data. After counting the 8 possible test orders, which will be explained in the 'Venue and Instrument Setting' section, it was decided to include 2 males and 2 females for every test order to minimize any possible order or gender bias. This resulted in 32 participants (16 males and 16 females) overall. It was considered inappropriate to conduct a power calculation therefore. G Power was not used in this study as the study is not examining statistical differences.

3.3. Participants

A total of 32 participants were included in the study. An overall sample of 32 participants (16 male and 16 female) were tested. Equal numbers of male and female participants were included to minimise the gender effect. All participants were recruited from the postgraduate students of School of Healthcare Studies, Cardiff University. The inclusion and exclusion criteria were applied to increase the validity of the test

and accuracy of the data. The inclusion and exclusion criteria are to ensure safety during maximal muscle testing.

3.3.1. Inclusion Criteria

The inclusion criteria for the participants were as follows;

Age range of 18-35 years.
Performing physical activity for at least 30 minutes, 3 times per week to avoid sedentary subjects and provide the minimal requirements of physical activity. (American College of Sports Medicine, 2013).
Being able to understand and perform the instructions and provide informed consent.
Having no experience on the isokinetic dynamometer. Any experience might change the understanding of the movement and may alter the performance pattern.

3.3.2. Exclusion Criteria

The exclusion criteria for the participants were as follows;

Any previous fractures or surgeries to the musculoskeletal structures in lower extremity.
Any acute injuries of lower extremity in the previous 3 months.
Any cardiovascular or neurological disorders.
Any ergogenic dietary supplementation intake. It may change the performance and the onset of fatigue; therefore, decrease the test validity (Tokish et al. 2004).

3.4. Ethical Considerations

A study proposal was submitted and approved by the Cardiff University School of Healthcare Sciences Ethics Committee (Appendix V). All participants were provided with written information regarding the study aim, study protocol and risk for injuries with a participant information sheet (Appendix VI) 36 hours before the study to decide whether they would like to volunteer for the study or not. Participants also had the chance to ask their questions about the study. The questions were answered by the

main investigator in a way that all participants could easily understand. Written consent was obtained from all participants before beginning the testing procedure on the test day (Appendix VII). Participants were informed that they had the right to leave the study at any time without reporting any reason.

3.5. Data Protection

Personal information and data protection was handled according to Data Protection Act (1998). The information was not used in any other research or work other than that has been told to the participants, all the information was used for the intended purpose. For safe and secure storage, there was only one hard copy of the information and test data of participants. Only the main investigator was able to access to those files kept in a locked cabinet. The computer of the main investigator used to analyse the data. Both the computer and the files were password protected. During the tests, only the given numbers to the participants and their initials were written on the system of the isokinetic dynamometer to protect the confidentiality. As this study is a clinical research, the data will be protected under the same conditions for nearly 15 years and subsequently destroyed in accordance with the Data Protection Act (1998).

The study did not include any sensitive data such as ethnic origin, religious beliefs, political opinions or sexual preferences; therefore, stricter controls were not used (Data Protection Act. 1998).

3.6. Risk Assessment

As the study includes a testing protocol with an isokinetic machine, there was a risk of injury. These injuries could be a muscle tear or possible discomfort from soreness. The risk of these injuries was calculated following the guide from Economic and Social Research Council Framework for Research Ethics (2015).

Table 1: Risk of Injuries

Injury	Likelihood	Severity	Risk

Muscle Tear	1	3	3
Muscle Soreness	5	1	5

Considering the likelihood and severity of the injuries, there was tolerable risk for all possible injuries. According to the guideline, no further action was needed when the injury risk is low (0-5). However, some precautions were taken to minimize the likelihood of any injuries. Two of these precautions were the warm-up protocol applied before the test. It aimed to reduce the possibility of a muscle injury (Woods et al. 2007). Another precaution was the education of the participants. All participants were educated about muscle warm-up and practicing gentle exercises after the test to reduce soreness (Cheung et al. 2003).

Contact details of the researcher was shared with the participants so they were able to discuss their situation if they had any discomfort following the test. The researcher was familiar to the instrument and the venue. Due to the nature of the test, there was no risk of harm or injury to the researcher. Despite all the precautions, first aid was available in the study lab in case of any acute injury. No injuries occurred during the study period.

3.7. Venue and Instrument Setting

The Kin-Com Isokinetic Dynamometer at Cardiff University School of Healthcare Sciences, the Research Centre for Clinical Kinesiology (RCCK) was used to perform the tests. Permission to access the RCCK and Kin-Com Isokinetic Dynamometer was acquired from the Healthcare Simulation Team via e-mail (Appendix I). The area for the Kin-Com Isokinetic Dynamometer was booked for every participant individually through the study period via e-mail using the booking form (Appendix II). The area also included a stationary bicycle (Monark, Ergomedic 828E, Sweden); used for the warm-up protocol.

The Kin-Com provides four modes of exercise; these are isokinetic (concentric and eccentric), isometric, isotonic and passive. These modes can be tested at different angular velocities ranged between 0°/s and 210°/s (Malone 1988). The system

reliability of the Kin-Com isokinetic dynamometer was previously reported as high for the functions of lever arm position, lever arm velocity and force measurement (Farrell and Richards 1986). The Kin-Com is also validated as a muscle performance evaluator as it produces the same values for repeated measurements of torque for the given subject if the machine is calibrated correctly (Hanten and Lang 1988). The test-retest reliability of the Kin-Com for knee muscles was also demonstrated by several studies for knee flexion and extension for both eccentric and concentric contractions at different angular velocities of 60°/sec, 90°/sec, 120°/sec and 180°/sec (White and Protas 1985; Harding et al. 1988; Tredinnick and Duncan 1988; Kramer 1990).

The most frequently assessed velocities, 60°/sec and 180°/sec, were tested in this study (Celes et al. 2009; Lundgren et al. 2011). Each velocity was tested on one leg of the participant for both flexion and extension. The velocities were randomly assigned to the right and the left leg to allow for multiple testing on a single day, minimising the effect of fatigue on subsequent testing. Leg order and flexion/extension order were counter-balanced to minimise any possible order bias. This allocation procedure resulted in 8 possible testing protocols. As this study includes 16 males and 16 females, each protocol was used for two males and two females. A list of these test orders can be found in Appendix III.

The Kin-Com isokinetic dynamometer used in this study was calibrated according to the manufacturer's instructions before the testing period in June 2017.

The Monark stationary bicycle (Monark, Varberg, Sweden) was used in warming-up. The warm-up was a 10-minute active cycling protocol specific to lower extremity. There was no resistance to avoid fatigue.

3.8. Pilot Study

Prior to actual data collection, a pilot study was completed with one participant to determine the required time to complete one test, to allow the researcher to familiarize with the instrument and to find out if the proposed protocol was suitable for the practice. The results of the pilot study were not included in the final analysis.

The study focused on the required trial numbers to reach the maximum performance and maintain consistency, and the beginning of fatigue during the isokinetic testing of knee flexion and extension for both concentric and eccentric contractions. Therefore, it was planned to require the participants to continue to the test until they were not able to continue because of fatigue. However, during the pilot study, the Kin-Com isokinetic dynamometer did not allow to repeat the movement more than 12 times. As a limitation, the test had to be completed in 12 repetitions and therefore the data were limited to 12 values for each movement.

Another issue noted during the pilot study was the data extraction from the computer. The printer of the system was not working; therefore, the best way to extract the data was writing them down right after the tests. For that reason, a specific sheet was designed for every participant to write down the test results as peak torque of every repetition for concentric and eccentric contractions. The participant data sheet was specifically designed for 8 different test orders which was reported earlier. 32 participant data sheets were prepared in accordance with the test orders. An example participant data sheet can be found in the Appendix IV. On the test day, participant data sheets were put into envelopes and sealed. The envelopes were put on two sides of a table; one side was for males and the other side was for females. Subjects randomly took one of the enveloped sheets on the table in accordance with their gender. After this random allocation, subjects were tested in their allocated test order.

The pilot test was firstly performed without verbal encouragement to the subject. However, this resulted in decreased performance and unmeaning patterns in the test results. After that, it was realized that the subjects had to be motivated and encouraged to give their maximum performance from the first repetition until the last. Therefore, during the normal data collection, the subjects were encouraged verbally to do their best for every repetition consistently.

During the piloting, the required time for the whole procedure was found as approximately 40 minutes per subject. This time included the preliminary paperwork, measurement of the demographics, warm-up and testing protocol. After including the data extraction from the computer, it was found that approximately 1 hour per subject

was needed to complete the whole procedure. Therefore, the overall testing procedure of one subject required 40 minutes of the participant and 1 hour of the investigator.

3.9. Study Protocol

Participants were recruited from postgraduate students of Cardiff University with flyers and referral from the people who completed the study. Applicants were assessed for their eligibility for the research by the main investigator. Inclusion and exclusion criteria were checked verbally for each applicant. All applicants meeting the inclusion and exclusion criteria were provided with written information about the study and given 36 hours to decide whether they were volunteering to be a participant. Participants were aware of their right to stop or leave the test at any time without giving any reason. After the decision, a suitable date and time were arranged for the test. The Kin-Com isokinetic machine was booked for every participant from Cardiff University Healthcare Sciences Laboratory via e-mail using the booking form. All participants were advised to wear proper and flexible clothing for the test day to allow free movement of legs and avoid extreme heating in the body. Subjects were required to stop smoking, exercising and consuming alcohol at least 24 hours before the testing; as they might alter the muscle performance (Barnes et al. 2010; Degens et al. 2015). Avoiding heavy meals at least two hours before the testing was also instructed to the participants.

On the test date, participants were once again informed about the risks of the study and the precautions the researchers took to decrease the likelihood of any injury. Written consent was obtained from every participant before the testing protocol. Before beginning the test, all participants were encouraged to immediately stop the test and tell the investigator if they feel any discomfort or pain during the test.

Participant demographics and baseline information including sex, age (y), height (m) and weight (kg) was collected by the main investigator.

The procedure began with a 10-minute cycling warm-up. The seat height of the stationary bicycle was adjusted for each participant. There was no resistance to prevent any possible fatigue. The participant decided the pace; they were instructed to find their comfortable pace without excessive effort. After the warm-up, the

participants were directly set on the isokinetic machine to start the test.

The initials of the participant, height and weight were entered into the Kin-Com isokinetic dynamometer computer. Also, the tested leg (right or left) was selected from the computer system according to the test order of the participant.

Each participant was seated on the Kin-Com seat with the back supported and the hip at an 80° angle. The seat and dynamometer height was arranged individually for proper alignment. The pelvis was stabilised with a strap to minimize body movements during testing. The distal end of the femur was placed over the pad attached to the bench and stabilised with a strap to isolate the optimal movement of the knee. The axis of rotation of the dynamometer arm was positioned individually just lateral to the lateral femoral condyle, aligned with the axis of rotation of knee joint. The lateral femoral condyle was determined by palpation. The distal pad of the lever arm was positioned just above the medial malleolus to allow full ankle dorsiflexion. The described position is shown in Figure 1. The length of the lever arm then recorded and entered to the computer system. The anatomical zero position was identified as full knee extension. The range of motion of the knee joint was set between 5° and 90° (0° = Straight Knee). The straight knee was avoided for safety reasons and 5° flexion was left, the maximum knee extension was 175° during the test. The gravity adjustment was done by the computer automatically with the movement of the leg between specified ranges; the movement also helped to ensure the alignment of the axis of rotation and normal movement.

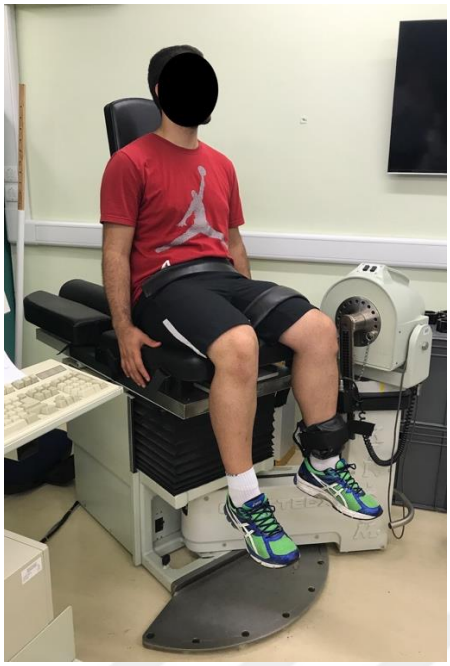


Figure 1. The position of the participants on the isokinetic dynamometer.

The test day was the first time on an isokinetic dynamometer for the participants; therefore, the movement were not familiar to them. The concentric movement was instructed as ‘Extend/bend the knee against the shin pad on the lower leg’ and the eccentric movement was instructed as ‘Resist the lever during the extension/bending’. Participants were not allowed to practice the movement sub-maximally or maximally to avoid any familiarization before the test. Only movement was done by the researcher passively in the beginning to arrange the machine.

The CON/ECC test mode in the KIN-COM dynamometer was selected for the testing. In this mode, all movements begin with concentric contraction and end with eccentric contraction of the same muscle group. Also, the investigator should start the movement for each discrete contraction by pressing a key on the computer keyboard. After the set-up, the test velocity was entered into the computer and the test begin with the assigned movement (flexion or extension) and continued until the 12 repetitions were completed. For the flexion, the leg was positioned in 175° extension; and for the extension, the leg was positioned in 90° flexion. Each contraction started with the instructions of the researcher with encouraging words like ‘Go/push/pull as much as you can’. After the contraction, the machine stopped and the researcher again started the movement by pressing a key from the computer keyboard. Each discrete

contraction was separated by 1-2 seconds from each other. Each concentric contraction was followed by an eccentric contraction. The whole testing was pushing or pulling the shin pad and then resisting the lever while it was moving on the opposite direction.

After finishing the first test, the opposite movement were chosen for the next test. When both movements were tested, the arm of the isokinetic dynamometer was moved to the other leg. The same set-up procedure was completed for the other leg too, and then the assigned velocity (60°/s or 180°/s) was tested on the other leg with the same testing protocol. The participants were permitted to hold on to the sides of the bench during the test and verbally encouraged by the researcher to give their maximum effort. Visual feedback from the monitor was also given during the test (Kim and Kramer 1997).

All tests were conducted by the same investigator to minimise the examiner variability and possible bias. At the end of the test, gentle exercises, including walking were recommended to every participant to decrease the level of soreness (Cheung et al. 2003).

3.10. Data Analysis

The main outcome measure of this study was the peak torque. Peak torque is defined as the single highest torque output throughout the range of motion of a joint movement produced by the muscles (Kannus 1994). The SI unit for Torque is the Newton meter (Nm). The peak torque of each repetition of concentric and eccentric contractions was recorded separately.

The demographic data were sex, age, height, and weight of the participants. Demographic data were calculated for their means and standard deviations, and presented as a table.

All data was firstly imported into Microsoft Excel (Microsoft Excel for Mac, Version 15.32, Microsoft, Redmond, Washington, USA). The isokinetic test data was explored

graphically. An average value for each repetition was produced for the two different velocities (60^{o}/sec and 180^{o}/sec), two different movements (flexion and extension), and two different contraction types (concentric and eccentric) which resulted in 8 different graphs. Each graph was explored separately in order to identify suitable cut-off points that would allow for determination of the peak performance or fatigue. To define both the consistent peak performance and fatigue horizontal trend lines were placed on the graph at specific values. The first value was the maximum value and the second was a variable value represented by the SD or a proportion of the SD. This second value was manipulated until there were three consecutive values between the two trend lines. These repetitions represented the first three consecutive repetitions and were taken as the first three repetitions that were consecutively closest to the peak performance. Fatigue was defined on the same graph as the first three consecutive repetitions that fell below these trend lines.

4. RESULTS

The results section will present the demographic data of the participants and the isokinetic test results of the study.

4.1. Descriptive Statistics

The data for 32 subjects (16 males and 16 females) were included in the analysis. The demographic data included age, height and weight; are shown in Table 2. The demographic data were similar to a normal postgraduate student population demographic.

Table 2: Demographic Data of the Participants

	Minimum	Maximum	Mean	Standard Deviation
Age (y)	18	32	25.66	3.56
Height (cm)	153	181	168.31	7.94
Weight (kg)	45	107	65.31	14.45
Key: y= years, cm= centimetre, kg= kilogram				

4.2. Isokinetic Tests

The following section will present the results from the isokinetic testing. There are total of two different directions and two types of contraction along at two different speeds. This gives a total of 8 separate aspects of the data. The 60^{o}/sec will be presented first and then the 180^{o}/sec.

The isokinetic test results are presented in individual graphs for knee extension and flexion for both concentric and eccentric contractions, at 60^{o}/sec and 180^{o}/sec. The

mean peak torque lines, the maximum peak torques and different ranges of maximum peak torques are shown with different coloured lines in each graph.

The horizontal axis of the graphs shows the repetition number while the vertical axis shows the mean peak torque (Nm) for each repetition. The black line represents the values for every repetition. The red line is for the point where the performance reaches to the maximum. After identifying the maximum peak torque, each graph was evaluated for different ranges of the maximum value, for identifying 3 consecutive points within a minimum range. Once the repetitions are plotted then horizontal trend line were added at set levels. The first horizontal trend line is set at the peak value. A second trend line is added at a lower value until three consecutive repetition are between the two trend lines. This is taken as indicating that the performance is consistent. The objective was to find the first three repetitions that produce consistent peak performance and the level that this was achieved.

4.2.1. Concentric Knee Extension Test at 60^{o}/sec

The graphical view of the data for concentric knee extension test at 60^{o}/sec is shown in Figure 2.

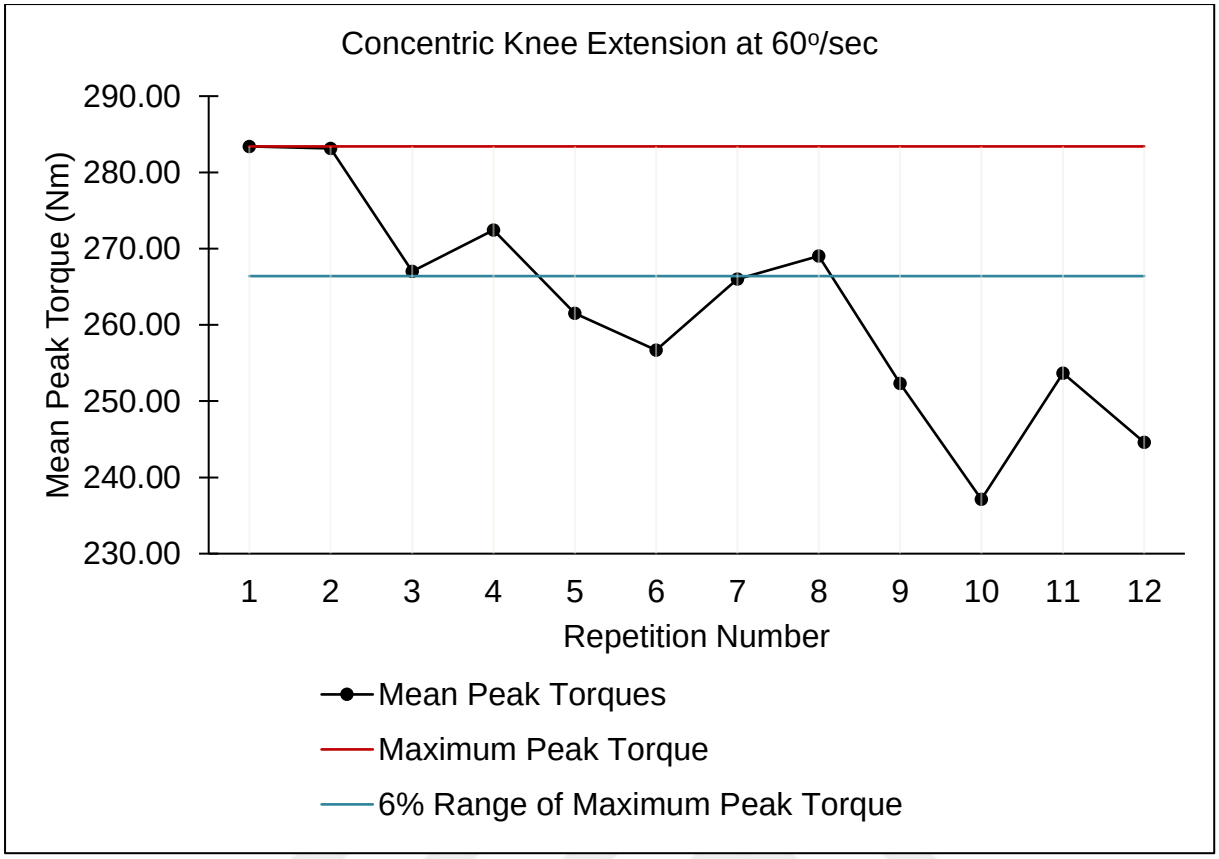


Figure 2. Graph representing the peak torque for concentric knee extension plotted against the repetition number. Horizontal lines for peak torque and 6% from the peak torque indicate the level of peak data consistency.

For the concentric knee extension test at 60º/sec, the trend overall was to see a maximal performance at the start followed by a steady decline. It is clear that the first three repetition fall between the peak value and the line representing a 6% reduction from the peak. Participants could perform their maximum performance in the first and second repetition attaining on average 283.41 Nm and 283.13 Nm respectively. The third repetition also followed the first and second in the 6% range, which was followed by an increased value at the forth repetition. After the fourth repetition, the values were decreased and situated outside the range of 6% of the maximum peak value. The eighth repetition also reached the range; however, there was only one value in the range without any consecutiveness. Overall, the first four repetitions were enough to reach the consistent maximum performance for this test.

4.2.2. Eccentric Knee Extension Test at 60º/sec

The graphical view of the data for eccentric knee extension test at 60º/sec is shown in Figure 3.

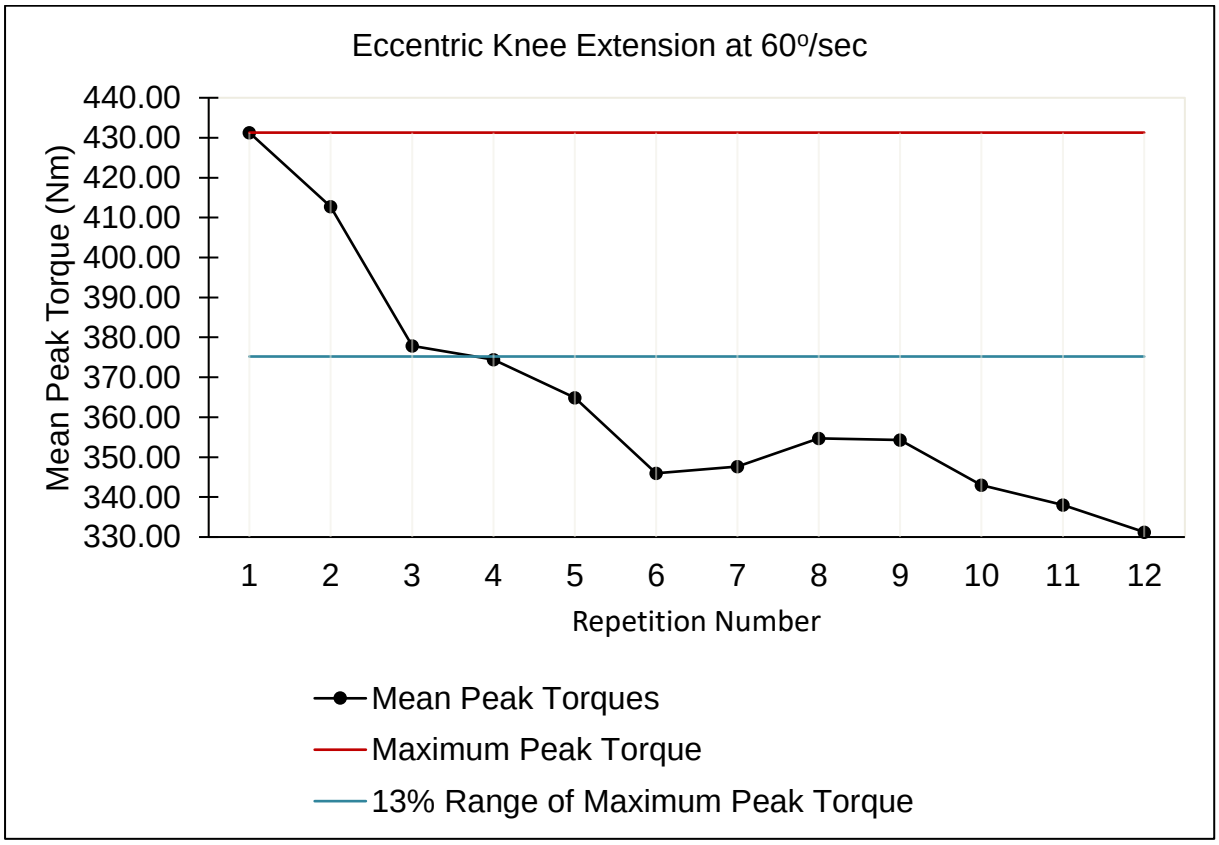


Figure 3. Graph representing the peak torque for eccentric knee extension plotted against the repetition number. Horizontal lines for peak torque and 13% from the peak torque indicate the level of peak data consistency.

For the eccentric knee extension test at 60º/sec, a similar trend to the data was seen where the maximal was attained at the start of the repetitions followed by a decline in performance on torque production. However, the decline was much more marked for eccentric extension with the maximum value of 430Nm being attained on the first repetition similar to the concentric test. The second and third values (380 Nm and 370 Nm, respectively) followed the first one with a decrease within the range of 13%, which is greater than the concentric test. After the third repetition, the values continued to decrease and stay out of the 13% range of the maximum peak torque. The first three repetitions were enough to reach the maximum consistent peak performance for this test.

4.2.3. Concentric Knee Flexion Test at 60º/sec

The graphical view of the data for concentric knee flexion test at 60º/sec is shown in Figure 4.

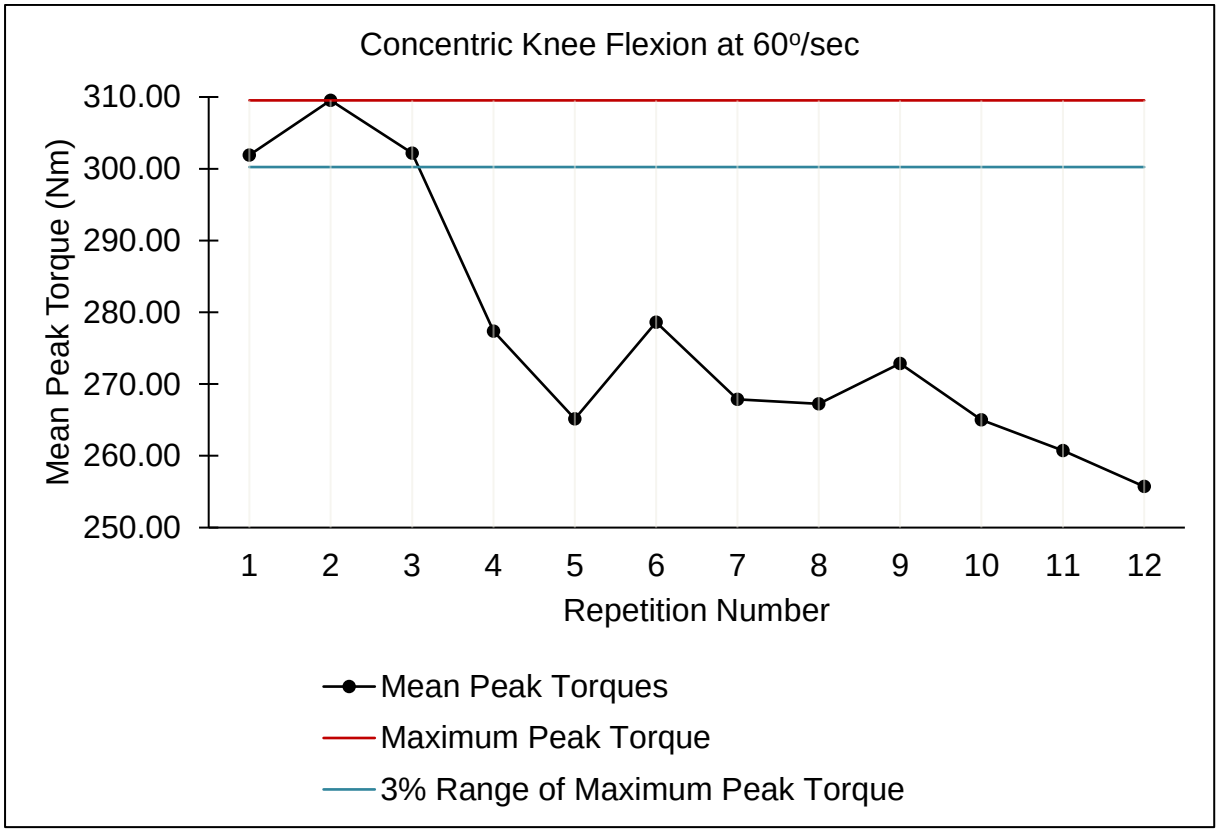


Figure 4. Graph representing the peak torque for concentric knee flexion plotted against the repetition number. Horizontal lines for peak torque and 3% from the peak torque indicate the level of peak data consistency.

For the concentric knee flexion test at 60º/sec, the maximum peak torque was at the second repetition with 310 Nm. The first and third repetitions were in the 3% range of the maximum performance, with the values of 301 Nm and 302 Nm, respectively. After the third repetitions, the values decreased by 8% and the following values were out of the 10% range of the maximum. The consistent maximum performance was reached at the first three repetitions for this test, just as the concentric and eccentric knee extensors at 60º/sec.

4.2.4. Eccentric Knee Flexion Test at 60º/sec

The graphical view of the data for eccentric knee flexion test at 60º/sec is shown in

Figure 5.

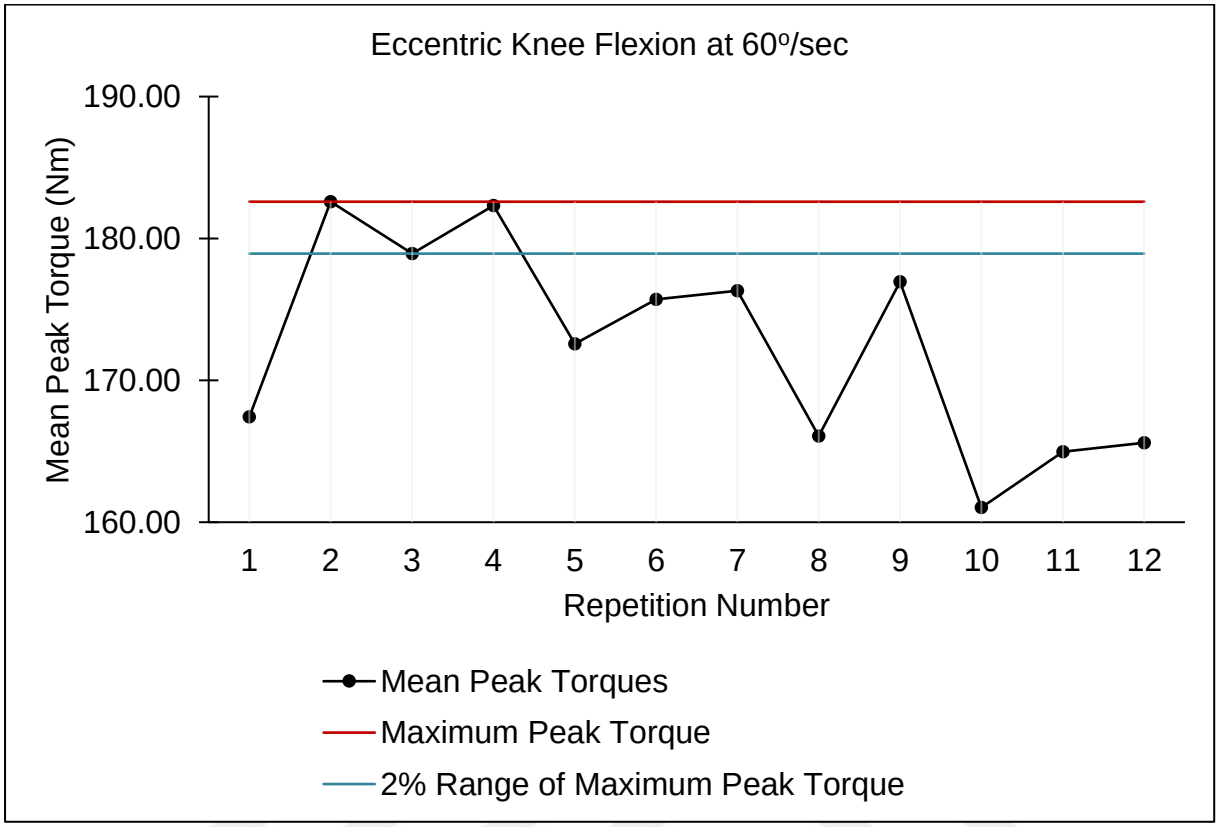


Figure 5. Graph representing the peak torque for eccentric knee flexion plotted against the repetition number. Horizontal lines for peak torque and 2% from the peak torque indicate the level of peak data consistency.

The maximum performance for the eccentric knee flexion test at 60º/sec was reached at the second repetition with the value of 182 Nm. The third value was in the 2% range of the second repetition with 178 Nm and the fourth value was almost the same as the maximum value, with a smaller decrease lower than 1%. After the fourth repetition, the values decreased and could not reach the 2% range of the maximum performance. Differently from the tests for knee concentric and eccentric extensor muscle test and concentric flexor muscle test at 60º/sec, the eccentric flexor test at 60º/sec could not perform the consistent maximum values in the first three repetitions. In this test, the first value was 8% lower than the second (maximum) value with 167 Nm. The maximum consistent performance was reached in the second, third and fourth repetitions in this test.

4.2.5. Concentric Knee Extension Test at 180º/sec

The graphical view of the data for concentric knee extension test at 180°/sec is shown in Figure 6.

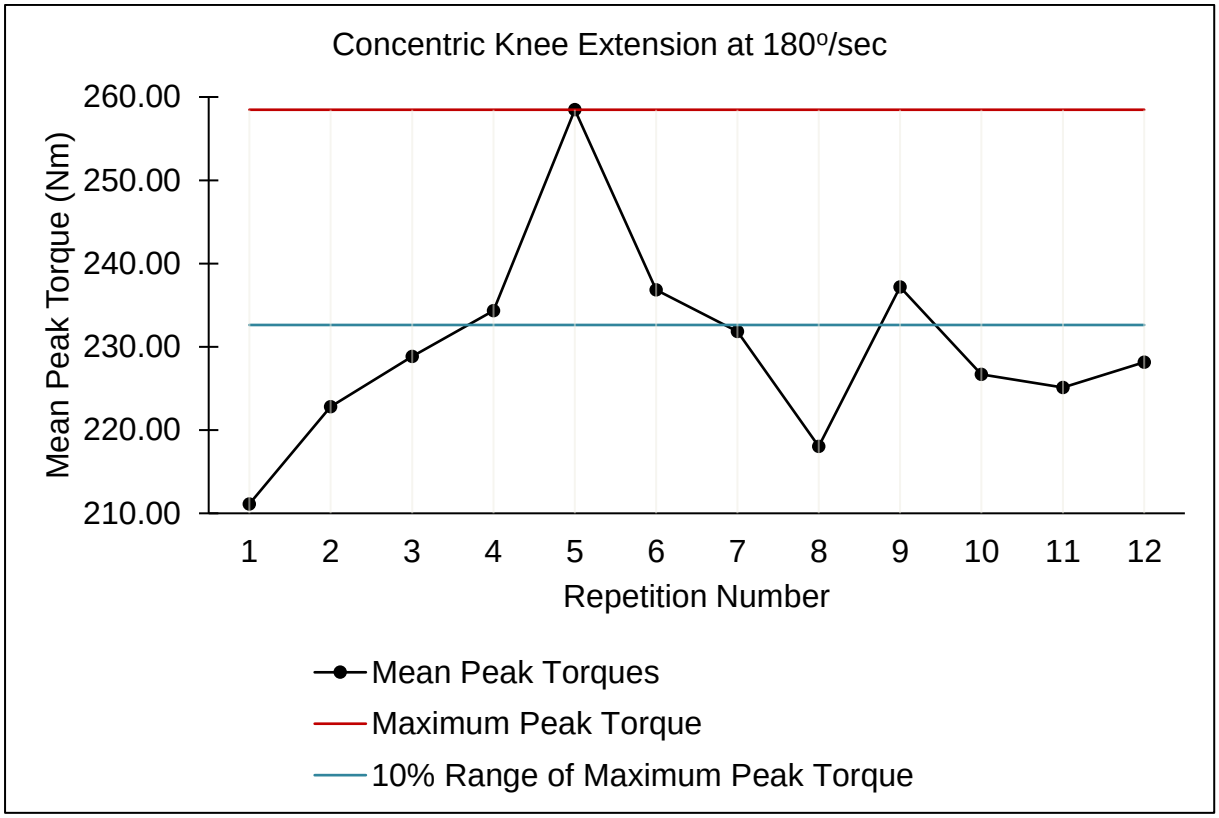


Figure 6. Graph representing the peak torque for concentric knee extension plotted against the repetition number. Horizontal lines for peak torque and 10% from the peak torque indicate the level of peak data consistency.

The values increased gradually from the first repetition until the fifth, where it reached the maximum value of 258 Nm. After the maximum value, the peak torque decreased and made the third consecutive value in the 10% range at the sixth repetition with 236 Nm. Following repetitions could not get within the 10% of the maximum value consecutively. For this test, the participants needed to continue until the sixth repetition to reach the consecutive maximum performance with a 10% range.

4.2.6. Eccentric Knee Extension Test at 180°/sec

The graphical view of the data for eccentric knee extension test at 180°/sec is shown in Figure 7.

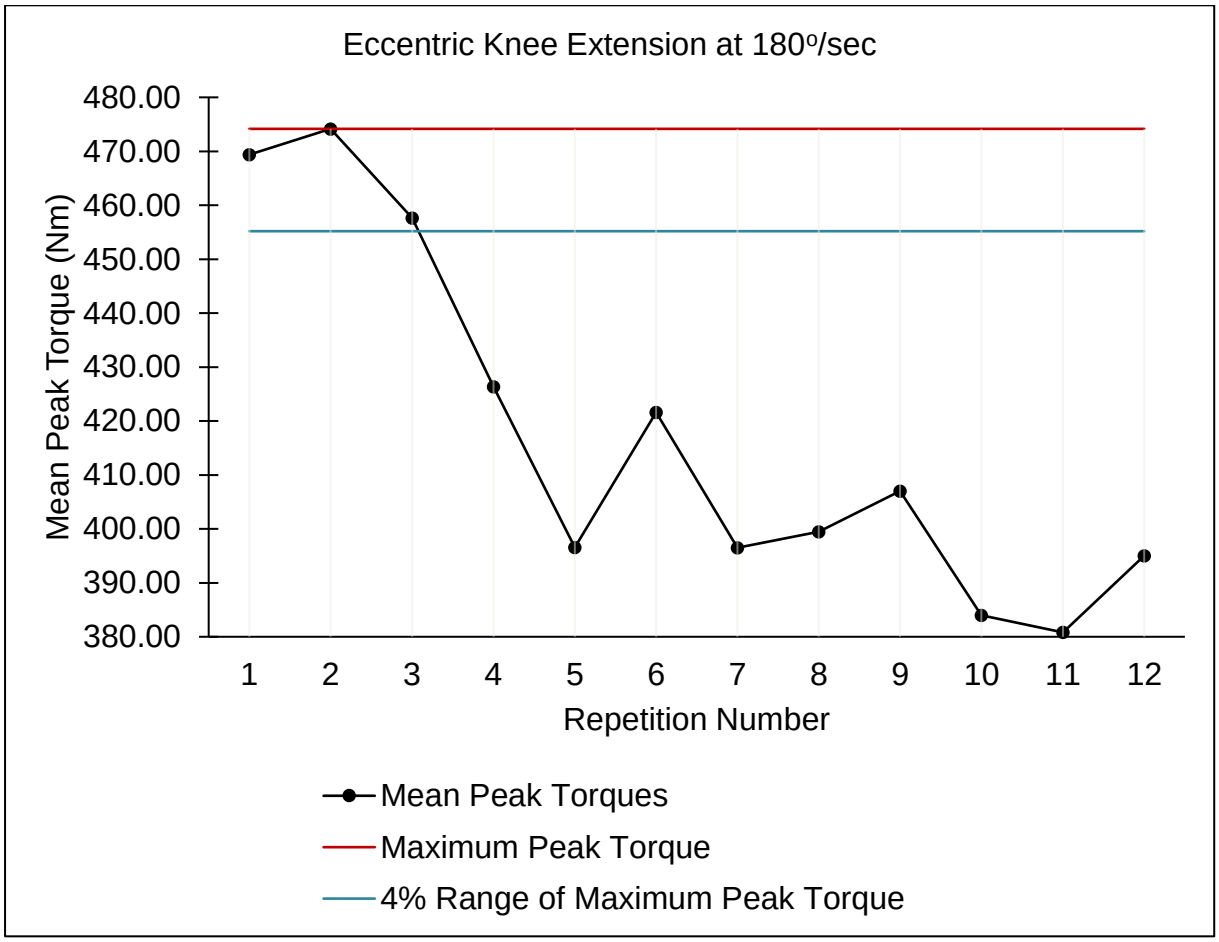


Figure 7. Graph representing the peak torque for eccentric knee extension plotted against the repetition number. Horizontal lines for peak torque and 4% from the peak torque indicate the level of peak data consistency.

For the eccentric knee extension test at 180º/sec, the participants could reach their maximum performance at the second repetition with 474 Nm. The first and the third repetitions were within the 4% range of the maximum value presenting at 469 Nm and 457 Nm, respectively. Following the third repetition, the values decreased dramatically and could not get in the specified range. The first three repetitions were enough for the subjects to perform the consecutive maximum performance, just like the tests for concentric and eccentric knee extension at 60º/sec, and eccentric knee flexion at 60º/sec.

4.2.7. Concentric Knee Flexion Test at 180º/sec

The graphical view of the data for concentric knee flexion test at 180º/sec is shown in

Figure 8.

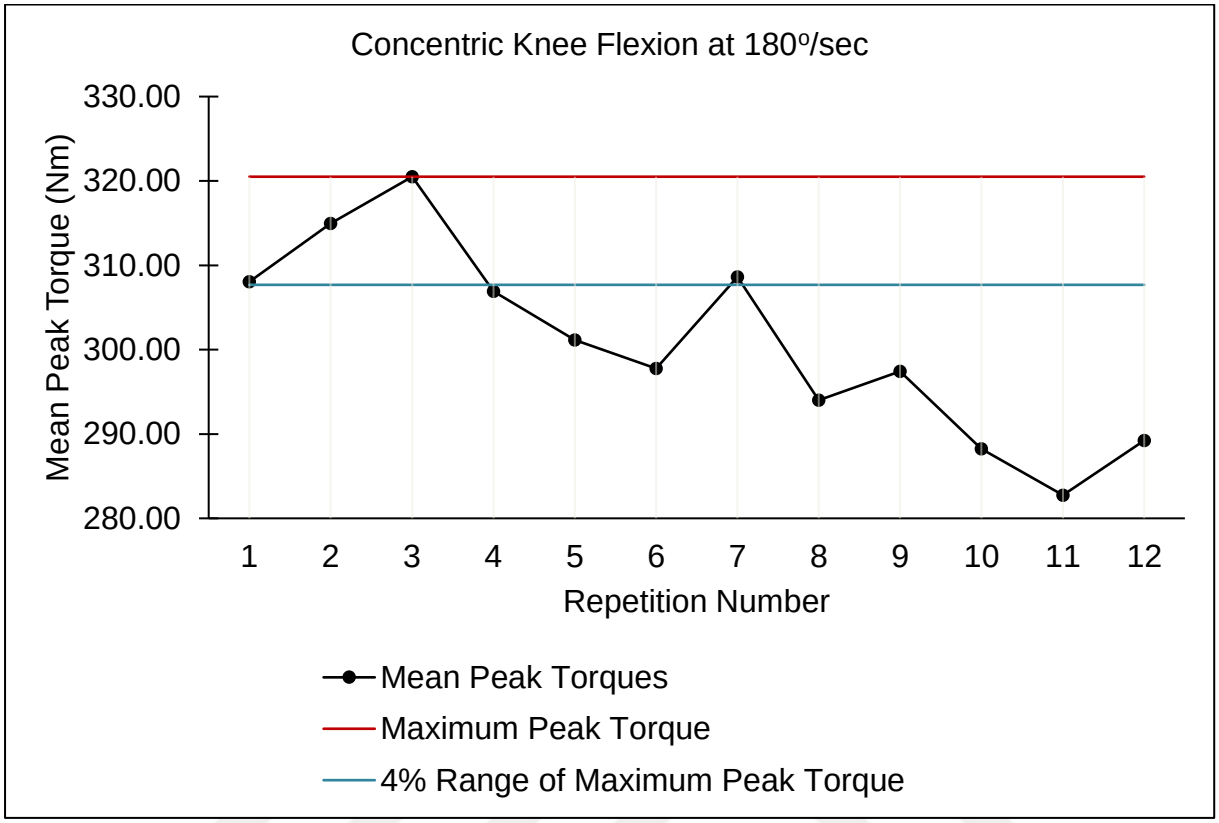


Figure 8. Graph representing the peak torque for concentric knee flexion plotted against the repetition number. Horizontal lines for peak torque and 4% from the peak torque indicate the level of peak data consistency.

Participants performed their maximum consecutive performance in the first three repetitions for the concentric knee flexion at 180º/sec. The value started to increase after the first repetition and peaked at the third repetition, from 308 Nm to 320 Nm. The range for this test were found to be 4%, the same as eccentric knee extension test at 180º/sec. Following the maximum value, the performance decreased and could not reach the 4% range consecutively. This test was the same as the tests of concentric and eccentric knee extension at 60º/sec, eccentric knee flexion at 60º/sec and eccentric knee extension at 180º/sec in terms of the required trial numbers for consecutive maximum performance, which was found to be the first three repetitions.

4.2.8. Eccentric Knee Flexion Test at 180º/sec

The graphical view of the data for eccentric knee flexion test at 180º/sec is shown in

Figure 9.

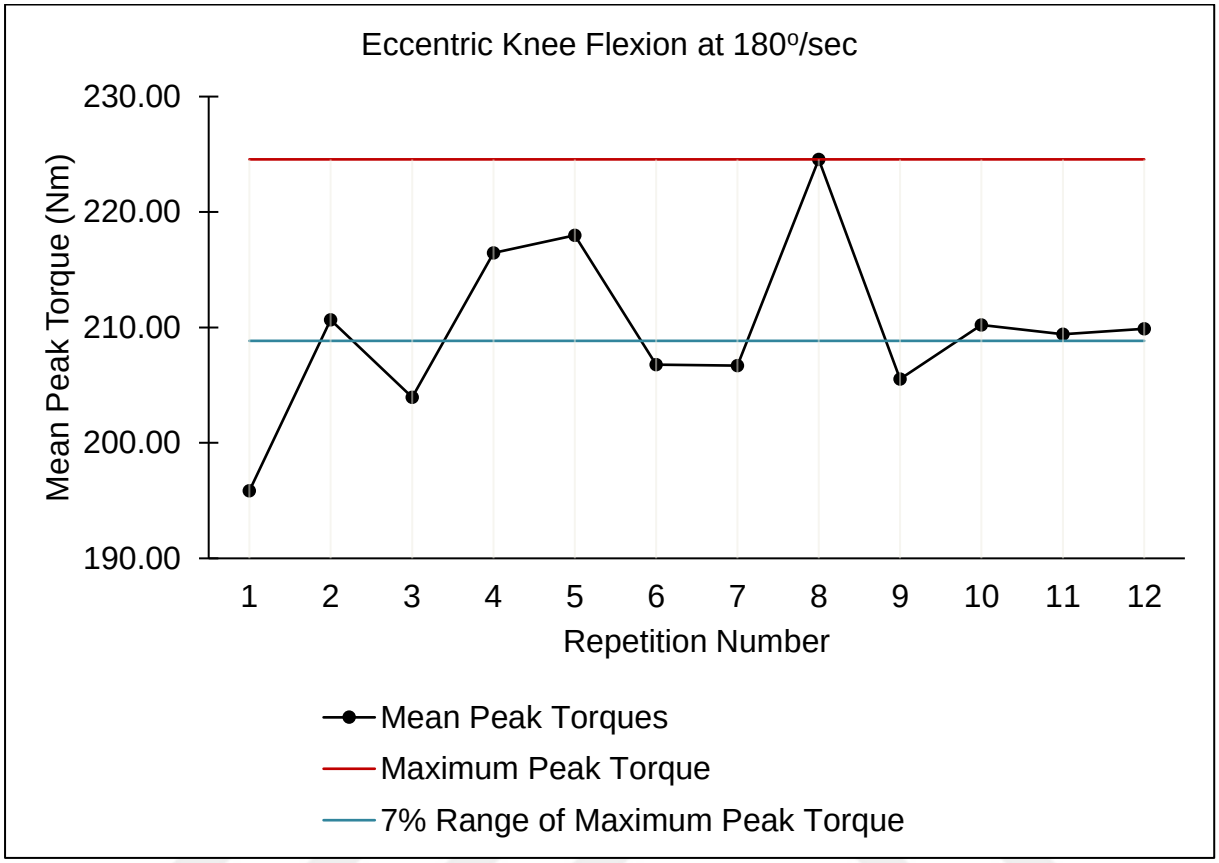


Figure 9. Graph representing the peak torque for eccentric knee flexion plotted against the repetition number. Horizontal lines for peak torque and 7% from the peak torque indicate the level of peak data consistency.

The graph for the eccentric knee flexion test at 180º/sec was the most fluctuating and inconsistent among the tests performed. Participants started with a low value and could reach the maximum value at the eighth repetition after inconsistent increases and decreases. However, the consistent performance could not be performed consecutively within the range of the maximum value, the tenth, eleventh and twelfth repetitions were the only consistent values within the 7% of the maximum peak torque. The test was the only one which the participants could not continue their maximum performance within the given range. The consistent performance required twelve repetitions and it did not involve the maximum value within.

5. DISCUSSION

In this chapter, the findings of the current study will be explained, discussed, and compared to previous related studies discussed in the literature review. Firstly, the demographic data of the sample will be discussed and then the isokinetic test results will be analysed individually. Even the graphs will be discussed one by one, the similarities and differences in different graphs will also be analysed and compared to each other while synthesising with previous related studies. This will be followed by the explanation of the limitations of the current study and some recommendations will be given for future research.

5.1. Demographic Data

The study included both male and females. To decrease any gender effect, the same number of participants were investigated for each gender. The target population was physically active and healthy university students. When the demographic data is analysed, it is seen that the mean (standard deviation) age of the participants was 25.66 (3.56). The height (standard deviation) and weight (standard deviation) was 168.31 (7.94) centimetres and 65.31 (14.45) kilograms, respectively. The data show that the age, weight and height of the participants of the current study is representative of the target population, healthy university students.

5.2. Isokinetic Tests

The isokinetic tests were resulted in 8 different graphs. There are two different directions (knee extension and flexion), two different types of contraction (concentric and eccentric), and two different angular velocities (60^o/sec and 180^o/sec). These variables resulted in 8 different test protocols. Each of these protocols were presented in the results section, beginning with knee extension, concentric contraction types and slower velocities. In this section, the same order will be used to discuss these results.

5.2.1. Concentric Knee Extension Test at 60^o/sec

The results of the concentric knee extension test at 60^o/sec showed that the

participants could perform their best performance at the first repetition with 283.41 Nm. This maximum performance was almost the same at the second repetition with 283.13 Nm. In the current study, three consecutive repetitions were aimed to identify the degree of variation from the maximum performance. In this test, the three consecutive repetitions were found in 6% range of the maximum peak torque. The first three repetitions have provided the maximum performance of the participants. After the third repetition, the fourth value was again in the 6% range; however, it did not exceed the value of the first repetition. The values started to decrease from the fourth repetition and stayed out of the 6% range from the fifth repetition. Therefore, the effect of fatigue was seen after the fourth repetition.

In the current investigation, participants were inexperienced with the isokinetic dynamometer and did not practice the movements on the machine sub-maximally or maximally before the actual test. Even these results cannot be directly compared to previous studies because of the different test protocols, the study by Mawdsley and Knapik (1982) may be similar in terms of tested velocities, movement and contraction type. Mawdsley and Knapik (1982) have tested concentric knee extension without any prior warm-up on the isokinetic machine in their study, just like the current study. Their angular velocity was 30^{o}/sec but in this study, it was 60^{o}/sec; however, both angular velocities can be classified as lower velocities. Therefore, a comparison of the results may be helpful. However, it should be known that their study has used a 1-minute rest period between each repetition; therefore, the differences in these results cannot be directly compared.

Mawdsley and Knapik (1982) have found the same result in their study in terms of maximum value. Their participants have performed the best value at the first trial, like in the current study. However, their values decreased gradually after the first trial and resulted in a greater range than 5% at the third one, which was also the lowest value. Because the values were not provided, the actual range is not known. The graphical presentation of the data shows a difference lower than 10%. In our study, the second repetition was almost as high as the first value. This difference might be a result of the rest period between the trials. From a physiological point of view, the contraction time for knee extension at 30^{o}/sec should continue about 3 seconds. The primary energy supply during this contraction is provided by ATP-PCr. The 1-minute rest period

between trials were supposed to be enough for the recovery of ATP-PCr. Therefore, this result may not result from fatigue or lack of recovery. It is highly likely that these differences were seen mainly because of the willingness of the participants. Because, in the current test, the second repetition resulted in a value which was as high as the first one and there was no rest period between these contractions. Therefore, the muscle may not be affected from fatigue or lack of recovery at this early phase of the test.

The range of the difference between the maximum and the following two values were 6% for this test. From a statistical perspective, this might be considered as a 'statistical difference' as it is higher than 5%. However, the importance of this range is that it gives an idea about the variability of the values without subtracting the maximum value. It is important to get the maximum value; however, it is also important to have an idea about the consistency of this maximum performance. Therefore, these ranges will be discussed for every test and then compared to each other to see if there is a difference between different test protocols in terms of variability of maximum performance.

As previously reported, concentric contractions and lower velocities are generally easier to perform for the participants and reliability of these tests are higher when compared to eccentric higher velocity tests (Wilhite et al. 1990; Brown 1993; Steiner et al. 1993; Deighan et al. 2003). Our results revealed that the participants can perform their maximum performance at the first trial, even they do not have any experience on the isokinetic dynamometer. These results are most likely applicable for the concentric knee extension tests at lower velocities such as 60º/sec.

5.2.2. Eccentric Knee Extension Test at 60º/sec

To our knowledge, no previous study has investigated the change in the performance through repetitions for the eccentric contraction. Therefore, a directly comparison of these results cannot be made to a previous research. However, it can be compared to the concentric test results of the current study. The maximum value for the concentric test was 283 Nm, while it was 431 Nm for the eccentric contraction. This was expected as the eccentric contraction generally results in a greater force when compared to

concentric (Westling et al. 1991).

The eccentric knee extension test at 60º/sec has shown that the maximum value was obtained from the first repetition, the same as the concentric test. However, when the graph is analysed, it can be seen that the values started to drop sharply following the first trial, until the sixth repetition. When the trendline was drawn from the three consecutive repetitions; it is seen that the range was 13%. This range was much greater when compared to the range of concentric test.

Differences between concentric and eccentric contraction were explained in the literature review chapter. When the test results are compared, it is seen that in both tests, participants could perform their best performance on the first trial. This performance could be kept in the second trial in concentric test; however, it could not be performed at the same level in the second trial in the eccentric test. While the concentric test gave the three consecutive trials in 6% range of the maximum value; in the eccentric test, this range was 13%. Participants could not perform their maximum performance steadily when the contraction mode is eccentric. Instead, the performance continued to decrease throughout repetitions. The eccentric performance of the participants was inconsistent when compared to their concentric performance. However, in both tests the maximal performance was obtained in the first three repetitions.

It was previously reported that the eccentric contraction is much harder to perform for the participants when compared to concentric (Steiner et al. 1993). Also, it is suggested that a possible inhibitory mechanism may help to protect the muscle from the damage of the eccentric contraction (Aagaard et al. 2000). In the current study, the decrease in the values after the first repetition may be the result of this possible neural inhibition. During the eccentric contraction, the subjects resist to the dynamometer while its applying force. The muscle lengthens during this type of contraction. This lengthening may not be familiar to most participants, as the test differs from the daily functional use of the eccentric contractions such as descending stairs, sitting down into a chair and running. The participants may have felt the hardness of the eccentric contraction and therefore, may have decreased their effort to deal with this hardness.

Overall, the results of this test showed that the participants could perform their maximum performance at the first trial for the eccentric contraction type, just like the concentric test. These results indicate that for the concentric and eccentric knee extension test at a slow speed (60°/sec), the maximum performance can be obtained from the first three repetition without any prior specific warm-up or familiarization session. However, it should be noted that the concentric contraction is steadier throughout repetitions when compared to eccentric contraction.

5.2.3. Concentric Knee Flexion Test at 60°/sec

Concentric knee flexion test at 60°/sec presented that the participants could perform their best value at the second repetition with 310 Nm. The first and third values were slightly lower with 301 Nm and 302 Nm, respectively. The three consecutive repetitions were the first three trials, staying in the 3% range of the maximum value. This shows that there was no statistical difference between these repetitions, as the difference was lower than 5%. After the third repetition, the values fall gradually and never reached to this 3% range again. This may indicate that the effects of fatigue were seen following the first three repetitions.

When compared to the knee extension test, the results were similar in terms of repetition numbers required to reach the peak performance. The concentric and eccentric knee extension tests at the same velocity have shown that the participants needed only three repetitions to perform their best value. This was the same for concentric knee flexion. While the best value was performed on the first repetition for the knee extension tests, it was performed on the second repetition during the knee flexion. Interestingly; the first three values were much steadier in concentric knee flexion than eccentric and concentric knee extension. The range was 6% for concentric and 13% for eccentric knee extension tests; these ranges indicate that there was a statistical difference between repetitions. However, for concentric knee flexion test, the first three repetitions were not different from each other from a statistical perspective. This shows that for the knee flexion, participants were able to keep their maximal performance through these first three repetitions.

These results may indicate that knee flexion is easier to understand and control the movement for the participants when compared to knee extension. However, when compared to concentric knee extension, the effects of fatigue were more significant. While the knee extension repetitions continued in a steadier line after the first three trials; the values significantly fell and stayed out of the specified range during the knee flexion. This might be a result of the greater force production, as well as the maximal consistent performance in the first three trials.

Overall, concentric knee flexion test results revealed that participants did not need to perform more than three repetitions to achieve their maximum values. When compared to knee extension, the required repetition numbers were the same. However, the values were more stable and the effect of fatigue was more significant during concentric knee flexion test. This might indicate that concentric knee flexion is more understandable for the participants so that they could reach the maximum level and could kept it through the first three repetitions.

5.2.4. Eccentric Knee Flexion Test at 60^{o}/sec

The pattern of the eccentric knee flexion test at 60^{o}/sec was different from the knee extension and concentric knee flexion tests at 60^{o}/sec. The participants could not perform their maximum performance on the first three repetitions. Differently, the first repetition was not in the range of three consecutive repetitions. The maximum value was obtained at the second repetition with 182 Nm, slightly decreased at the third repetition to 178 Nm and again increased to 182 Nm on the fourth repetition. When the trendline was drawn, it was on the 2% range of the maximum value including the second, third and fourth repetitions. This range was lower from the knee extension and concentric knee flexion tests; representing a more stable performance. However, the participants needed one repetition to reach their consistent performance.

Unexpectedly, the maximum value for eccentric knee flexion was lower (182 Nm) when compared to the concentric test (310 Nm). Normally, eccentric contraction results in a greater force production when compared to concentric (Westling et al. 1991). This raises questions about the validity of this test. Previously, poorer eccentric reliability results were reported by many investigators (McCrory et al. 1980; Wessel et

al. 1988). It was also suggested to provide a familiarization session for the eccentric test one week before the actual test (Wessel et al. 1988). As explained earlier, the nature of the eccentric contraction is different from the movement on the isokinetic dynamometer. It is seen that for the knee extension it was most probably not a problem for the participants in this study, as they could perform their best in just three repetitions with a higher score than concentric test. Even it cannot be known for sure, because the reliability of the current tests was not assessed, it may be assumed that eccentric knee extension is easier to understand and perform when compared to eccentric knee flexion. Normally in functional performances like daily life activities or running, knee flexors are contracting eccentrically in relation to the concentric contraction of knee extensors. However, on the isokinetic machine, it is expected from the participants to perform it in isolation. Therefore, it may be harder for the participants to understand the movement on the machine at first. Participants of the current study was inexperienced with the isokinetic dynamometer. This might be the reason why these results are lower than expected, they might have not understood the movement to be able to apply their maximal force.

The current investigation included 12 repetitions for each test session. Interestingly, 12 repetitions were not enough for the current participants to perform a greater performance than the concentric test. When the graph is analysed, it can be seen that after the maximum values on the second, third and fourth repetitions, the values are always lower than the range of 2% of the maximum. Normally, a learning affect was being expected during this testing session. However, the values did not increase with repetitions. This might be a result of the fear of the participants. It was explained in the literature review section that during the eccentric contraction, a possible inhibitory mechanism may be limiting the activity of the muscles. This was suggested to be a protective mechanism to avoid the muscle damage caused by the eccentric contraction. Therefore, another explanation of this lower performance and the absence of learning effect of this test may be the fear of the participants to have a damage to their muscle, as it was their first time experiencing the isolated eccentric movement of knee flexion.

Another explanation for these results may be that the participants could not understand the movement from our instructions at the beginning. All movements have

been explained in detail to the participants prior to the specific test. However, it is highly possible that the participants did not understand the movement for eccentric knee flexion. Therefore, this test may be needed to be explained separately from the other tests or even may be performed before the actual test for the participants to completely understand the movement and apply their force maximally.

Overall, while the results of this test should be interpreted with caution because of the lower values than concentric, the results showed that a stable performance can be obtained with four repetitions during eccentric knee flexion test. The stability of the values was higher than knee extension and concentric knee flexion tests at the same velocity. However, more repetition numbers, a more detailed and specific explanation of the movement, or familiarization sessions prior to test may be needed for the maximal consistent performance for eccentric knee flexion.

5.2.5. Concentric Knee Extension Test at 180^{o}/sec

The graph of the concentric knee extension test at 180^{o}/sec showed that the participants needed five repetitions to exert their maximum force. Beginning from the first repetition, the values gradually increased throughout the repetitions and peaked at the fifth repetition with 258 Nm. This gradual increase may indicate that there was a learning effect throughout these repetitions (Almåsbakk and Hoff 1996). The increase may be a result of the greater motor unit recruitment provided by the neuro-motor learning (Henneman et al. 1965).

The maximum value of the test was 258 Nm, which was lower than that of the same test protocol at 60^{o}/sec, which was 283 Nm. This result proves that the force-velocity relationship was observed in these two tests (Hill et al. 1938). When compared to the test of 60^{o}/sec, the pattern was distinctly different. While the maximum performance could be obtained with only three repetitions at 60^{o}/sec, the current test of 180^{o}/sec revealed that participants needed at least five repetitions to be able to exert their maximum performance. This result was expected because of the differences in motor unit recruitment in different speeds (Citterio and Agostoni 1984; Moritani and Muro 1987; Moritani et al. 1991). The current results reveal that participants may need more repetitions to fully perform their maximal voluntary contraction during faster

movements when compared to slower movements of concentric knee extension.

When the trendline for the consecutive three repetitions was set, the range was seen as 10%, including the fourth, fifth and sixth repetitions. This was slightly greater when compared to the 6% range of the same test at 60º/sec. Therefore, it may be assumed that the stability of these measurements is lower for higher angular velocity tests for concentric knee extension.

The protocol of the current test was comparable to previous studies by Sawhill et al. (1982) and by Johnson and Siegel (1978). The study by Sawhill et al. have used higher velocities of 200º/sec, 300º/sec and 400º/sec for knee extension test of 5 males. They concluded that at least four repetitions were required to achieve a stable performance. However, they have used 25% range to define stability. In our study, the maximum value was reached at the fifth repetitions and the range was as lower as 10%. The rest between trials and contraction mode was not reported by Sawhill et al. (1982); therefore, these possible differences between protocols may be the reason of different findings. Also, only 5 participants were included in their study, this sample size was really small for representing the general population.

The other study by Johnson and Siegel (1978), have used the same velocity of 180º/sec as the current test. Their research was focused on the reliability of a test protocol. Their study included 3 submaximal repetitions before the actual test and they have reported that the reliability was excellent (0.99) when the 3 submaximal and 3 maximal repetitions are ignored. Even the current study did not include a submaximal warm-up or a 20-second rest between each trial, the findings may be similar in terms of required repetition numbers to achieve the best performance. The reliability study has used 6 maximal repetitions and the last three repetitions were reported as excellently reliable. Our findings suggest that at least five maximal contractions should be performed to obtain the maximum value. It is possible that the participants could reach their maximum performance at the fifth repetition just like the current study; therefore, when the earlier repetitions are ignored, the reliability was found really high.

Overall, the concentric knee extension test at 180º/sec showed that the participants need at least six trials for the consistent maximum performance, while the fifth

repetition is providing the maximum. These findings were also supported by a previous reliability study by Johnson and Siegel (1978).

5.2.6. Eccentric Knee Extension Test at 180°/sec

The eccentric test graph of knee extension at 180°/sec showed that the participants could perform their best on the second repetition with a value of 474 Nm. The trendline of the consecutive three repetitions were within the range of 4%, which is statistically accepted as no difference between trials. This gives a really stable measurement at the first three repetitions for this test. After the third value, the effects of fatigue were explicit as the values rapidly fell to 397 Nm at the fifth repetition.

When compared to the concentric test of the same movement, the pattern of the graphs was significantly different. While the participants needed at least four trials to be able to perform their best value in the concentric test, they could perform it on the very first three repetitions in eccentric. In terms of the maximum value, the eccentric test result was greater with 474 Nm than the concentric value of 258 Nm, as expected (Westling et al. 1991). There was no indicator of any learning-effect or any gradual recruitment of the motor units in this graph. This might be the result of the nature of the eccentric movement. It is known that the muscle unit recruitment is lower during eccentric contraction when compared to concentric (Westling et al. 1991). However, the force production is greater (Westling et al. 1991). It is mainly because of the physical resistance of the muscle to the movement. Therefore, for the resistance, a motor-neuro learning phase may not be needed as much as the concentric contraction. However, as seen in the test of eccentric knee flexion, it must be ensured that the participants really understand the movement and can exert their maximum voluntary force.

The pattern of the graph was similar to the same test at 60°/sec, the repetition number required to achieve peak performance was also the same. In both tests, the first three repetitions were enough to obtain the maximum value. Previously, it was suggested that the participants may need more repetitions to understand the eccentric movement (Steiner 1993). However, our findings revealed that the maximum eccentric knee extension performance could be obtained with only three repetitions for both lower

(60º/sec) and higher (180º/sec) velocities.

The maximum value for the same test at 60º/sec was 430 Nm, while it was 474 Nm at 180º/sec. These findings are supporting the previous findings suggesting that the speed change may not be affecting the force production during eccentric contractions as much as concentric (Komi 1973; Colliander and Tesch 1989).

Overall, the eccentric knee extension test at 180º/sec showed that the participants could perform their best value with only three repetitions, which was the same for the same test at 60º/sec.

5.2.7. Concentric Knee Flexion Test at 180º/sec

The pattern of the concentric knee flexion test at 180º/sec was similar to the pattern of the same test at 60º/sec. The maximum value was obtained from the first three repetitions and the ranges for 60º/sec and 180º/sec were similar as 3% and 4%, respectively. Interestingly, the maximum values were very close with 310 Nm at 60º/sec and 320 Nm at 180º/sec. This was not expected as the normal force-velocity relationship requires greater forces at lower velocities (Hill et al. 1938). Interestingly, for both tests, the first three repetitions were very consistent when compared to the other tests in the current study. There was a gradual decrease after the third repetition, this may indicate the onset of fatigue after that point. This pattern was again the same in the slower test at 60º/sec.

For the concentric knee extension tests, the higher velocity required more repetitions when compared to the lower velocity. This was interpreted as a result of learning effect and gradual recruitment of motor units during higher speeds. However, for knee flexion, there was no difference between lower and higher velocities in terms of required repetition number to obtain the maximum value, onset of fatigue and consistency of performance. Interestingly, the range was so similar to the slower test with only 4% difference between trials, which shows that there was no statistical difference between these trials. These results show that the participants could understand the movement easily and did not need practice repetitions to exert their maximum force. This was not expected as it was proposed that the participants may

need more repetitions during higher velocities. This assumption was approved for knee extension test; however, knee flexion tests at slower and higher velocities were almost resulted in the same pattern. Interestingly, when the first three repetitions of the test at 180º/sec were observed, it is seen that the force was gradually increasing and peaking at the third repetition. Even this may be a sign of gradual recruitment of motor units or a possible learning effect, the difference between these trials was lower than 5%. Therefore, the reported effects are not seen in this test as significant as in the concentric knee extension test at 180º/sec.

Overall, the concentric knee flexion test at 180º/sec showed that the participants could perform their maximum force in the first three repetitions. These results were similar to the same test at 60º/sec.

5.2.8. Eccentric Knee Flexion Test at 180º/sec

The graph of the eccentric knee flexion test at 180º/sec had the most fluctuating pattern among the other tests in this study. This was the only test where the consistent three repetitions were not including the maximum value of the graph. Instead the tenth, eleventh and twelfth repetitions were representing the stable performance.

The same problem at 60º/sec eccentric knee flexion test was present in this angular velocity, too. The maximum value was 224 Nm, while it was 320 Nm in the concentric test. Normally, the eccentric test gives a greater force production when compared to the concentric (Westling et al. 1991). Therefore, the results of this test may not be representing the actual performance of the participants. As discussed earlier at the section of eccentric knee flexion test at 60º/sec, the participants probably could not understand the movement. Thus, the validity of these results is questionable.

As explained earlier, the nature of the eccentric knee flexion is different from the isokinetic test on isokinetic dynamometer. These results of eccentric knee flexion show that only explaining the movement to the participants were not enough to make them understand the movement and perform their maximum. Therefore, a familiarization session prior to testing of eccentric knee flexion may be needed to obtain valid and reliable measurements during these tests for both lower and higher velocities.

5.3. Limitations of the Study and Recommendations for Future Research

A limitation of the current study was the chosen contraction mode. The protocol consisted of concentric and eccentric contractions of the same muscles consecutively. However, the reciprocal contraction mode, which the subjects perform concentric or eccentric contraction of agonist-antagonist muscles consecutively, is a commonly used test protocol in practice. To imitate the reciprocal contraction mode in terms of work:rest ratio, a short rest period was given after each contraction (1-2 seconds). This rest period is very similar when the contraction mode is reciprocal. While the agonist muscle is contracting, the antagonist muscle is resting for about 1.5 seconds at 60^{o}/sec and 0.5 seconds at 180^{o}/sec. However, even contradictory results have been reported (Bohannon et al. 1986), reciprocal contraction type may have an increasing effect on muscle strength, providing positive stimuli to increase the muscle response (Grabiner and Hawthorne 1990; Jeon et al. 2003). The pre-activation of the antagonist muscle may influence the strength generation of the agonist muscles. Therefore, this type of contraction mode may change the strength exposure patterns. Also, even there was a similar rest period to a reciprocal contraction mode, the protocol of the current study included concentric and eccentric contractions of the same muscles consecutively. Performing only concentric or only eccentric contractions may result in different results when compared to our protocol. Therefore, the study may be replicated with a reciprocal contraction mode in future to find out if these patterns are changing.

The second limitation of this study was that the reliability of these measurements was not tested. This was mainly because of the limited time for the study. Future research may investigate the test-retest reliability with the suggested repetition numbers within sets.

The third limitation of the study was that the activity level of the participants was not assessed objectively. They have only been asked verbally if they are performing 30 minutes of physical activity three times of week. A more objective, valid and reliable measurement tool could be used to classify the physical activity levels of the participants.

The fourth limitation was the race differences among subjects. The African-American males shown to have more type II muscle fibres when compared to Caucasian males (Ama et al. 1986). As the fibre type affects the recruitment of the motor units within the muscle, the differences in race may have affected the results. However, due to the limited participant number, the inclusion criteria could not be restricted more.

The fifth limitation was that both genders were included in the study. Even the numbers of both genders were equal, it is shown that males and females may have different muscle fibre recruitments. Therefore, the optimal repetition number may change between genders. Future studies may investigate if there is a gender effect on these measurements.

The sixth limitation was the subject reliability. Even every subject was encouraged during the testing, their willingness to perform their maximum values may change. However, due to the nature of the isokinetic test, it was not possible to annihilate this limitation any further.

The seventh limitation is that the tests were not performed on the same time of the day due to limited time and laboratory access. As the tests had to be finished in a limited time period, it was not possible to test every participant on the same time of the day. It might have affected the results as biorhythmic changes may influence the muscle performance (Wyse et al. 1994; Deschenes et al. 1998).

Another limitation of the study was that the dominant and non-dominant sides were not considered during the tests. Because the dominant leg is used in daily life more than non-dominant, the muscle recruitment pattern may be different between the legs. Therefore, the repetition numbers may show differences while obtaining the maximal strength.

In the current study, it is found that the eccentric knee flexion was probably not understood by the participants. This was mainly because of the lower results when compared to the concentric test results of the same movement. Therefore, the future studies may investigate the reliability and the effects of a familiarization session for this specific test for both lower and higher angular velocities.

These testing protocols was performed by a physically active and healthy population. Conclusions driven from non-athletic populations may not be assumed for groups of athletes. It is known that the sport-specific training changes the attribution of muscle fibre types to force production (Meijer et al. 2015). Even our population was physically active, the professional athletes practice much more trainings; therefore, the results of the current study may be different if an athletic population is tested. Also, it cannot be assumed that a population with an injury or history of injury would yield the same results. Thus, the same protocol should be replicated with athletic populations or populations with an injury or history of injury to ensure its validity for that specific population in future studies.

The current study has not investigated the responses of the tested subjects during the testing. A previous study has subjectively reported that the tested subjects may feel discomfort during the first testing session while getting used to the isokinetic machine (Mawdsley and Croft 1982). However, in our study, we did not ask the tested subjects about their discomfort. The subjects were only required and advised to report their discomfort during the test for safety reasons and no subject has reported any discomfort during the tests. Future studies may investigate the responses and feeling of the participants during isokinetic testing. Also, investigating that if the participants really understand the movement and exert their maximum performance may be investigated to understand the perception of the participants.

6. CONCLUSION

Strength is an important component of health, sports performance, injury prevention and rehabilitation. Isokinetic dynamometer is accepted as the gold standard to assess strength. Despite its wide use, there is no consistency in testing protocols when assessing the maximum performance on isokinetic dynamometer. Studies have used different familiarization sessions, warm-ups, repetitions, speed orders and rest periods. This situation makes the comparison of findings of different studies difficult.

The repetition number to obtain the maximum performance is the main variable during isokinetic strength testing. While few trials may result in a lower value than the real performance, too many trials may cause fatigue. Studies generally do not report the reason of their choice of repetition number; while some cites outdated research to support their choice. However, the studies investigating the repetition number have some major limitations and fail to inform the current practice because of their protocols. Therefore, standardizing the optimal repetition number for different testing modes, contraction types, movements and speeds are important for both clinical practice and research.

The current study has investigated the required repetition numbers to obtain the maximum consistent performance of 32 healthy participants without any prior specific warm-up or familiarization sessions. Knee extension and knee flexion movements were tested on concentric and eccentric contraction modes at 60^{o}/sec and 180^{o}/sec. These variables were tested on 8 different testing sessions on the same day in a counter-balanced order. Data were analysed by graphs, setting ranges from the maximum performance until obtaining three consecutive values. The maximum values and ranges were different for each graph.

Results of the current investigation revealed that the maximum consistent performance could be obtained with only three repetitions at 60^{o}/sec for concentric and eccentric knee extension, and concentric knee flexion. The ranges from the maximum value were more consistent for concentric knee flexion, while it was most inconsistent for eccentric knee extension. The tests at 180^{o}/sec showed that for the concentric knee extension, participants needed at least five repetitions to exert their

maximum force. Also, the range was greater than the same test at 60º/sec. The tests of eccentric knee extension and concentric knee flexion at 180º/sec showed similar results of the same tests at 60º/sec, revealing that the participants needed only three repetitions to perform their maximum value. The consistency was also greater than other tests with only 4% change between trials. The eccentric knee flexion tests were not considered as 'real performance' as they resulted in a lower value than the concentric test values. Normally, the eccentric strength of a muscle is greater than the concentric strength. Therefore, it is highly likely that the participants could not understand the movement and could not perform their maximum performance in the current study for eccentric knee flexion.

The main limitation of the study was the lack of reliability tests. Future studies should investigate the reliability of the suggested repetition numbers. Also, the current study has investigated healthy university students; athletic and patient populations should be tested for the same aim in future. This study revealed that the main thing during the eccentric knee flexion is to ensure that the participants understand the movement and can resist it. Future studies may investigate the effect of a familiarization or a specific warm-up session for this test.

The current study revealed that in clinical and research environments, participants may exert their maximum force without any prior familiarization or warm-up sessions. Only three repetitions may be enough to obtain the maximum performance; however, at least five trials should be performed for concentric knee extension at higher speeds. More repetitions than these seem like unnecessary for healthy young populations. However, for the eccentric test of knee flexion, the instruction of the test on the same day without any prior specific familiarization or warm-up may result in faulty results. Therefore, a specific instruction, familiarization session or warm-up session may be needed for this test.

7. REFERENCES

Aagaard, P. et al. 1995. Isokinetic hamstring/quadriceps strength ratio: influence from joint angular velocity, gravity correction and contraction mode. *Acta Physiologica, 154*(4), 421-427.

Aagaard, P. et al. 2000. Neural inhibition during maximal eccentric and concentric quadriceps contraction: effects of resistance training. *Journal of applied physiology, 89*(6), 2249-2257.

Alentorn-Geli, E. et al. 2009. Prevention of non-contact anterior cruciate ligament injuries in soccer players. Part 1: Mechanisms of injury and underlying risk factors. *Knee surgery, sports traumatology, arthroscopy, 17*(7), 705-729.

Almåsbakk, B. and Hoff, J. 1996. Coordination, the determinant of velocity specificity? *Journal of applied physiology, 81*(5), 2046-2052.

Askling, C. et al. 2003. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scandinavian journal of medicine & science in sports, 13*(4), 244-250.

Ama, P. et al. 1986. Skeletal muscle characteristics in sedentary black and Caucasian males. *Journal of applied physiology, 61*(5), 1758-1761.

American College of Sports Medicine. 2013. *ACSM's guidelines for exercise testing and prescription*. Lippincott Williams & Wilkins.

Appen, L. and Duncan, P. W. 1986. Strength relationship of the knee musculature: effects of gravity and sport. *journal of orthopaedic & sports physical therapy, 7*(5), 232-235.

Baltzopoulos, V. et al. 1988. A comparison of power outputs on the Wingate test and on a test using an isokinetic device. *Ergonomics, 31*(11), 1693-1699.

Baltzopoulos, V. and Brodie, D. 1989. Isokinetic dynamometry. *Sports medicine, 8*(2), 101-116.

Barnes, W. S. 1980. The relationship of motor-unit activation to isokinetic muscular contraction at different contractile velocities. *Physical therapy, 60*(9), 1152-1158.

Barnes, M. J. et al. 2010. Acute alcohol consumption aggravates the decline in muscle performance following strenuous eccentric exercise. *Journal of Science and Medicine in Sport, 13*(1), 189-193.

Baron, R. 2001. Aerobic and anaerobic power characteristics of off-road cyclists. *Medicine and science in sports and exercise, 33*(8), 1387-1393.

Bawa, P. and Jones, K. 1999. Do lengthening contractions represent a case of reversal in recruitment order? *Progress in brain research, 123*, 215-220.

Bernard, P. et al. 2016. Influence of recovery time on strength during a testing protocol of knee. *Journal de Traumatologie du Sport, 33*(3), 161-166.

Bigland-Ritchie, B. et al. 1978. Central and peripheral fatigue in sustained maximum voluntary contractions of human quadriceps muscle. *Clinical Science, 54*(6), 609-614.

Bigland-Ritchie, B. and Woods, J. 1984. Changes in muscle contractile properties and neural control during human muscular fatigue. *Muscle & nerve, 7*(9), 691-699.

Blazquez, I. N. et al. 2013. An adequate interset rest period for strength recovery during a common isokinetic test. *The Journal of Strength & Conditioning Research, 27*(7), 1981-1987.

Bohannon, R. W. et al. 1986. Effect of resisted knee flexion on knee extension torque. *Physical therapy, 66*(8), 1239-1241.

Brooks, G. A. et al. 1996. *Exercise physiology: Human bioenergetics and its*

applications: Mayfield publishing company.

Brown, L. E. et al. 1993. Reliability of the Biodex system 2 isokinetic dynamometer concentric mode. *Isokinetics and exercise science, 3*(3), 160-163.

Brown, L. E. and Weir, J. P. 2001. ASEP PROCEDURES RECOMMENDATION I: ACCURATE ASSESSMENT OF MUSCULAR STRENGTH AND POWER. *Professionalization of Exercise Physiology, 4*(11).

Câmara, L. C. et al. 2010. Cardiovascular responses during isokinetic muscle assessment in claudicant patients. *Arquivos brasileiros de cardiologia, 95*(5), 571-576.

Câmara, L. C. et al. 2012. Isokinetic strength and endurance in proximal and distal muscles in patients with peripheral artery disease. *Annals of vascular surgery, 26*(8), 1114-1119.

Celes, R. et al. 2009. Effect of recovery interval between sets of isokinetic knee extensions among untrained young men. *Brazilian Journal of Physical Therapy, 13*(4), 324-329

Cheung, K. et al. 2003. Delayed onset muscle soreness. *Sports medicine, 33*(2), 145-164.

Citterio, G. and Agostoni, E. 1984. Selective activation of quadriceps muscle fibers according to bicycling rate. *Journal of applied physiology: respiratory, environmental and exercise physiology, 57*(2), 371-379.

Colliander, E. B. and Tesch, P. A. 1989. Bilateral eccentric and concentric torque of quadriceps and hamstring muscles in females and males. *European journal of applied physiology and occupational physiology, 59*(3), 227-232.

Cramer, J. T. et al. 2004. Acute effects of static stretching on peak torque in women. *The Journal of Strength & Conditioning Research, 18*(2), 236-241.

Data Protection Act. 1998. [Online]. Available at: http://www.legislation.gov.uk/ukpga/1998/29/contents [Accessed: 15 January 2017].

Day, S. H. et al. 1998. Electromyogram activity and mean power frequency in exercise-damaged human muscle. *Muscle & nerve, 21*(7), 961-963.

Degens, H. et al. 2015. Smoking-induced skeletal muscle dysfunction. From evidence to mechanisms. *American journal of respiratory and critical care medicine, 191*(6), 620-625.

Deighan, M. A. et al. 2003. Reliability of isokinetic concentric and eccentric knee and elbow extension and flexion in 9/10 year old boys. *Isokinetics and exercise science, 11*(2), 109-115.

Deschenes, M. R. et al. 1998. Biorhythmic influences on functional capacity of human muscle and physiological responses. *Medicine and science in sports and exercise, 30*(9), 1399-1407.

Dibrezzo, R. et al. 1985. Peak torque values of the knee extensor and flexor muscles of females. *journal of orthopaedic & sports physical therapy, 7*(2), 65-68.

Drouin, J. M. et al. 2004. Reliability and validity of the Biodex system 3 pro isokinetic dynamometer velocity, torque and position measurements. *European journal of applied physiology, 91*(1), 22-29.

Economic and Social Research Council. 2015. *Economic and Social Research Council Framework for Research Ethics. Section 2* [Online]. Available at: http://www.esrc.ac.uk/files/funding/guidance-for-applicants/esrc-framework-for-research-ethics-2015/ [Accessed: 7 January 2017].

Edwards, R. H. 1981. Human muscle function and fatigue. *Human muscle fatigue: physiological mechanisms*, 1-18.

Enoka, R. M. and Duchateau, J. 2008. Muscle fatigue: what, why and how it influences muscle function. *The Journal of physiology, 586*(1), 11-23.

Farrell, M. and Richards, J. G. 1986. Analysis of the reliability and validity of the kinetic communicator exercise device. *Medicine and science in sports and exercise, 18*(1), 44-49.

Fitts, R. H. 1994. Cellular mechanisms of muscle fatigue. *Physiological reviews, 74*(1), 49-94.

Frisch, A. et al. 2011. Association between preseason functional tests and injuries in youth football: A prospective follow-up. *Scandinavian journal of medicine & science in sports, 21*(6), e468-e476.

Garrandes, F. et al. 2007. Neuromuscular fatigue profile in endurance-trained and power-trained athletes. *Medicine and science in sports and exercise, 39*(1), 149-158.

Gear, W. S. 2011. Effect of different levels of localized muscle fatigue on knee position sense. *Journal of sports science & medicine, 10*(4), 725.

Grabiner, M. and Hawthorne, D. 1990. Conditions of isokinetic knee flexion that enhance isokinetic knee extension. *Medicine and science in sports and exercise, 22*(2), 235-244.

Gransberg, L. and Knutsson, E. 1983. Determination of dynamic muscle strength in man with acceleration controlled isokinetic movements. *Acta Physiologica, 119*(3), 317-320.

Gravel, D. et al. 1987. Study of human muscle contraction using electrically evoked twitch responses during passive shortening and lengthening movements. *European journal of applied physiology and occupational physiology, 56*(6), 623-627.

Greenberger, H. B. et al. 1994. Comparison of quadriceps peak torque using three different isokinetic dynamometers. *Isokinetics and exercise science, 4*(2), 70-75.

Haff, G. G. and Triplett, N. T. 2015. Essentials of Strength Training and Conditioning 4th Edition: Human kinetics.

Hanten, W. and Lang, J. 1988. Reliability and validity of the kinetic communicator for the measurements of torque, work and power. Paper presented at the Physical therapy.

Harding, B. et al. 1988. Reliability of a reciprocal test protocol performed on the kinetic communicator: an isokinetic test of knee extensor and flexor strength. *journal of orthopaedic & sports physical therapy, 10*(6), 218-223.

Harris, R. et al. 1976. The time course of phosphorylcreatine resynthesis during recovery of the quadriceps muscle in man. *Pflügers Archiv European Journal of Physiology, 367*(2), 137-142.

Henneman, E. et al. 1965. Functional significance of cell size in spinal motoneurons. *J neurophysiol, 28*(3), 560-580.

Henneman, E. and Olson, C. B. 1965. Relations between structure and function in the design of skeletal muscles. *Journal of neurophysiology, 28*(3), 581-598.

Henneman, E. et al. 1974. Rank order of motoneurons within a pool: law of combination. *Journal of neurophysiology, 37*(6), 1338-1349.

Herbert, R. D. et al. 2011. Stretching to prevent or reduce muscle soreness after exercise. *The Cochrane Library*.

Hirvonen, J. et al. 1992. Fatigue and changes of ATP, creatine phosphate, and lactate during the 400-m sprint. *Can J Sport Sci, 17*(2), 141-144.

Howell, J. N. et al. 1993. Muscle stiffness, strength loss, swelling and soreness

following exercise-induced injury in humans. *The Journal of physiology, 464*(1), 183-196.

Howell, J. et al. 1995. Motor unit activity during isometric and concentric-eccentric contractions of the human first dorsal interosseus muscle. *Journal of neurophysiology, 74*(2), 901-904.

Jenkins, W. L. et al. 1984. Speed-specific isokinetic training. *journal of orthopaedic & sports physical therapy, 6*(3), 181-183.

Jeon, H.-S. et al. 2003. Facilitation of Quadriceps Activation Following a Concentric Knee Flexion During Reciprocal Knee Movement: The Influence of Muscle Preloading. *Physical Therapy Korea, 10*(4), 1-15.

Johnson, J. and Siegel, D. 1978. Reliability of an isokinetic movement of the knee extensors. *Research Quarterly. American Alliance for Health, Physical Education and Recreation, 49*(1), 88-90.

Johnson, M. A. et al. 1973. Data on the distribution of fibre types in thirty-six human muscles: an autopsy study. *Journal of the neurological sciences, 18*(1), 111-129.

Jonhagen, S. et al. 1994. Hamstring injuries in sprinters: the role of concentric and eccentric hamstring muscle strength and flexibility. *The American journal of sports medicine, 22*(2), 262-266.

Kannus, P. 1994. Isokinetic evaluation of muscular performance. *International journal of sports medicine, 15*(S 1), S11-S18.

Kent-Braun, J. A. et al. 2012. Skeletal muscle fatigue. *Comprehensive Physiology*.

Kim, H. J. and Kramer, J. F. 1997. Effectiveness of visual feedback during isokinetic exercise. *journal of orthopaedic & sports physical therapy, 26*(6), 318-323.

Kramer, J. 1990. Reliability of knee extensor and flexor torques during continuous concentric-eccentric cycles. *Archives of physical medicine and rehabilitation, 71*(7), 460-464.

Koller, A. et al. 2015. Decrease in eccentric quadriceps and hamstring strength in recreational alpine skiers after prolonged skiing. *BMJ open sport & exercise medicine, 1*(1), bmjsem-2015-000028.

Komi, P. 1973. Relationship between muscle tension, EMG and velocity of contraction under concentric and eccentric work *New Concepts of the Motor Unit, Neuromuscular Disorders, Electromyographic Kinesiology* (Vol. 1, pp. 596-606): Karger Publishers.

Li, R. et al. 1996. Eccentric and concentric isokinetic knee flexion and extension: a reliability study using the Cybex 6000 dynamometer. *British journal of sports medicine, 30*(2), 156-160.

Malone, T. 1988. *Evaluation of isokinetic equipment*: Williams & Wilkins.

Mawdsley, R. H. and Croft, B. J. 1982. The effects of submaximal contractions on an isokinetic test session. *journal of orthopaedic & sports physical therapy, 4*(2), 74-77.

Mawdsley, R. H. and Knapik, J. J. 1982. Comparison of isokinetic measurements with test repetitions. *Physical therapy, 62*(2), 169-172.

McCrory, M. et al. 1980. Reliability of concentric and eccentric measurements on the LIDO active isokinetic rehabilitation system. *Medicine and science in sports and exercise, 21*(2), S52.

Mclean, S. G. and Samorezov, J. E. 2009. Fatigue-induced ACL injury risk stems from a degradation in central control. *Medicine and science in sports and exercise, 41*(8), 1661-1672.

Meijer, J. et al. 2015. Single muscle fibre contractile properties differ between body-

builders, power athletes and control subjects. *Experimental physiology, 100*(11), 1331-1341.

Metzger, J. M. and Moss, R. L. 1987. Greater hydrogen ion-induced depression of tension and velocity in skinned single fibres of rat fast than slow muscles. *The Journal of physiology, 393*(1), 727-742.

Mikesky, A. E. et al. 2000. Relationship between quadriceps strength and rate of loading during gait in women. *Journal of Orthopaedic Research, 18*(2), 171-175.

Mizner, R. L. et al. 2005. Quadriceps strength and the time course of functional recovery after total knee arthroplasty. *journal of orthopaedic & sports physical therapy, 35*(7), 424-436.

Moritani, T. and Muro, M. 1987. Motor unit activity and surface electromyogram power spectrum during increasing force of contraction. *European journal of applied physiology and occupational physiology, 56*(3), 260-265.

Moritani, T. et al. 1991. Activation patterns of the soleus and gastrocnemius muscles during different motor tasks. *Journal of Electromyography and Kinesiology, 1*(2), 81-88.

Nardone, A. et al. 1989. Selective recruitment of high-threshold human motor units during voluntary isotonic lengthening of active muscles. *The Journal of physiology, 409*, 451-471.

Nickols-Richardson, S. et al. 2007. Concentric and eccentric isokinetic resistance training similarly increases muscular strength, fat-free soft tissue mass, and specific bone mineral measurements in young women. *Osteoporosis international, 18*(6), 789-796.

Nugent, E. P. et al. 2015. The effect of velocity and familiarisation on the reproducibility of isokinetic dynamometry. *Isokinetics and exercise science, 23*(3), 205-214.

Osternig, L. R. 1986. 2 Isokinetic Dynamometry: Implications for Muscle Testing and Rehabilitation. *Exercise and sport sciences reviews, 14*(1), 45-80.

Overend, T. J. et al. 2000. Cardiovascular stress associated with concentric and eccentric isokinetic exercise in young and older adults. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 55*(4), B177-B182.

Owens, D. J. et al. 2014. Vitamin D supplementation does not improve human skeletal muscle contractile properties in insufficient young males. *European journal of applied physiology, 114*(6), 1309-1320.

Ozcakar, L. et al. 2003. Comprehensive isokinetic knee measurements and quadriceps tendon evaluations in footballers for assessing functional performance. *British journal of sports medicine, 37*(6), 507-510.

Östenberg, A. and Roos, H. 2000. Injury risk factors in female European football. A prospective study of 123 players during one season. *Scandinavian journal of medicine & science in sports, 10*(5), 279-285.

Parcell, A. C. et al. 2002. Minimum rest period for strength recovery during a common isokinetic testing protocol. *Medicine and science in sports and exercise, 34*(6), 1018-1022.

Perrine, J. and Hislop, H. 1967. The isokinetic concept of exercise. *Pittsburgh: Physical Therapy*, 114-117.

Pincivero, D. and Campy, R. 2004. The effects of rest interval length and training on quadriceps femoris muscle. Part I: knee extensor torque and muscle fatigue. *Journal of Sports Medicine and Physical Fitness, 44*(2), 111.

Pincivero, D. et al. 1997. Reliability and precision of isokinetic strength and muscular endurance for the quadriceps and hamstrings. *International journal of sports medicine, 18*(02), 113-117.

Portney, L. and Watkins, M. 2014. Exploratory research: observational designs *Foundations of Clinical Research: Applications to Practice*: Pearson, Harlow.

Psatha, M. et al. 2017. Age-related changes in the effects of strength training on lower leg muscles in healthy individuals measured using MRI. *BMJ open sport & exercise medicine, 3*(1), e000249.

Rahnama, N. and Bambaeichi, E. 2008. Musculoskeletal assessment in soccer: a review. *J Move Sci Sports, 1*, 13-24.

Raven, P. et al. 2012. *Exercise Physiology*: Nelson Education, pp. 80-87

Salavati, M. et al. 2007. Changes in postural stability with fatigue of lower extremity frontal and sagittal plane movers. *Gait & posture, 26*(2), 214-218.

Sato, K. et al. 2011. Effects of eccentric hamstring strength exercise on knee flexor strength. *British journal of sports medicine, 45*(4), 372-372.

Sawhill, J. et al. 1982. Variability of isokinetic measures. *Medicine & Science in Sports & Exercise, 14*(2), 177.

Schmidt, R. A. and Lee, T. D. 2005. Introduction to Motor Learning and Performance. How Skills are Studies. In: *Motor control and learning: A behavioral emphasis* (Vol. 4): Human kinetics Champaign, IL, pp.

Serresse, O. et al. 1988. Estimation of the contribution of the various energy systems during maximal work of short duration. *International journal of sports medicine, 9*(06), 456-460.

Small, K. et al. 2010. The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. *Journal of Science and Medicine in Sport, 13*(1), 120-125.

Sole, G. et al. 2007. Test-retest reliability of isokinetic knee extension and flexion.

Archives of physical medicine and rehabilitation, 88(5), 626-631.

Søgaard, K. et al. 1996. Motor control and kinetics during low level concentric and eccentric contractions in man. *Electroencephalography and clinical neurophysiology, 101*(5), 453.

Spurway, N. et al. 2000. The effect of strength training on the apparent inhibition of eccentric force production in voluntarily activated human quadriceps. *European journal of applied physiology, 82*(5-6), 374-380.

Staublr, W. T. 1989. Eccentric action of muscles: physiology, injury, and adaptation. *Exercise and sport sciences reviews, 17*(1), 157-186.

Stotz, P. J. and Bawa, P. 2001. Motor unit recruitment during lengthening contractions of human wrist flexors. *Muscle & nerve, 24*(11), 1535-1541.

Thorstensson, A. et al. 1976. Force-velocity relations and fiber composition in human knee extensor muscles. *Journal of applied physiology, 40*(1), 12-16.

Tokish, J. M. et al. 2004. Ergogenic aids: a review of basic science, performance, side effects, and status in sports. *The American journal of sports medicine, 32*(6), 1543-1553.

Tredinnick, T. J. and Duncan, P. W. 1988. Reliability of measurements of concentric and eccentric isokinetic loading. *Physical therapy, 68*(5), 656-659.

Trivedi, B. and Danforth, W. H. 1966. Effect of pH on the kinetics of frog muscle phosphofructokinase. *Journal of Biological Chemistry, 241*(17), 4110-4114.

Tsiros, M. D. et al. 2011. Test-retest reliability of the Biodex System 4 Isokinetic Dynamometer for knee strength assessment in paediatric populations. *Journal of allied health, 40*(3), 115-119.

Undheim, M. B. et al. 2015. Isokinetic muscle strength and readiness to return to sport

following anterior cruciate ligament reconstruction: is there an association? A systematic review and a protocol recommendation. *Br J Sports Med, 49*(20), 1305-1310.

Vodička, T. et al. 2014. *ISOKINETIC STRENGTH IN LEUKEMIA PATIENTS PRIOR TO AND AFTER TREATMENT–PILOT STUDY.* Paper presented at the 7TH INTERNATIONAL SCIENTIFIC CONFERENCE ON KINESIOLOGY.

Yeung, J. et al. 2016. Mobility, proprioception, strength and FMS as predictors of injury in professional footballers. *BMJ open sport & exercise medicine, 2*(1), e000134.

Young, A. 1984. The relative isometric strength of type I and type II muscle fibres in the human quadriceps. *Clinical Physiology and Functional Imaging, 4*(1), 23-32.

Warren, B. L. and Longwell, K. K. 2010. Rest period effect on peak torque in female collegiate and recreational athletes. *Isokinetics and exercise science, 18*(4), 179-184.

Wessel, J. et al. 1988. *Reliability of eccentric and concentric measurements.* Paper presented at the Physical therapy.

Westing, S. et al. 1990. Effects of electrical stimulation on eccentric and concentric torque-velocity relationships during knee extension in man. *Acta Physiologica, 140*(1), 17-22.

Westing, S. et al. 1991. Muscle activation during maximal voluntary eccentric and concentric knee extension. *European journal of applied physiology and occupational physiology, 62*(2), 104-108.

White, L. and Protas, E. 1985. *The reliability of the kinetic communicator during isokinetic concentric knee extension.* Paper presented at the Physical therapy.

Wilhite, M. R. et al. 1992. Reliability of concentric and eccentric measurements of quadriceps performance using the KIN-COM dynamometer: the effect of testing order

for three different speeds. *journal of orthopaedic & sports physical therapy, 15*(4), 175-182.

Wilhite, M. R. et al. 1992. Reliability of concentric and eccentric measurements of quadriceps performance using the KIN-COM dynamometer: the effect of testing order for three different speeds. *journal of orthopaedic & sports physical therapy, 15*(4), 175-182.

Woods, K. et al. 2007. Warm-up and stretching in the prevention of muscular injury. *Sports medicine, 37*(12), 1089-1099.

Wuerker, R. B. et al. 1965. Properties of motor units in a heterogeneous pale muscle (m. gastrocnemius) of the cat. *Journal of neurophysiology, 28*(1), 85-99.

Wyatt, M. P. and Edwards, A. M. 1981. Comparison of quadriceps and hamstring torque values during isokinetic exercise. *journal of orthopaedic & sports physical therapy, 3*(2), 48-56.

Wyse, J. et al. 1994. Time-of-day dependence of isokinetic leg strength and associated interday variability. *British journal of sports medicine, 28*(3), 167-170.

8. APPENDICES

Appendix I: Permission to Access Research Centre for Clinical Kinesiology

RE: Permission for Using RCCK for MSc Dissertation

HCARE Simulation Team

Tue 18/04/2017 12:19

To: Beyza Tayfur <TayfurB@cardiff.ac.uk>;

Morning Beyza,

I can confirm you are able to access this equipment. We'll check the equipment availability when you have the dates/times you require them.

Please accept this as your confirmation letter.

Many thanks,

Wayne

From: Beyza Tayfur
Sent: 18 April 2017 09:18
To: HCARE Simulation Team <HCARESimulation@cardiff.ac.uk>
Subject: Permission for Using RCCK for MSc Dissertation

Hello,

I am sending this e-mail as I need the informal consent for using the KIN-COM Isokinetic Dynamometer in HCARE Research Centre for Clinical Kinaesiology for my MSc dissertation.

My programme is MSc Sports and Exercise Physiotherapy and my dissertation supervisor is Mr. Timothy Sharp.

The name of the study is 'A Data consistency of strength testing on an isokinetic dynamometer; an investigation into the number of repetitions required to peak performance and until fatigue.'

The application form is attached in this e-mail if more details are needed.

Best Regards

Beyza Tayfur

Appendix II: **Booking Form**

School of Healthcare Sciences Laboratory Space Booking form
Submit this form to HCARESimulation@cardiff.ac.uk

All equipment booking requests must be sent as an email to HCARESimulation@cardiff.ac.uk

Submit both equipment & space request at least 10 DAYS before the first date

Name: Beyza Tayfur **Supervisor: Tim Sharp**

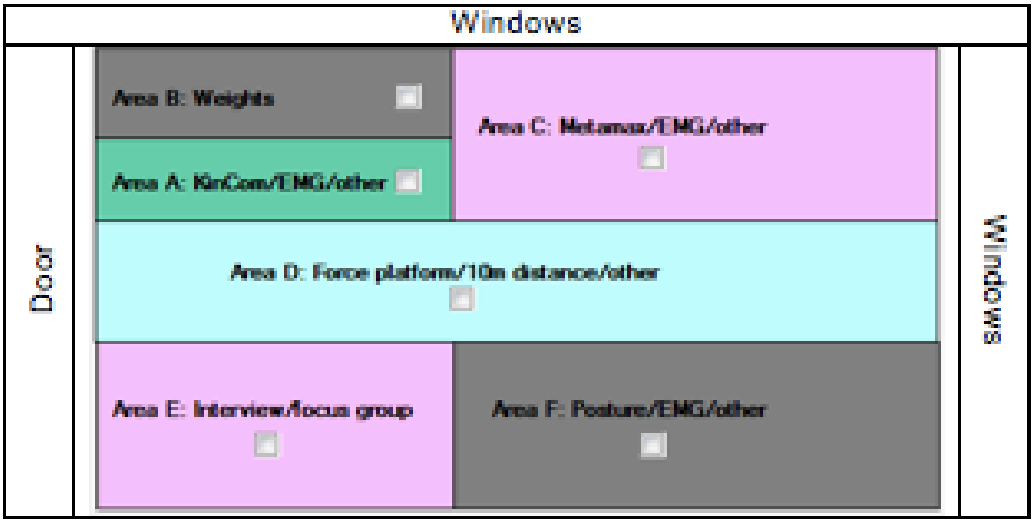
***** Required for all bookings by Students

Dates and Times of space required (list all):

Dates- 27/07/17 and 28/07/2017

Time- between 12.00 – 16.00 for both days.

Area A – KINCOM



NB For RCCK space & equipment bookings please email with Professor van Deursen vanDeursenR@cardiff.ac.uk

If you require other rooms in TDS or EGH you must contact HCARESchedulling@cardiff.ac.uk
You must inform HCARESimulation@cardiff.ac.uk of any changes to laboratory room requirements immediately or HCAREscheduling@cardiff.ac.uk if you have booked a room with them.

Appendix III: Test Orders

1. Right Leg: 60 Left Leg: 180

    I. Right Leg Extension
    II. Right Leg Flexion
    III. Left Leg Extension
    IV. Left Leg Flexion

2. Right Leg: 60 Left Leg: 180

    I. Right Leg Flexion
    II. Right Leg Extension
    III. Left Leg Flexion
    IV. Left Leg Extension

3. Right Leg: 60 Left Leg: 180

    I. Left Leg Extension
    II. Left Leg Flexion
    III. Right Leg Extension
    IV. Right Leg Flexion

4. Right Leg: 60 Left Leg: 180

    I. Left Leg Flexion
    II. Left Leg Extension
    III. Right Leg Flexion
    IV. Right Leg Extension

5. Right Leg: 180 Left Leg: 60

    I. Right Leg Extension
    II. Right Leg Flexion
    III. Left Leg Extension
    IV. Left Leg Flexion

6. Right Leg: 180 Left Leg: 60

    I. Right Leg Flexion

II. Right Leg Extension
III. Left Leg Flexion
IV. Left Leg Extension

7. Right Leg: 180 Left Leg: 60

I. Left Leg Extension
II. Left Leg Flexion
III. Right Leg Extension
IV. Right Leg Flexion

8. Right Leg: 180 Left Leg: 60

I. Left Leg Flexion
II. Left Leg Extension
III. Right Leg Flexion
IV. Right Leg Extension

Appendix IV: Participant Data Sheet

Participant Number:	Date:	Telephone:	E-Mail:
Participant Name:		Date of Birth:	Height:	Weight:
	Right: 60	Left: 180	First: Left Side	First: Flexion	Gender: Female

Left 180 Quadriceps Concentric

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11	Rep 12
Peak Torque												

Left 180 Quadriceps Eccentric

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11	Rep 12
Peak Torque												

Left 180 Hamstring Concentric

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11	Rep 12
Peak Torque												

Left 180 Hamstring Eccentric

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11	Rep 12
Peak Torque												

Right 60 Quadriceps Concentric

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11	Rep 12
Peak Torque												

Right 60 Quadriceps Eccentric

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11	Rep 12
Peak Torque												

Right 60 Hamstring Concentric

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11	Rep 12
Peak Torque												

Right 60 Hamstring Eccentric

	Rep 1	Rep 2	Rep 3	Rep 4	Rep 5	Rep 6	Rep 7	Rep 8	Rep 9	Rep 10	Rep 11	Rep 12
Peak Torque												

Consent form is obtained. ☐

Appendix V: Ethics Result

School of Healthcare Sciences
Head of School and Dean Professor Heather Waterman

Ysgol Gwyddorau Gofal Iechyd
Pennaeth yr Ysgol a Deon Yr Athrawes Heather Waterman

19 June 2017

Cardiff University
Eastgate House
13th Floor
35 – 43 Newport Road
Cardiff CF24 0AB

Tel Ffon: +44 (0)29 20 688559
Email E-bost: HCAREEthics@cardiff.ac.uk

Prifysgol Caerdydd
13ed Llawr
Ty Eastgate
35 – 43 Heol Casnewydd
Caerdydd CF24 0AB

Beyza Tafur
Roy Jenkins Hall, House 2, Flat 8
Crwys Rd, Cardiff
CF24 4NE

Dear Mrs Tayfur

A data consistency of strength testing on an isokinetic dynamometer; an investigation into the number of repetitions required to peak performance and until fatigue.

The School's Research Ethics Committee Chair has considered your re-submitted research proposal. The decision of the Chair is that your work should:

Pass –and that you proceed with your Research in collaboration with your supervisor

This decision will be ratified at the next meeting on July 11th 2017.

Please note that if there are any subsequent major amendments to the project made following this approval you will be required to submit a revised proposal form. You are advised to contact me if this situation arises. In addition, in line with the University requirements, the project will be monitored on an annual basis by the Committee and an annual monitoring form will be despatched to you in approximately 11 months' time. If the project is completed before this time you should contact me to obtain a form for completion.

Please do not hesitate to contact me if you have any questions.

Yours sincerely

Mrs Liz Harmer – Griebel
Research Administration Manager

Cc : Tim Sharp

Appendix VI: Participant Information Sheet

Participation Information Sheet

This form is to inform you about the research study that you have been invited to participate. It is important to know the aim and procedures of the study, before making decision whether you would like to join the study or not. This sheet provides all the information about the process and you will be free to have your time to decide after reading it. Please read the information carefully and ask if you have any questions about the study. One member of the research team will be there to assist you with the information sheet and answer any queries that you may have. You can discuss with your colleagues or other participants if you are still not sure about participating in the study.

Study Title: A data consistency of strength testing on an isokinetic dynamometer; an investigation into the number of repetitions required to peak performance and until fatigue.

What is the purpose of the study?

Strength is a key component of both athletic performance and functional recovery following injury or absence from play. Within the field of research and rehabilitation the best and most accurate way of assessing muscle strength is the use of the Isokinetic Dynamometer such as Kin-Com. This machine measures the amount of force produced at a single joint at a set speed. This can be for both shortening and lengthening contractions. This strength measure however is not very functional and provided information on pure muscle force and doesn't give a clear indication of functional ability. As such, it is somewhat difficult to learn how to use the machine to get the best results. When learning a new movement or skill it is recognised that practice is a key aspect to achieving peak performance, with athletes rehearsing their movements and performance elements prior to competition. However, within the clinical testing protocols and within the research literature there is a paucity of evidence which indicates the optimum number of repetitions that would be needed prior to peak performance on this machine. It is often cited that enough attempts were allowed for familiarization with the testing procedure. This does not give a good indication if the testing procedure allows for sufficient practice to capture the optimal strength output or whether indeed there have been too many and that fatigue is now playing a significant role within the testing.
The aim of the study is to identify the exact trial numbers to provide familiarisation and reach the maximum performance consistency and minimize the effects of fatigue during the isokinetic testing of knee flexion and extension for both concentric and eccentric strength.

Why have I been invited to participate?

You are invited to participate in the study as you fit our inclusion criteria, (1) Age range of 18-60 years, (2) Performing physical activity for at least 30 minutes, 3 times per week and (3) Able to understand

and perform the instructions and provide informed consent.

If you have any previous fractures or surgeries to the musculoskeletal structures in lower extremity, any acute injuries of lower extremity in the previous 3 months, cardiovascular or neurological disorders, or use ergogenic dietary supplementation intake; it means you are not eligible for the study.

A total of 30 subjects will be included in this study.

Do I have to take part?

Taking part in this study is purely voluntary. Therefore, it is important to read this information sheet carefully, and decide without any obligation. If you decide to join in the study, you will be asked to sign a consent form. However, the consent form does not mean that you have to finish the study; you can withdraw at any time without the necessity to report any reasons.

What will happen to me if I take part?

If you decide to take part in the study, you will need to come to Cardiff University School of Healthcare Sciences the Research Centre for Clinical Kinesiology (RCCK). You only need to come once. The session will take approximately 120 minutes. The researcher will be helping you all the time, as you will be the only participant at that particular time. After the enrolment and signing the consent form, you will cycle for 10 minutes as a warm-up. This will prepare your muscles for the isokinetic test. After that, the isokinetic test will start. Your legs will be tested separately. The device will be arranged for your leg. You will be sitting with your back supported. Straps will be used to stabilize your body. Also, your legs will be attached to the isokinetic machine with two straps, one just above your ankle and one just above your knee. You will be able to bend and straighten your knee freely while you are set on the machine. However, for your own safety, the maximum straightening will be in about 5° bended position. This is to protect your knee from any possible injuries and it is totally in normal ranges of knee movement. Also, the bending will allow you to use about 90° of motion. Again, it is totally in normal ranges of knee movement and for your safety.

The test will include bending and straightening movements of your knee. The machine will apply a continual resistance to your movements and assess your strength through it. Your movements should be smooth and powerful as possible to obtain accurate readings. You will practice 12 repetitions for each movement. There is a total of 8 movements.

The same procedure will be used for both legs. You will have enough time to rest after finishing the test of first leg. When you feel ready, the test will begin for your other leg.

What is the device/procedure being tested?

The KIN-COM Isokinetic Dynamometry from Cardiff University School of Healthcare Sciences the Research Centre for Clinical Kinesiology (RCCK) will be used to perform tests.

What are the possible benefits of taking part?

After the test, you will be able to learn your muscle strength in objective numbers. Despite that, there will not be any direct benefits to you by participating in this study. The findings of the study will help the researchers and clinicians by providing a guidance on the number of trials required to achieve maximum consistence performance on isokinetic muscle testing of knee bending and straightening, which may benefit future functional measures for athletes and patients, and also future research.

What are the possible disadvantages and risks of taking part?

As the study includes a testing protocol with an isokinetic machine, it carries a risk for injuries. These injuries may include muscle tear and possible discomfort from soreness.
However, the likelihood of muscle tear is very low. To our knowledge, there is no example of this in the literature. However, the range of motion of knee will be set to normal limits, so this will protect your muscles from stretching excessively. Also, the warm up before testing should reduce the possibility of a muscle strain or soreness. You will be educated about muscle warm-up and stretching within physiological limits properly in case of any discomfort after the test. If you experience extreme discomfort or would like to discuss your discomfort after testing, you will be able to contact the researcher via e-mail.

Will my taking part in the study remain confidential?

Your participation or results will not be shared with any other individual or organization. The information will not be used in any other research or work other than that has been told to you, all the information will be used for the intended purpose. For a safe and secure storage, there will be only one hard copy of the information and data of you. These files will be stored in a locked cabinet in a locked room and only the main investigator will be able to access with their keys. During data analysis, no name information will be entered into the analysis programme, only the numbers will be calculated. The computer to be used in this process will be the personal computer of the main investigator and will be protected with a private password. The files and folders will also be password protected, so it will only be accessible to the main investigator. As this will be a clinical research, the data will be protected under the same conditions for nearly 15 years and subsequently destroyed in accordance with the Data Protection Act (1998).

What will happen to the results of the research study?

The researchers may publish the results in a scientific journal or share it in scientific meetings in future; however, no name will be mentioned in any possible publication or presentation.

Who has reviewed the study?

The study has been reviewed by the Cardiff University Ethics Committee.

Further information and contact details;

Timothy Sharp

SharpTN@cardiff.ac.uk

Appendix VII: Consent Form

Subject Consent Form

Title of Study: An investigation into the consistency of performance of Isokinetic strength testing to identify the repetitions for peak performance and fatigue.

Name of Researcher: Mrs. Beyza Tayfur

Please initial box

I confirm I have read and understood the participant information sheet dated ……for the above study and have had the opportunity to consider the information, to ask questions and to have these answered. ☐

I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, this will not affect how I am treated in any way. ☐

I understand that all information about me will be kept in a confidential way and destroyed once the study is completed. ☐

I agree to take part in this study. ☐

Name of subject…….. ……..

Signature ……..……... Date ……..

Name of Witness (Researcher) ……

Signature ……..….. Date ……..

When completed, 1 copy for patient, 1 for researcher site file