BRNO UNIVERSITY OF TECHNOLOGY

Faculty of Electrical Engineering
and Communication

BACHELOR'S THESIS

Brno, 2020 Tereza Přidalová

BRNO UNIVERSITY OF TECHNOLOGY
VYSOKÉ UČENÍ TECHNICKÉ V BRNĚ

FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION
ÚSTAV BIOMEDICÍNSKÉHO INŽENÝRSTVÍ

FAKULTA ELEKTROTECHNIKY A KOMUNIKAČNÍCH TECHNOLOGIÍ
DEPARTMENT OF BIOMEDICAL ENGINEERING

THE UTILIZATION OF ISOKINETIC DYNAMOMETER FOR THE MEASUREMENT AND EVALUATION OF MUSCLE STRENGTH OF LOWER LIMBS IN ATHLETES

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VYUŽITÍ IZOKINETICKÉHO DYNAMOMETRU PRO MĚŘENÍ A HODNOCENÍ SVALOVÉ SÍLY DOLNÍCH KONČETIN U SPORTOVCŮ

BACHELOR'S THESIS

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BRNO 2020

BRNO UNIVERSITY OF TECHNOLOGY
FACULTY OF ELECTRICAL ENGINEERING AND COMMUNICATION

Bachelor's Thesis

Bachelor's study field **Biomedical Technology and Bioinformatics**

Department of Biomedical Engineering

Student: Tereza Přidalová ***ID:*** 195193

Year of study: 3 ***Academic year:*** 2019/20

TITLE OF THESIS:

The utilization of isokinetic dynamometer for the measurement and evaluation of muscle strength of lower limbs in athletes

INSTRUCTION:

1) Present an overview of current knowledge about isokinetic testing and training to determine strength in athletes mainly from foreign sources and focus on utilization of isokinetic dynamometer Isomed 2000. 2) Perform a number of measurement series of athletes at the CESA VUT workplace using isokinetic dynamometer Isomed 2000 under the supervision of responsible employees. 3) Suggest methods for data processing and evaluation of muscle strength. 4) Analyze acquired data using appropriate methods. 5) Interpret achieved results. Discuss the advantages and disadvantages of the methods that were used.

RECOMMENDED LITERATURE:

[1] DVIR, Z. (2004). Isokinetics: Muscle testing, interpretation, and clinical applications. Edinburgh: Churchill Livingstone.

[2] DIRNBERGER J, WIESINGER HP, STÖGGL T, KÖSTERS A, MÜLLER E.(2012). [Absolute and relative strength-endurance of the knee flexor and extensor muscles: a

reliability study using the IsoMed 2000-dynamometer]. Sportverletz Sportschaden. 26(3):142-7.

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Date of project specification: 3.2.2020 ***Deadline for submission:*** 5.6.2020

Supervisor: Mgr. Daniela Chlíbková, Ph.D.
Consultant: Ing. Marina Ronzhina, Ph.D.

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ABSTRACT

Isokinetic dynamometry is the up-to-date method for evaluation of muscle strength. It is mostly used to estimate the effect of training over time and for rehabilitation purposes. Clinicians, researchers and physiotherapists usually employ only the basic parameters obtained by the dynamometry to assess the muscle strength. Therefore, this work aims to propose an alternative approach for data interpretation, together with revealing possible applications and limitations of this method. The torque of the knee joint and subsequent analysis was performed. Fifteen parameters are used for data evaluation. The peak torque values of professional athletes (men: 111.1 ± 51.0 [Nm/kg], women: 99.6 ± 90.8 [Nm/kg]) were compared against amateur athletes (men: 146.2 ± 40.1 [Nm/kg], women: 45.3 ± 14.6 [Nm/kg]). The relation was observed among parameters of the peak angle and time from peak torque to the end of motion (flexion: $r = -0.65$, extension: $r = 0.71$) and between the peak angle and ratio work produced before maximum (flexion: $r = 0.91$ extension: $r = -0.86$). The parameter of work performed in the submaximal area was higher for extension (median= 3.0 J) than for flexion (median= 2.6 J).

KEYWORDS

Isokinetic dynamometry, knee joint, muscle strength testing, parameter evaluation

ABSTRAKT

Izokinetická dynamometrie je moderní metodou pro hodnocení svalové síly. Nejvíce se využívá pro posouzení tréninkového efektu během určitého období a pro rehabilitační účely. Kliničtí lékaři, vědci a fyzioterapeuti obvykle využívají pouze základních parametrů pro vyhodnocení svalové síly. Cílem této práce je tedy navrhnout alternativní přístup pro interpretaci dat a předložit možné využití a limitace této metody. Byl měřen moment síly v kolenním kloubu a následně provedena datová analýza. Patnáct parametrů je využito pro vyhodnocení dat. Moment síly byl porovnán mezi profesionálními sportovci (muži: 111.1 ± 51.0 [Nm/kg], ženy: 99.6 ± 90.8 [Nm/kg]) a amatérskými sportovci (muži: 146.2 ± 40.1 [Nm/kg], ženy: 45.3 ± 14.6 [Nm/kg]). Vztah byl pozorován mezi parametry úhlové pozice maxima a dobou od dosažení maxima do konce pohybu (flexe: $r = -0.65$, extenze: $r = 0.71$) a mezi úhlovou pozicí maxima a poměrem vykonané práce před maximem (flexe: $r = 0.91$ extenze: $r = -0.86$). Parametr práce v submaximální oblasti byl vyšší pro extenzi (median= 3.0 J) než pro flexi (median= 2.6 J).

KLÍČOVÁ SLOVA

Izokinetická dynamometrie, kolenní kloub, testování svalové síly, vyhodnocení parametrů

PŘIDALOVÁ, Tereza. *The utilization of isokinetic dynamometer for the measurement and evaluation of muscle strength of lower limbs in athletes.* Brno, 2020, 62 p. Bachelor's Thesis. Brno University of Technology, Faculty of Electrical Engineering and Communication, Ústav biomedicínského inženýrství. Advised by Mgr. Daniela Chlíbková, Ph.D.

Vysázeno pomocí balíčku `thesis` verze 2.63; `http://latex.feec.vutbr.cz`

ROZŠÍŘENÝ ABSTRAKT

ÚVOD

V současné době jsou sportovní aktivity napříč různými úrovněmi široce rozšířené v populaci po celém světě. Vysoce intenzivní trénink je běžný způsob, jak dosáhnout co nejlepších výkonů. Avšak špatně navržený tréninkový plán nerespektující nutnou dobu potřebnou na regeneraci často vede k různým zraněním. Velmi náchylný ke zraněním je kolenní kloub, jelikož je vystaven vícenásobnému působení sil z různých směrů. Dnešní technologie umožňují důkladně monitorovat zdravotní stav jedince, a jsou proto neodmyslitelnou součástí profesionálního sportu. Příkladem takovéto technologie je izokinetický dynamometr, jehož využití pro sport zatím nebylo plně prozkoumáno, a je proto předmětem této práce. Konkrétně je práce zaměřena na vyšetření a vyhodnocení maximální síly ve svalech působící na kolenní kloub, tedy na kvadricepsy a hamstringy. Hlavními cíli bylo získat potřebné vědomosti o izokinetické dynamometrii, jejích principech a současného využití. Na základě toho byl navržen testovací protokol a provedeny série vlastního měření sportovců. Byl navržen program pro zpracování dat, kterým byla získaná data analyzována a byly předloženy nové metody pro jejich interpretaci.

POPIS ŘEŠENÍ

Bylo testováno 25 sportovců věnující se určitému sportu na výkonnostní či rekreační úrovni. Bylo provedeno testování pro pravou i levou dolní končetinu, přičemž účastníci vykonávali pohyb flexe a extenze v kolenním kloubu. Součástí testování bylo i vyplnění dotazníku, který následně sloužil pro zařazení účastníků do skupin a pro interpretaci výsledků.

Data byla zpracována v softwarovém prostředí MATLAB. Výstupem z každého měření byly signály momentu síly, časové průběhy, úhlové pozice a úhlové rychlosti. Nejdříve byla tato data uložena zvlášť do proměnných a převedena do standardních SI jednotek. Signály momentu síly byly filtrovány dolní propustí s mezní frekvencí 20 Hz. Následovala segmentace signálu, aby mohla být každá křivka reprezentující jeden pohyb analyzována zvlášť. Křivka momentu síly naměřená izokinetickým dynamometrem se skládá z fáze zrychlení do předem dané úhlové rychlosti, fáze, kde je rychlost udržována konstantní (izokinetická oblast) a fáze zpomalení na konci pohybu. Signál úhlové rychlosti byl součástí výstupu dynamometru, a byl použit pro nalezení bodů značících začátek a konec segmentu a pro nalezení bodů vymezujících izokinetickou oblast. Z každého segmentu bylo vytažena sada parametrů, reprezentující různé časové a úhlové úseky, vykonanou sílu a práci.

Parametry každého sportovce byly uloženy a hodnoceny zvlášť pro pohlaví, příslušnou výkonnostní/amatérskou skupinu a pro pohyby flexe/extenze. Data byla analyzována statistickými metodami, které zahrnovaly testování normality, výpočet Spearmanova korelačního koeficientu, párový a nepárový Wilcoxonův test.

Konkrétními cíli datové analýzy bylo ověření naměřených dat, porovnání parametrů mezi výkonnostním a rekreačními sportovci, zjištění vzájemného vztahu mezi navrženými parametry a jejich případné rozdíly pro pohyby flexe a extenze, a ověření vybraných parametrů pro vhodnost využití v praxi.

SHRNUTÍ A ZHODNOCENÍ VÝSLEDKŮ

Cíl 1.1

Problémem uváděným při izokinetickém testování je určení maximální hodnoty momentu síly, který se vyskytuje mimo izokinetickou oblast (konstantní rychlost) a je ovlivněn zrychlením či zpomalováním dynamometru. V naměřených testovacích datech bylo ověřeno, že maximální moment síly detekovaný v celé oblasti křivky se v některých případech lišil od hodnoty maxima detekovaného pouze v izokinetické oblasti (p <0.001). Aby se zamezilo špatné interpretaci výsledků, je vhodné využít data z izokinetické oblasti.

Cíl 1.2

Pro zjištění, zda může být první či poslední opakování vyřazeno z analýzy, byl pro každého sportovce určen maximální moment síly z celého testování. Bylo zjištěno, že všech šest opakování bylo několikrát zastoupeno jako maximální. Pokud tedy testovací protokol obsahuje šest opakování pro každý pohyb, měly by všechny být zahrnuty pro zhodnocení.

Cíl 2

Druhým hlavním cílem bylo porovnat sílu mezi skupinami profesionálních a amatérských sportovců.

Tabulka průměrného momentu síly vyjádřeného v % tělesné hmotnosti.

Typ pohybu	Pohlaví	Moment síly [Nm/kg] Výkonnostní sportovci	Moment síly [Nm/kg] Rekreační sportovci
Flexe	Muži	111.1 ± 51.0 min 6.3 – max 248.5	146.2 ± 40.1 min 67.8 – max 245.9
	Ženy	99.6 ± 90.8 min 22.9 – max 434.9	45.3 ± 14.6 min 14.6 – max 76.5
Extenze	Muži	385.5 ± 177.5 min 22.8 – max 889.4	555.3 ± 186.7 min 256.5– max 1147.3
	Ženy	243.6 ± 119.2 min 39.4 – max 618.2	195.7 ± 64.1 min 66.7 – max 353.0

Předpokladem bylo, že výkonnostní sportovci budou dosahovat většího momentu síly oproti rekreačním sportovcům. To bylo potvrzeno u skupiny, žen naopak u mužů byl výsledek opačný. Vysvětlením může být relativně malý počet účastníků měření a záležitost individuální motivace vyvinout maximální úsilí. Z tohoto důvodu byl dále vyšetřován moment síly v okolí maximální hodnoty. Byl hodnocen zprůměrovaný moment síly z hodnot dosahujících alespoň 90% maximální hodnoty a také vykonaná práce z této oblasti. Porovnání mezi skupinami na základě průměrného momentu síly vyšlo stejně jako při porovnání maxima (muži: p = 1.00, ženy: p <0.001). Parametr práce vykonané v oblasti 90% maxima neprokázal rozdíly mezi skupinami (p> 0.05)

Cíl 3.1

Další otázkou bylo vyšetřit vzájemné vztahy mezi parametry. Jelikož test normality u většiny parametrů neprokázal normální rozložení, byl vypočten Spearmanův korelační koeficient. Ze všech extrahovaných parametrů byly pouze některé využity k interpretaci. Nejvýznamnější vztahy byly pozorovány mezi úhlem dosažení maxima (angle), časem od dosažení maxima do konce pohybu (t2) a poměrem práce vykonané do maxima ku celé práci během jednoho pohybu (RS1).

Tabulka Spearmanova korelačního koeficientu pro vybrané parametry.

Typ pohybu	Pohlaví	angle-t2	angle-RS1	t2-RS1
Flexe	Muži	*r* = - 0.65	*r* = 0.91	*r* = - 0.69
	Ženy	*r* = - 0.55	*r* = 0.84	*r* = - 0.56
Extenze	Muži	*r* = 0.71	*r* = - 0.86	*r* = - 0.64
	Ženy	*r* = 0.55	*r* = - 0.75	*r* = - 0.55

Cíl 3.2

Spolu s předchozí otázkou bylo v zájmu pozorovat, zda se jeví nějaké rozdíly v parametrech a jejich vztazích mezi flexí a extenzí. Můžeme vidět že vztahy mezi úhlem dosažení maxima a časem t2 mají opačný trend. Při flexi dosažení maxima spíše při menších úhlech odpovídá delší době do konce pohybu a menšímu poměru vykonané práce. Naopak u extenze bylo dosaženo delšího času t2 ve větších úhlech a poměr vykonané práce rostl při úhlech menších. Při extenzi byly maxima nejčastěji pozorovaná v úhlech mezi 50°-60° pro obě pohlaví. Při flexi bylo u mužů nejvýrazněji pozorováno maximum mezi 30°-37°, naopak u žen maximum při konkrétních úhlech pozorováno nebylo.

Cíl 4

Posledním cílem bylo ověřit, zda některé parametry reprezentující plochu v submaximální oblasti mohou být využity pro hodnocení. Byl navržen parametr angle90 vyjadřující úhlový rozsah pohybu, ve kterém bylo dosaženo alespoň 90 % a 80 % maximálního momentu síly. Dále byla hodnocena plocha v těchto oblastech a poměr mezi nimi. Bylo zjištěno, že při flexi (30 °– 50°) je úhlový rozsah větší než při extenzi (21°-29°). Při porovnání tohoto parametru mezi skupinami výkonnostních a amatérských sportovců nebylo dosaženo jednoznačných výsledků, a jeho využití je třeba nadále ověřit v další práci. Plocha v submaximální oblasti byla při pohybech flexe (1.1 J–4.2 J) menší než při extenzi (1.5 J–5.1 J) i přes to, že dosahovala většího úhlového rozsahu. To naznačuje větší schopnost produkce síly u kvadricepsů než u hamstringů. Poměr ploch vyšel při flexi i extenzi kolem 33-34 %. Velmi malé hodnoty tohoto poměru se vyskytovaly u sportovce, který utrpěl zranění předního křížového vazu. Malé hodnoty tohoto poměru tedy mohou poukazovat na potenciál zranění, avšak pro potvrzení je třeba získat více dat od podobně zraněných sportovců.

DECLARATION

I declare that I have written the Bachelor's Thesis titled "The utilization of isokinetic dynamometer for the measurement and evaluation of muscle strength of lower limbs in athletes" independently, under the guidance of the advisor and using exclusively the technical references and other sources of information cited in the thesis and listed in the comprehensive bibliography at the end of the thesis.

As the author I furthermore declare that, with respect to the creation of this Bachelor's Thesis, I have not infringed any copyright or violated anyone's personal and/or ownership rights. In this context, I am fully aware of the consequences of breaking Regulation § 11 of the Copyright Act No. 121/2000 Coll. of the Czech Republic, as amended, and of any breach of rights related to intellectual property or introduced within amendments to relevant Acts such as the Intellectual Property Act or the Criminal Code, Act No. 40/2009 Coll., Section 2, Head VI, Part 4.

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author's signature

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor Mgr. Daniela Chlíbková, Ph.D. and to my consultant Ing. Marina Ronzhina, Ph.D. for their time, dedication and helpful comments when consulting my work. Their constructive comments and advice helped to keep the focus of this thesis in the right direction. I would like to thank also to Mgr. Jan Šťastný, Ph.D. for his help with the isokinetic dynamometer, and his expert opinion on the experimental data analysis. Last but not least, I would like to express my gratefulness to my family and friends for their constant emotional support and eternal patience. Especially to my fellow student Ing. Filip Mívalt MSc. for his technical comments about the structure of this thesis.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

It is known that high-level sport has played a significant part in a human society already in antic Greece (4). Plenty of sport disciplines throughout many performance levels are broadly represented among today's world population. High-intensity training is a common way to improve performance (16). However, poorly designed training schedule with insufficient recovery time usually leads to the risk elevation of sport-based injuries. The knee joint is extremely susceptible to injuries due to multidirectional forces exposure (23). Thorough physical condition monitoring enabled by modern technologies and the-state-of-the-art devices has a significant role in professional sport. One example of such a device is an isokinetic dynamometer (20).

Evaluation of peak torques and derived hamstring to quadriceps ratio are standard methods to assess the muscle strength, muscle imbalance or joint stability. Although isokinetic dynamometry is widely used to determine strength-related parameters, its aspects have not been unified, and possible methods for data interpretation have not been fully discovered so far (34). Therefore, the purpose of this thesis was to gather the current knowledge about isokinetic dynamometry, perform isokinetic testing, verify the appropriateness of the method, and finally to suggest new approaches for data interpretation. Specifically, it is focused on the examination of the movement in the knee joint and muscle strength assessing for quadriceps and hamstring.

The thesis is organised as follows. The first chapter summarises a brief overview of the anatomical and mechanical functions of the knee joint. Furthermore, it introduces the principles and utilisation of isokinetic dynamometry along with factors that need to be considered when performing a measurement. The second chapter is divided into two sections. The first section provides in detail a description of the procedure used for the measurement. The second section incorporates methods of processing the acquired data. The third chapter presents the results of the conducted data analysis. The last chapter involves the interpretation of obtained results, possible applications and limitations of performed methods.

1.1 Muscle structure and function

The muscular system in humans contains three types of muscle tissue: skeletal, cardiac and smooth. The type responsible for the movement, therefore the point of interest of this work is the skeletal muscle. Its function is to provide body motions and support (14).

The surface of the skeletal muscle covers a thin layer called sarcolemma. Skeletal muscles are formed into units called sarcomeres. They consist of parallel bundles of long, multinucleated fibres known as myofibrils. Each myofibril contains two types of cytoskeletal proteins-myofilaments. Thin filaments are called actin, and thick filaments are called myosin. When a muscle is contracted, actin and myosin slide along each other without changing its length but shortening the length of the whole muscle (25). The structure of skeletal muscle fibre is shown in Fig. 1.1.

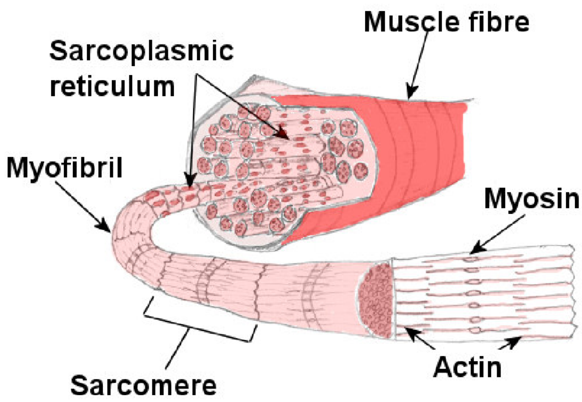


Fig. 1.1: Structure of skeletal muscle fiber. Source: (37)

The muscle activity is controlled by the neuromuscular junction providing nerve impulses resulting in a molecular cascade of processes allowing the muscle to contract or relax (25).

Types of muscle contraction

Types of muscle contraction can be classified according to whether a mechanical work is produced or not. When no mechanical work, hence no motion is produced, it is referred to as a static work. Corresponding muscle contractions are called **isometric**. These contractions can serve to restrain or hold action, e.g. when maintaining posture. During an isometric contraction, the torque exerted by the muscle is equal to resistance to be overcome, and the muscle length does not change (28).

When the muscle produces mechanical work, thus joint motion occurs, it is called dynamic work. Dynamic work of the muscle is typically represented by concentric and eccentric contractions. **Concentric** contractions cause muscle shortening and movement of joint due to the development of tension necessary to overcome the resistance of a body segment. The torque created by the muscle is in the same direction as the change in the joint angle (28). In this study, it is the contraction of quadriceps during extension at the knee joint. **Eccentric** contractions, conversely, induce muscle lengthening. They occur when the muscle is not capable of developing sufficient tension to resist the external load. The external load then overcomes the muscle tension. The produced torque is in the opposite direction from the change in the joint angle. Eccentric contractions help to decelerate the limb at the end of the movement (28).

1.2 Biomechanics of joints

This section introduces the biomechanical principles of muscles and joints related to an exercise performed by isokinetic dynamometry. We focused on the flexion/extension movement of the knee. Human limbs are subject to basic laws of mechanics just like any other body, and it can be described with fundamental physical quantities (29).

By action of **force** F, an object can be pushed or pulled, and therefore perform a movement. Force also enables to stop the movement, accelerate or decelerate the speed or alter the direction of the movement. It is a vector quantity defined by three attributes, its magnitude, direction and point of application. The magnitude of the force vector is the amount of force applied to an object with the action of gravity. It is defined as:

$$F = m \times g \tag{1.1}$$

where m is body mass and g is the gravitational acceleration. The unit of force is newton (N).

The magnitude of muscle force is directly proportional to the number and size of the fibres acting during muscle contractions. Since muscles do not contract individually but in groups, it is impossible to determine the strength of each fibre and their strength needs to be measured collectively.

In general, the direction of a force vector is along its line of action. Regarding muscles, the direction is determined by the line of pull. "The direction is identified as the angle of pull, which is defined as the angle between the line of pull and that

portion of the mechanical axis of bone that lies between the point of application of the muscle force and the joint, which acts as the fulcrum" (17).
The point of application refers to the point of the body at which the force acts. When the gravity is taken into account, this point passes through the centre of gravity of the body. In the human body, the point of application corresponds to an intersection between the line of force and the mechanical axis of the bone. Mechanical axis is the line that links the midpoints of joints at the proximal and distal ends of a bone (17).

Forces acting on the body are divided into two types; internal and external. Internal forces produced by muscles exert on different locations within the body, whereas external forces act from the outside of the body (17).

Torque, or moment of force, is a vector quantity occurred when describing a rotary motion. It is formulated as a cross product:

$$M = F \times r \tag{1.2}$$

where M is moment (torque), F is the force acting at the distance r from the center of rotation of the joint. The moment vector passes through the centre of rotation and is perpendicular to the vectors of force and distance. The magnitude of the torque is defined as

$$M = F \times r \times \sin(\theta). \tag{1.3}$$

The unit of torque is newton-meter (Nm). Its direction expresses the direction in which the limb rotates.

Work (W) is defined as

$$W = F \times r \tag{1.4}$$

stating the force needed to overcome a given resistance and move an object a certain distance. It is expressed in units of joules (J).

Power formulates the rate of work W performed over time t. The equation is following:

$$P = \frac{W}{t} \tag{1.5}$$

The unit of power is watt (W=newton $\times meter/second$).

1.3 Knee function

The knee joint is one of the most complicated joints in the human body. It needs to withstand excessive stresses and strains because of weight-bearing and locomotion.

To enable such requirements, it is supported by large condyles, strong ligaments and robust musculature. The knee joint is responsible for movements of flexion and extension (17).

1.3.1 Structure of the knee

The knee joint connects three bones: the distal end of the femur, proximal end of tibia and patella. The distal end of femur contains lateral and medial condyle. Their surfaces provide articulation for the patella. The condyles are separated from each other by the intercondylar fossa which mounts the anterior and posterior cruciate ligaments. The intercondylar area allows attachments of the medial and lateral menisci and anterior and posterior cruciate ligaments. The patella is embedded in the tendon of the quadriceps femoris muscle. The function of the patella is to increase the angle of application and to protect the quadriceps tendon from extreme friction from the femur.

The menisci are located on the medial and lateral site of the tibia. They increase the contact surface between the femur and the tibia reducing the stress by the articular cartilage. Secondary functions are knee stabilization and lubrication. Due to their position, enormous loading and involvement in twisting and rotary motions, they often suffer from injuries.

The knee is also supported by non-contractile structures including capsules and ligaments. The ligaments exist in three types: collateral, crucial and accessory. The collateral ligaments provide the primary support in controlling the mediolateral and rotary stability of the knee joint. The primary function of crucial ligaments is the stabilization in anterior and posterior directions (29).

1.3.2 Muscles acting on the knee joint

The muscles attached to the knee joint perform two main movements; flexion and extension. Consequently they are sometimes grouped according to their function. The group of flexors contains three hamstring muscles including biceps femoris, semimembranosus and semitendinosus, farther the sartorius and the gracilis. Two additional muscles allowing flexion are the popliteus and the gastrocnemius. For extension are responsible four muscles that together make the quadriceps femoris group. Particularly they are the rectus femoris, the vastus intermedius, the vastus lateralis and the vastus medialis (17). The anatomical structure of the knee is shown in Fig. 1.2.

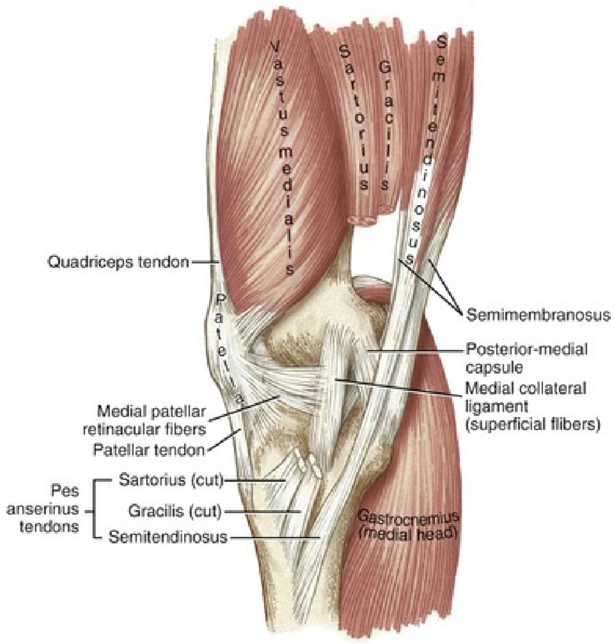


Fig. 1.2: Anatomy of the knee. Source: (27)

1.4 Muscle strength

"Muscle strength has been defined as the maximum force (in N), or torque (in Nm) developed during maximal voluntary contraction under a given set of conditions"(19). Demand for evaluating muscle strength comes from various areas of interest. Regarding medicine it is the muscle function examination, predicting risks of injuries, providing normative values for a healthy population and analyzing results from surgical or therapeutic procedures. In the sport field, it serves to study the effect of special training on the athletic performance, to set normative values in specific sport disciplines and to differentiate among different performance levels (19).

1.4.1 Assesement of muscle strength

Methods currently used to determine muscle static strength are cable tensiometry, dynamometry and one-repetition maximum. Computer-assisted, electromechanical and isokinetic methods allow measuring dynamic strength. **Cable tensiometry** (24) consists in pulling on a cable with corresponding tension on it. A tensiometer measures the resulting tension. Advantages of this method are feasibility and versatile use for diverse angles about the axis of a specific joint. Principle of **dynamometry** (static) (8) is the application of external force which compresses a steel spring and moves a pointer on a dynamometer. The force needed to move the pointer a stated length defines the external force applied to the dynamometer. **One-**

repetition maximum (1-RM) (38) is a method based on a regular weightlifting exercise. Subject estimates an initial weight to be lifted and once perform the specific weightlifting movement. The load is subsequently increased until the maximum lift capacity of an individual is reached. A disadvantage of this method is the need for pre-estimation and calculation of the initial weight to avoid the risk of injury caused by the inappropriate load (24). All these methods only provide outcomes of the static measurement and do not allow an examiner to analyse the dynamic behaviour of the movement. These limitations can be solved due to the development of microprocessor technology and computer assist. Machine allowing assessment of functional movement performance and measurement of muscle strength within a certain range of motion (ROM) is called an isokinetic dynamometer (24). The device can be seen in Fig. 1.3.

1.4.2 Isokinetic testing

Term isokinetic means movement at a constant speed. Isokinetic exercise contributes to resistance training. Its objectives differ. It can be used for studying and understanding muscle physiology, muscle structure, function and adaptability. Regarding utilization in sports, it helps to design proper training in a particular sport to achieve the best possible results (24).

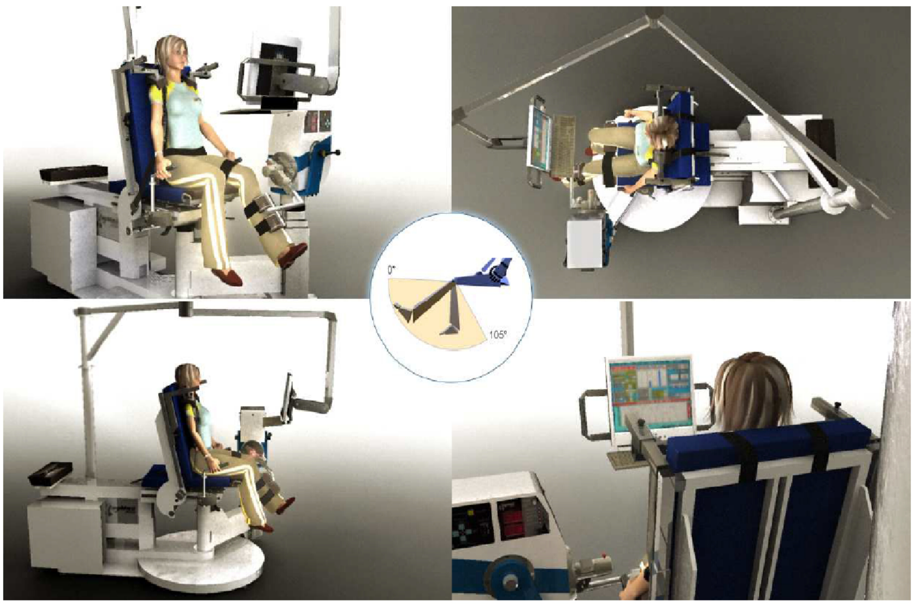


Fig. 1.3: Isokinetic dynamometer.ISOMED 2000.
Source:(1)

1.5 Isokinetic dynamometry

Isokinetic dynamometry is a procedure to assess the amount of strength of single or group muscles at the specific joint angle. An isokinetic dynamometer is a machine enabling such task, due to controlling mechanism that accommodates its resistance in order to carry out required constant speed. When the velocity is reached, the isokinetic loading mechanism automatically adapts to provide the corresponding counterforce to the alternating force produced by muscles throughout the whole ROM. It is possible to do measurements under various conditions. According to the selected mode, the produced strength can be isometric, concentric or eccentric. The options for angular velocity ranges from low to high. The monitor cooperating with the control system shows ongoing feedback about performance (8).

1.5.1 Preparation for measurement

Prior to isokinetic testing, the warm-up exercise should be done to assure the safety and comfort of the tested person (10). Keating and Matyas (21) summarised different types of already reported warm-up exercising. Those include the use of bicycle ergometers, a stretch of the particular muscle groups or using a various set-up of the dynamometer. Many authors used dynamometer when subject performed unspecified numbers of submaximal contractions. The number of repetitions of submaximal contractions varied between 2 and 10 repetitions. Other authors decided to perform a combination of submaximal and maximal contractions. In general, there is no established procedure describing the warm-up and its justified effect on testing (21).

1.5.2 Range of motion

Although a principle of isokinetic dynamometry lies in a motion of constant speed, in fact, it consists of three phases: acceleration, constant velocity and deceleration (see Fig. 1.4). The acceleration phase can be described as matching of constant velocity without loading. The ROM where speed is constant and external load is employed is referred to as a load range. Deceleration phase is caused by slowing down before reaching the endpoint of a movement and just like by acceleration; it does not include the load. Therefore, acceleration and deceleration phases should not be included in results interpretations (10). This was confirmed by Ozdemir *et al.* (30) who were monitoring the improvement of muscle strength concerning the full range of motion (fROM) compared to the valid isokinetic sector (VIS). They concluded that assessment of muscle performance considering only fROM data could be misinterpreted, especially for higher angular velocities. From their results, it is apparent that it should be taken into account whether to use VIS results or fROM results for interpretation. Similarly, Kurdak *et al.* (22) were examining contractile characteristics of adolescence wrestlers with a focus on the load range phase of motion within different velocities. Their results showed that with increasing angular velocities, the load range significantly reduces, unlike when using lower velocities. From these findings arises the need for consideration of the choice of the angular velocity. Choosing of too high angular velocity possibly leads to performing complete contraction without even reaching the determined velocity. That can have an impact on the final results. Consequently, there is an upper limit for angular velocity, and it should be taken into consideration when designing the test or train measurement and interpreting the results.

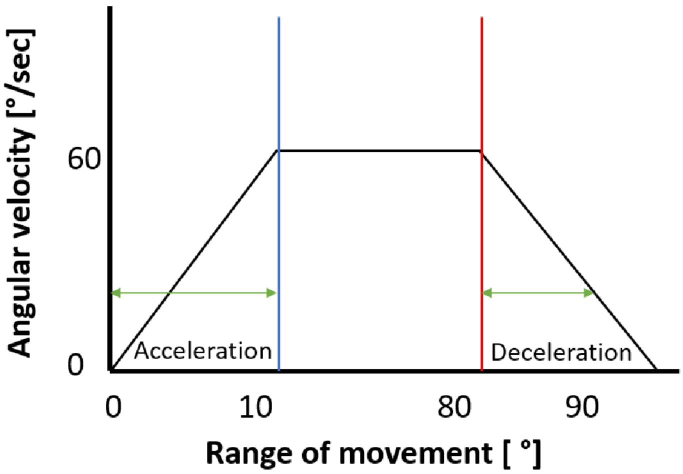


Fig. 1.4: A curve of an isokinetic movement phases. The first phase: acceleration, the second phase: constant angular velocity, the third phase: deceleration. Adapted from: (39)

1.5.3 Rest periods

Resting periods differ depending on if dynamometry is used for training or testing. Having a training purpose, the time varies depending on the type of training. In general, longer rest periods are used for strength development, whereas for endurance training, shorter rest periods are employed. According to Brown's protocols (10) for testing the break periods between series are 20-30 seconds for the general population as well as for athletes. While recovery testing, those periods should prolong up to 60-120 seconds. The rest between different angular velocities should last 120 seconds for each mentioned group.

1.5.4 Choice of angular velocity

The choice of angular velocity is an important factor of isokinetic testing. It should be derived from the intended aim of the testing, and subsequent output data should be correctly evaluated. By concentric testing, the peak torque decreases with increasing angular velocity. On the contrary, studies examining eccentrical testing did not show torque to be decreased with higher testing speeds (21). Testing protocols by Brown (10) suggest to use the angular speed of 60°/sec and 120°/sec for general population and patients recovering from injuries. For testing of professional athletes, velocities from 60 up to 300°/sec can be used depending on the particular sport.

Similarly, as with the rest period, the choice of an optimal angular velocity depends on training/testing preferences and the target population. As far as training is concerned, Brown (10) summarises that for overall improvement in the whole range of velocities, it is appropriate to train in velocities of 180-240°/sec. If improvement at only specific velocity is desired, the training should be performed at this velocity only.

Chena *et al.* (13) assessed torque of quadriceps and hamstring during concentric and eccentric loading at different angular velocities from 60 to 450°/sec. They came to conclusions that torque production of quadriceps and hamstring significantly decreased at velocities increasing from 60 to 300°/sec. For eccentric mode, hamstring torque reached significantly higher values at velocities of 60 and 120°/sec. Concentric hamstring-to-quadriceps ratio (H-Q ratio) increased with increasing angular velocities.

1.5.5 Verbal and visual feedback

Modern isokinetic dynamometers provide immediate visual feedback on the monitor in front of the tested person. It includes multicolour bar graphs and torque curves of current performance to enhance the subject's motivation. That is often supported by verbal encouragment of the examiner. Campenella *et al.* (12) were determining the effect of visual and verbal feedback on concentric peak torques in hamstrings and quadriceps. Their literature research showed that this feedback had a positive impact on the performance. They carried out own measurements with only verbal encouragment, only visual feedback, combined feedback and no feedback for control. They confirmed their assumptions, thus peak torque values increased with the visual and combined feedback compared to no feedback provided. They did not prove any improvement of peak torque values when only verbal encouragment was given, however that was in contrast to their earlier findings. Overall it can be summarised, that verbal and visual feedbak is helpful for obtaining higher torque values.

1.5.6 Gender difference

Wagner *et al.* (36) were examining gender differences for the peak torque values and angle-specific torque values during leg flexion/extension within various angular velocities. Their findings showed less decline in torque values in male group than in female group with increasing speeds, which supported the presence of gender differences. In the study of Andrade *et al.* (6) was observed that male and female athletes possess a variant muscular balance between hamstrings and quadriceps (H-Q ratio), concretely female performed lower H-Q ratio. Keating and Matyas (21) investigated several studies, which all showed greater values for torque measurements for men compared to women of similar age and athletic background following the same test protocol. They suggest taking into account gender differences before data comparison.

1.5.7 Gravity compensation

Most exercises on isokinetic dynamometer are performed under a gravitational force, which influences actions of forces exerted by muscles. Hence, every examiner should realise this fact when designing a test and should consider a gravity compensation. For example, knee flexion and extension is a typical example of this gravitational acting. During the flexion phase gravity assists the motion by pulling the limb and the lever arm down. On the contrary, during the extension phase, the limb together with the lever arm are lifted against gravity action. Thus, torques for flexion can reach misleadingly higher values; alternatively, torque values for extension tend to be lower. In this case, gravity compensation is strongly recommended (10).

1.5.8 Number of repetitions

Completing a movement of fROM in both directions is considered as one repetition. The number of repetitions is chosen according to the desired outcome of a test. For the strength testing purpose, 5 repetitions should be a sufficient amount to obtain information about maximal torque value. Regarding testing for endurance, the number of repetitions can increase up to 50 (10). Researchers have involved a different number of repetitions for their testing. Brockett *et al.* (9) used isokinetic dynamometry to predict hamstring strain injury according to peak torque values at the optimal angle with subjects performing 7 repetitions. Calmels *et al.* (11) were determining hamstring and quadriceps strength in elite gymnasts doing 6 repetitions. Pelegrinelli *et al.* (31) were comparing velocity specific knee flexor/extensor strength among volleyball players who accomplished 5 repetitions.

1.6 Conventional data interpretation

This section presents an outlook on parameters commonly used for data evaluation and mentions the issues regarding data normalisation.

Parametres obtained by isokinetic dynamometry:

- **Peak torque**
  The isokinetic peak torque represents the maximal torque of muscles that can be applied in dynamic conditions. It usually occurs within second to sixth repetitions. The peak torque depends on the angular position of the joint. Together with the knowledge of preset angular velocity, power can be derived (8).
- **Angle of the peak torque**
  It is the angular position of joint at which the peak torque occurred. It gives information about the mechanical properties of the particular muscle group. This position changes depending on the angular velocity, consequently it does not always correspond to the mechanically optimal joint position. Therefore, it is essential to include the angular position to evaluation (8).
- **The reciprocal muscle group ratio**
  This ratio indicates the muscle strength balance around the joint. The ratio evaluates peak torques recorded in antagonist movements (8). Typical example of this parameter is the **hamstring to quadriceps ratio**. It is important to realise that during knee extension, a significantly larger amount of force is produced compared to knee flexion. That is caused by the greater amount of extensor muscles mass. According to studies, the ratio between hamstring and quadriceps strength (H-Q ratio) is approximately from 0.45 to 0.65 (29). Nevertheless, this ratio is influenced by gender, knee joint position, speed and mode of contraction (29).
- **Muscle work**
  Work is defined as a force acting at a given distance. It expresses the muscle tension produced during the contraction. It is calculated from torque values and angular range. Sometimes it is termed as muscle endurance rate (15).
- **Power**
  Power corresponds to the amount of work produced over time. Determination of power is used for examining improvement in sports activities that are not limited by maximal force (15). It can also be calculated from the torque and the angular velocity values (8).

Data normalisation

Jaric (19) emphasises the importance of considering the body size of an individual and mentions that many authors' results are confounded and inappropriately explained due to incorrect or none data normalisation. Furthermore, he points out that due to different normalisation techniques comparisons among various studies are limited. He reviewed many studies dealing with the suggestion of universal allometric parameter independent on body size. Accordingly, he proposed formula with particular allometric parameter. This parameter b is equal to 0.67 when determining muscle force and to 1 for muscle torque (which was measured in this study). The equation is the following:

$$S_n = \frac{S}{m^b} \tag{1.6}$$

S_n represents normalised strength or torque index, S is the measured value of strength or torque, m expresses body mass, and b is the aforementioned allometric parameter.

1.7 Research issues

The muscles acting on the knee joint are involved during various motions of almost every sport activity. Thorough examination of their function helps to control suitability and effectiveness of the training. Isokinetic dynamometer allows measuring the torque of the knee muscles throughout the whole range of motion. The objectives of this work are to find an alternative approach on how to evaluate the output data from this device and to investigate the suitability of the chosen method aiming at the maximal performance. The first task is to design a framework for data processing (see section 2.2). The second task is to conduct data analysis focused on answering the following questions and assumptions:

- **Research issue 1**
  The first issue deals with the validation of the measured data. The aim is to suggest a proper selection of data which should be used for processing and interpretation regarding the maximal muscle strength. Specifically, the following questions will be examined.
  Question 1.1: "Are the parameters detected in the valid isokinetic area equivalent to parameters detected in the whole segment?"
  Question 1.2: "Can the first and the last repetition be excluded from evaluation?"

- **Research issue 2**
  The second issue compares the group of professional and amateur athletes. Differences in parameters obtained from the measurement will be investigated.
  Question 2: "Do the quadriceps and hamstring muscle groups of professional athletes produce higher strength values compared to amateur athletes?"
- **Research issue 3**
  The third issue regards the examination of designed parameters. The relation among parameters will be analysed as well as the differences between parameters of flexion and extension movement.
  Question 3.1: "How the designed set of parameters such as time, angle or surface mutually correlate?
  Question 3.2: "What is the relation between parameters of flexion and extension movement?"
- **Research issue 4**
  The last issue deals with the verification of particular parameters that could be applicable for muscle strength evaluation.
  Question 4: "Can surface parameters of the submaximal area be used for muscle strength evaluation?"

2 METHODS

The first part of this section introduces the measurement set-up and the testing procedure. The second part is focused on the processing of acquired data.

2.1 Measurement

Isokinetic dynamometer ISOMED2000 was used for the measurement.Twenty-five college students: twelve women (age 21.6 ± 1.3 years, body mass 62 ± 6.5 kg, height 166.9 ± 6.6 cm, BMI 22.3 ± 2.2 kg/m^2) and thirteen men (age 25.7 ± 5 years, body mass 72.8 ± 9 kg, height 181 ± 6.3 cm, BMI 22.2 ± 2.5 kg/m^2) voluntarily participated in the study. They were tested for evaluation of the maximal strength of knee flexors and extensors. The test exercise consisted of a series of unilateral knee flexion/extension movements. Prior to testing the whole procedure was clearly explained to prevent undesirable situations (e.g. cause of injury) and to obtain valid and reproducible data. Moreover, subjects were given a questionnaire to fill in additional information, which was later used for data normalisation and interpretation. The questionnaire can be seen in the appendix A.1.

Firstly, all subjects stretched their lower limbs. Afterwards, they were positioned to the seat with a hip flexion at approximately 75°. Displacement of the seat was set in the way, so there was space for two fingers between the seat and the limb. The axis of the dynamometer was aligned with the axis of movement at the knee joint. The laser pointer was used to precisely determine the point of application of the knee rotation.Only the muscles responsible for knee flexion and extension must be involved to obtain reproducible results. Therefore, the proper fixation restricting possible action of other body parts was desired. The tested thigh was stabilised on the seat using a thigh strap. The lower part of the leg (2-4 cm above the ankle) was fixed to the dynamometer mechanical lever using the appropriate adapter. The upper body was secured with a waist strap. The shoulder support was fixed to enable the subject to sit upright and simultaneously to sufficiently restrain additional movements of the upper body. During testing, subjects were holding side grips on the facility to help them stabilise the upper body. The time needed to adjust the dynamometer positions correctly was about 15 minutes. Figure 2.1 presents the setting of the dynamometer during the testing.

The manual testing mode was chosen for the measurement. The first step was to apply the gravity compensation due to reasons that were stated in section 1.5.7. The limb was raised to the horizontal position, where it was stopped and held by the dynamometer. Subsequently, the weight of the extremity was measured and processed by the dynamometer to provide corrected data. Before actual testing, subjects performed few submaximal contractions in the initialization mode until they were confident about the adaptation for isokinetic movement at the particular speed. The range of angular motion was adapted to each individual's capabilities; on average, the setting was approximately 90° range. The starting position was with the knee extended at the angle about 10° followed by the flexion movement that ended with the knee bent at the angle about 90°. That was subsequent starting position of the extension movement.

The testing protocol consisted of 6 repetitions of concentric knee flexions and extensions at angular speeds of 60 and 120°/sec for each leg. The velocities and number of repetitions were chosen according to findings as it was discussed in section 1.5.4 and 1.5.8. The rest period between the velocities was 90 seconds, and the break before testing the other leg was 3 minutes. The subjects were encouraged continuously by both verbal feedback of the examiner and visual feedback on the monitor, to achieve the maximal possible torque value, see section 1.5.5 All measurement were saved and transferred from the dynamometer to the computer for evaluation.

Fig. 2.1: Setting of the dynamometer ISOMED2000. The initial position of the flexion movement.

2.2 Data analysis

The flowchart shown in Fig. 2.2 represents single steps performed in the processing part. Following sections closer describe action of each block.

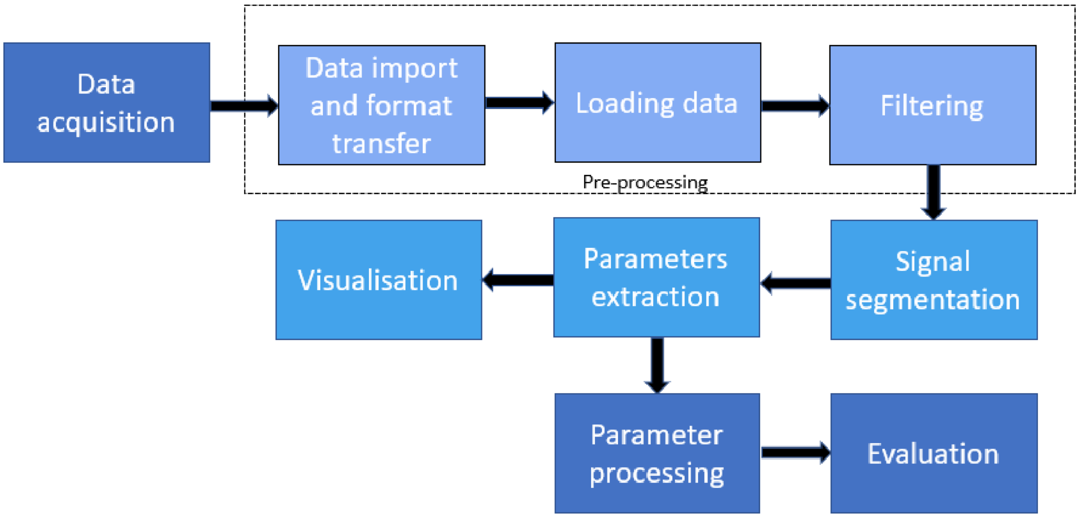


Fig. 2.2: Scheme of procedures undertaken within the study. The first step was to measure on the dynamometer. Raw data were exported to the computer and processed. The initial processing steps included a change of data format, loading and filtering. The next phase involved signal segmentation and decomposition, and extraction of the time-angle-related parameters. A segmented signal was then visualised to check the output of the programme. In the final phase, parameters were analysed using statistical methods, the research questions were examined, and their answers interpreted.

2.2.1 Pre-processing of data

Pre-processing phase involved initial adjustment of data format, creating a function to load individual signals and filtering the torque curve.

Data import and format transfer

Raw data were exported from the dynamometer to the computer in the text format. It included a header with information about the particular testing such as subjects personal data, positions and set angles of the dynamometer, test angular speed, the number of repetitions, break period etc. Further there was explanation of the single columns of exported data.

The columns represented following:

1. time in milliseconds
2. relative position in 1/10 degree or millimeter
3. torque in 1/10 Nm or force in newton
4. speed in 1/10 degree/second or 1/10 millimeter/second
5. torque without gravity calibration in 1/10 Nm
6. current repetition(about 1.2 degrees delayed)
7. current set
8. torque on dynamometer
9. force on right leg or deviation of force
10. force on left leg or deviation of position

The list of explained columns was followed by information specifying the row at which the measurement started. The last part of the format included intrinsic measured values.

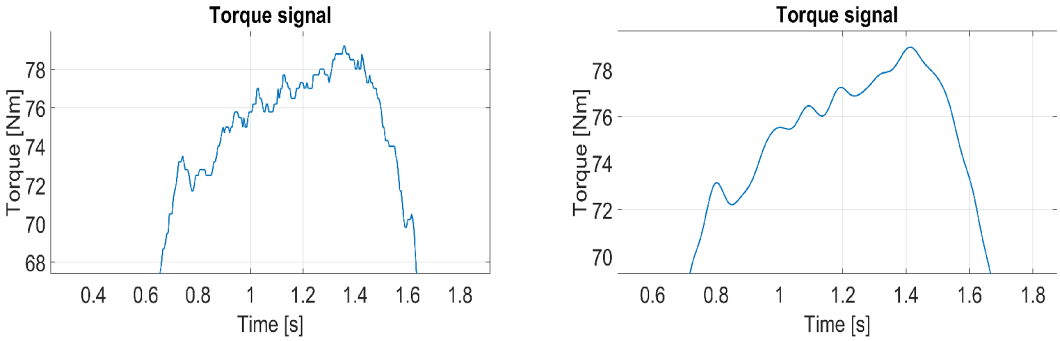
For each subject, four data files were obtained. These files contained values from measurements at angular velocities of 60 and 120°/sec, separately for each leg. They were imported into MATLAB software environment which was used for the processing and analysis. The header was removed, and data to evaluate were transformed into format double and saved as a matrix for subsequent processing.

Loading data

Signals acquired from every tested subject were processed separately. After loading data, columns containing the desired values were assigned as single vector variables. Those variables included time, angle position, torque and angular velocity. The values were converted so that they matched SI base units.

Filtering

The torque signal was filtered using a 5th-order Butterworth low pass filter with a cutoff frequency of 20 Hz. That helped to smoothen the signal and facilitate further detection of some particular points. Small fluctuations were removed but distinctive deflections remained in the signal. The filtration was executed in forward and reverse directions to avoid the phase shift. Example of effects of filtration can be seen in Fig. 2.3.



(a) (b)

Fig. 2.3: Example of the filtering effect on zoomed torque signal. a) unfiltered signal b) filtered signal.

2.2.2 Signal segmentation

The process of signal segmentation decomposed the whole signal into smaller fragments. That enabled the calculation of the parameters from each segment. The signal obtained in our measurement represented torques of 2 alternating movements denoting knee flexion and extension. Flexion movement corresponded to lower peaks, conversely extension to higher peaks. Angular velocity signal was used to indicate the point of change of the movement direction. The curve of angular velocity showed insignificant fluctuations around the baseline. Those were eliminated to obtain zero velocity values and positions. Occasionally while testing, unintended initial limb movements occurred (represented in Fig. 2.4). Besides some subjects switched the movement direction during the phase of deceleration and did not reach the velocity close to zero. That resulted in the detection of unforeseen zero crossings. When the number of zero crossings differed from the expected, algorithm switched to manual signal segmentation. Otherwise, the signal was segmented automatically. Two consecutive zero-velocity points bordered a fragment from which a set of parameters was extracted. Simplified flowchart of signal segmentation is presented in Fig. 2.5.

Angular velocity signal was also used to determine the isokinetic sector, thus when the limb was moving with constant speed. Fluctuations in the range ± 0.5 were rounded and considered as isokinetic. The acceleration and deceleration phases were marked as zeros. The signal then consisted of non-zero values indicating the isokinetic area and zero values indicating the acceleration and deceleration phase. Indices denoting the isokinetic area were saved and utilized in the following phase of processing.

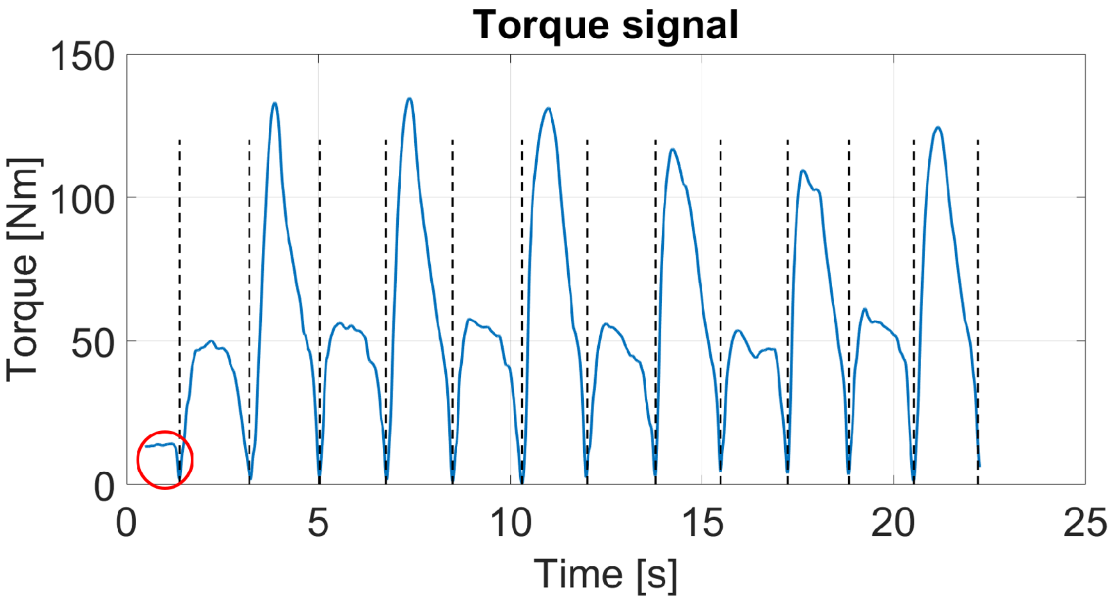


Fig. 2.4: Example of an unintended movement at the beginning of the measurement - red circle. Black lines: indicate single segments.

2.2.3 Parameters extraction

For each segment were derived parameters characterizing time and surface properties of the signal. The indication points served to calculate the attributes of each segment. Those included: $\boldsymbol{t_{start}}$ - beginning of the movement; $\boldsymbol{t_{end}}$ - end of the movement; $\boldsymbol{t_{max}}$ - position (describing time or angle) of the maximal reached torque in the segment; $\boldsymbol{t_{isostart}}$ - beginning of the isokinetic area (index of the first non-zero value in the angular velocity signal); $\boldsymbol{t_{isoend}}$ - end of the isokinetic area (index of the last non-zero value in the angular velocity signal); $\boldsymbol{t_{90}, t_{80}, t_{50}}$ - position of 90% of peak torque value, 80% and 50% of peak torque value respectively. Their location within a segment can be seen in Fig. 2.6a.

The parametres were:

- **type** - containing information whether the segment describes the flexion movement (odd segments - value 1) or extension movement (even segments - value 2)
- **maxVal** [Nm] - value of the maximal reached torque in the segment
- **t1** [s] - time period until the peak torque was reached

$$t1 = t_{max} - t_{start} \tag{2.1}$$

- **t2** [s] - time period from reaching the peak torque until the end of the movement

$$t2 = t_{end} - t_{max} \tag{2.2}$$

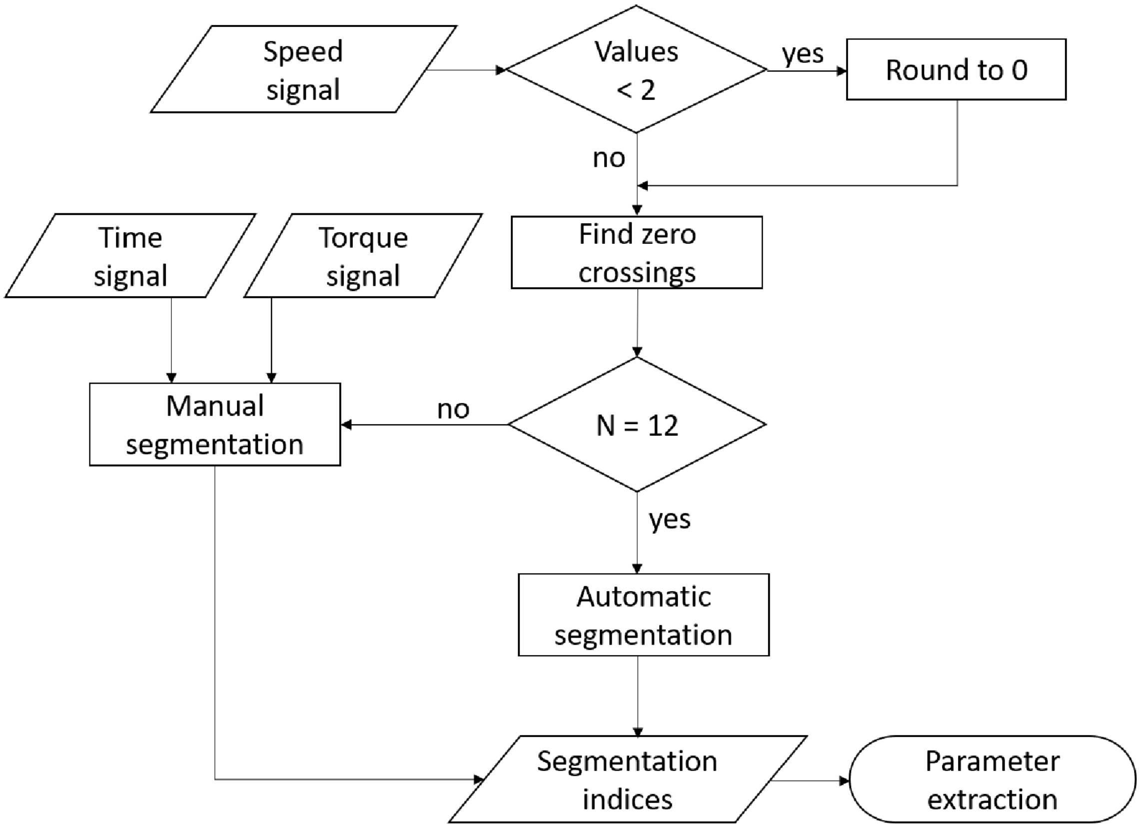


Fig. 2.5: Simplified flowchart representing processes to obtain segmentation points. The signal of angular velocity was used to determine points of movement direction change. Baseline fluctuations smaller than two degrees per second were considered as zero velocity. Zero crossings were detected and counted. If the number of zero crossings was twelve, indices of zero crossings were marked as segmentation points and saved for parameters extraction. Otherwise, the time-torque signal was visualised, and segmentation points were labelled manually.

- **angle** [°] - specifying the value of angle at which the peak torque was reached
- **Stotal** [**J**] - surface under the whole curve
- **S1** [**J**] - surface delineated by the start of a movement and the peak torque position
- **S2** [**J**] - surface delineated by the peak torque position and the end of a movement

  All the surfaces under the curves also referred to as work was calculated by performing numerical integration.

$$Stotal = \frac{t_{end} - t_{start}}{2N} \sum_{n=1}^{N} (f(t_n) + f(t_{n+1})) \tag{2.3}$$

- **RS1** [-] - relative surface of S1 to total surface

$$RS1 = \frac{S1}{Stotal} \tag{2.4}$$

- **RS2** [-] - relative surface of S2 to total surface

$$RS2 = \frac{S2}{Stotal} \tag{2.5}$$

- **isotime** [**s**] - duration of movement during constant velocity only

$$isotime = t_{isoend} - t_{isostart} \tag{2.6}$$

- **time** [**s**] - duration of one whole movement

$$time = t_{end} - t_{start} \tag{2.7}$$

- **timeratio** [-] - ratio of the isokinetic time and the whole time

$$timeratio = \frac{isotime}{time} \tag{2.8}$$

- **Tslowdown** [**s**] - period between end of the isokinetic sector and the end of the movement

$$Tslowdown = t_{end} - t_{isoend} \tag{2.9}$$

- **Taccel** [**s**] - period between beginning of the movement and the beginning of the isokinetic sector

$$Taccel = t_{isostart} - t_{start} \tag{2.10}$$

- **Thalf** [**s**] - time to reach 50% of peak torque value

$$Thalf = t_{50} - t_{start} \tag{2.11}$$

- **isoMax** [**Nm**] - maximal torque value of the isokinetic sector

- **isoAngle [°]** - angle corresponding to the isoMax value
- **isoSurf [J]** - surface of the isokinetic sector
- **Rsurf [-]** - ratio between the surfaces of the whole movement and the isokinetic area
- **work90, work80 [J]** - area of torque reaching above 90%/80% of the maximum
- **R90-80 [-]** - ratio between work90 and work80
- **angle90, angle80 [°]** - angle range of the movement when torque reaching above 90%/80% of the maximum

$$angle90 = angle(t_{90b}) - angle(t_{90a}) \tag{2.12}$$

- **surf90, surf80 [J]** - surface of the 90%/80% of peak torque - the top of the curve only
- **RS90-80 [-]** - ratio between surf80 and surf90

$$RS90 - 80 = \frac{surf90}{surf80} \tag{2.13}$$

- **mean90, mean80 [Nm]** - average value of torque reaching above 90%/80% of the maximum

$$mean90 = \frac{1}{N}\sum_{n=1}^{N} torque(n) \tag{2.14}$$

- **slope [Nm/s]** - peak torque divided by the time to reach the peak torque

$$slope = \frac{maxVal}{t1} \tag{2.15}$$

The designed set included parameters commonly used for interpretation (see section 1.6). Some of them were detected in the isokinetic area as well as in the whole movement segment. The intention was to see if they change in the isokinetic area. Design of other parameters was in general inspired by the motor unit action potential curve (32). The time characteristics were further adapted to the isokinetic torque curve segments, as shown in Fig. 1.4. As far as it is known, some of the parameters have not been reported so far. Those include angle90(80), surf90(80), RS90-80. The surface parameters expressed produced work, so it seemed promising to use them as an alternative indicator for muscle strength evaluation.

All parameters were saved in a matrix, where each row corresponded to one segment, and each column expressed the value of the certain parameter. After extraction, all torque signals and its main marker points were visualised to check their correct detection and to highlight some areas of interest. Example of a segment outline is shown in Fig. 2.6.

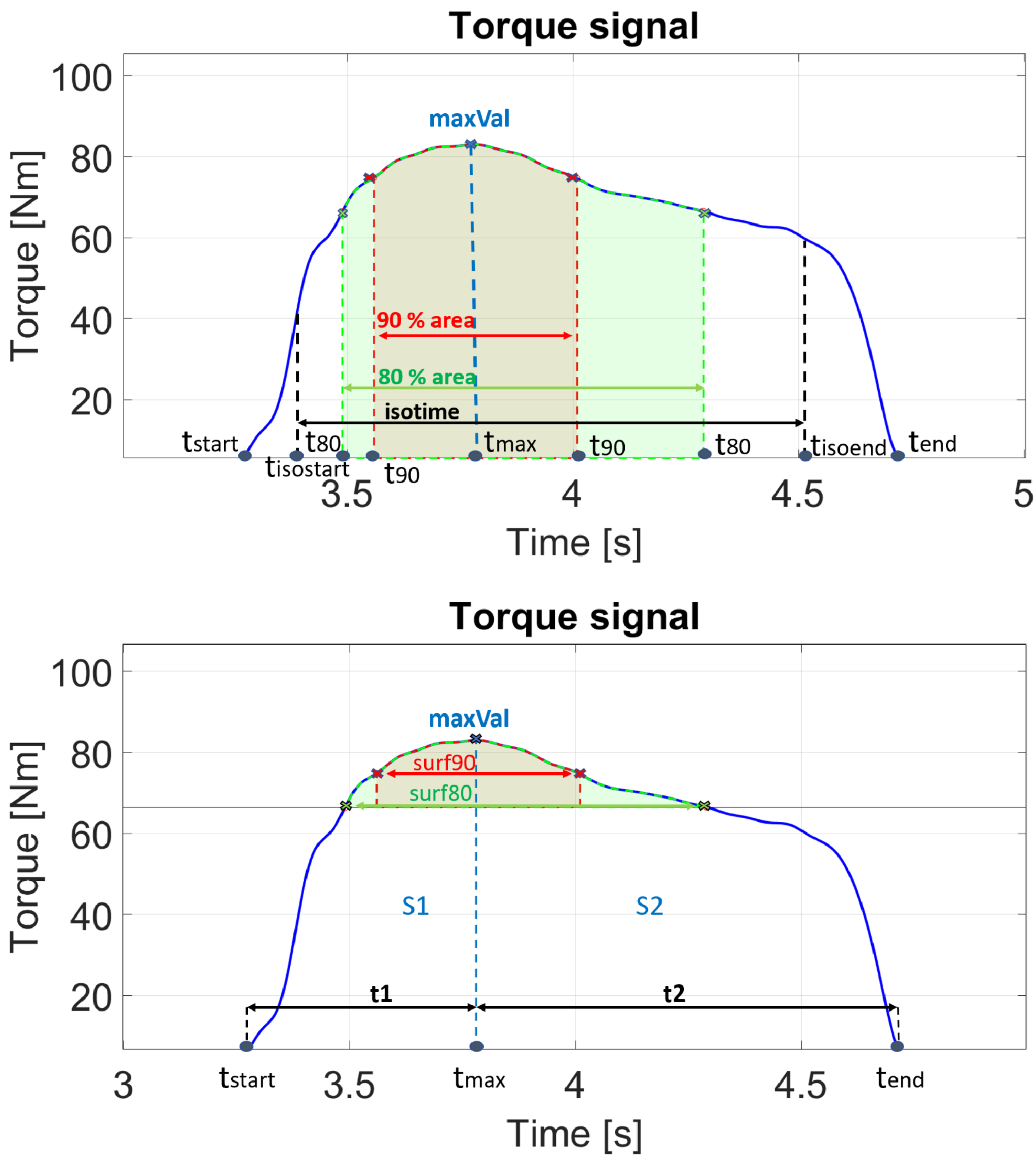


Fig. 2.6: Example of the single time-torque curve outline. a) Datapoints t_{start}, $t_{isostart}$, t_{80}, t_{90}, t_{max}, t_{isoend}, t_{end} indicate borders of a segment portions. Datapoint maxVal marks the peak torque value. Red line labels the area of 90% peak torque, green line labels the area of 80% peak torque. Parameters work90, work80, mean90, mean80 are extracted from these (red, green) areas. Isotime denotes an isokinetic area (constant angular velocity is held). b) S1, S2 mark the work produced before/after the peak torque; t1,t2 indicate the time duration before/after the peak torque; surf90, surf80 denotes the surface at the top of the curve reaching above 90% / 80% of the peak torque.

2.2.4 Parameter analysis

Every participant of the testing was asked to fill in a questionnaire to get the information about their physiological parameters, training units and injury history. The information was used for division tested subjects into groups and for normalising their performance according to the physiological parameters. For the analysis the matrix of parameters was split according to the type of movement and gender.
Peak torque values which occurred during acceleration or deceleration phase were corrected to values identified in the range of constant angular velocity. For comparison purposes the torque values were subsequently normalised to body weight as stated in 1.6 to avoid data misinterpretation due to different body size.

Normality test

In order to determine whether data come from normal distribution or not, the normality test was performed. For this purpose, one-sample Kolmogorov–Smirnov (2) test was used:

$$D = \max_x(|F(x) - G(x)|) \tag{2.16}$$

$F(x)$ represents cumulative frequency of the tested dataset and $G(x)$ is the cumulative frequency of the hypothesized distribution. The value of D was compared to a critical value D_{max} for a significance level of $\alpha = 0.05$.

Correlation

Using correlation analysis was intended to find whether some of the parametres has a relation to another and if it can be beneficial for the data interpretation. Since majority of data did not prove to come from a normal distribution, Spearman's rank correlation coefficient (3) was calculated.

$$r_s = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{2.17}$$

d_i is the difference between the two paired ranks of each observation and n is the number of observations of the two variables. The interpretation of resulting values of r_s ranges from -1 to 1. The edge values of this interval show that the variables correlate or anticorrelate, while when equals 0, the variables do not correlate.

Comparison between groups

Questionnaire findings regarding the sports activity showed that participants dedicate to various kind of sport throughout different levels. The intention was to split them into two groups: professional athletes and amateur or non-sporting group. At first, they were split directly according to the number of training units per week. Since this attitude was not suitable for creating groups of similar nature, MET (Metabolic equivalent of task) units were used instead. MET is defined as “the ratio of the work metabolic rate to the resting metabolic rate“ (5). MET units system has been developed by Compendium of physical activities and is commonly used in studies to score various sports activities (5). The border to differentiate between more and less physically active was 30 MET-hours. It was the most distinctive value in the database of the measured athletes able to divide them into approximately equally-sized groups. This resulted in creating groups of 14 professionals (7 men and 7 women) and 11 amateur athletes (5 men and 6 women).

To determine if any differences between groups ocurred, the Wilcoxon rank sum test (18) was used. The alternative hypothesis stated that the group of professionals has a greater median value of the peak torque than the amateur group.

$$z = \frac{W - E(W)}{\sqrt{V(W)}} \tag{2.18}$$

W is equal to the rank sum of the particular variable, E is the expected value and V corresponds to variance.

Differences between torque values from the whole vs isokinetic sector were tested by paired Wilcoxon sign rank test (33). The null hypothesis stated that differences of torque values in the whole and the isokinetic area has a zero median against the alternative hypothesis that the median of differences does not equal zero.

$$z = \frac{\frac{W - n(n+1)}{4}}{\sqrt{\frac{n(n+1)(2n+1)}{24}}} \tag{2.19}$$

W is the sum of the ranks of positive differences between the pairs and n corresponds to its number.

3 RESULTS

As stated in Introduction, the aim of this study was to verify some aspects regarding isokinetic dynamometry and to put forward unconventional possibilities for evaluation of dynamometry data. The results presented in this chapter provide answers to the hypotheses defined in section 1.7.

3.1 Research issue 1

Question 1.1: "Are the parameters detected in the valid isokinetic area equivalent to parameters detected in the whole segment?"

Relating to the problematics of the range of motion (section 1.5.2), there was an interest in evaluating peak torque within the isokinetic area compared to the full motion range. Torque values detected in the isokinetic sector differed ($p < 0.001$) from torque values determined in the whole sector. Peak torque detected in the isokinetic area was used for comparison between professionals and non-athletes.

Question 1.2: "Can the first and the last repetition be excluded from evaluation?"

Assessment of the repetition of the total peak torque from each testing set was done. The purpose was to investigate whether the absolute maximum at the first and last repetition occurs less frequently than during middle repetitions. The results are shown in Fig. 3.1.

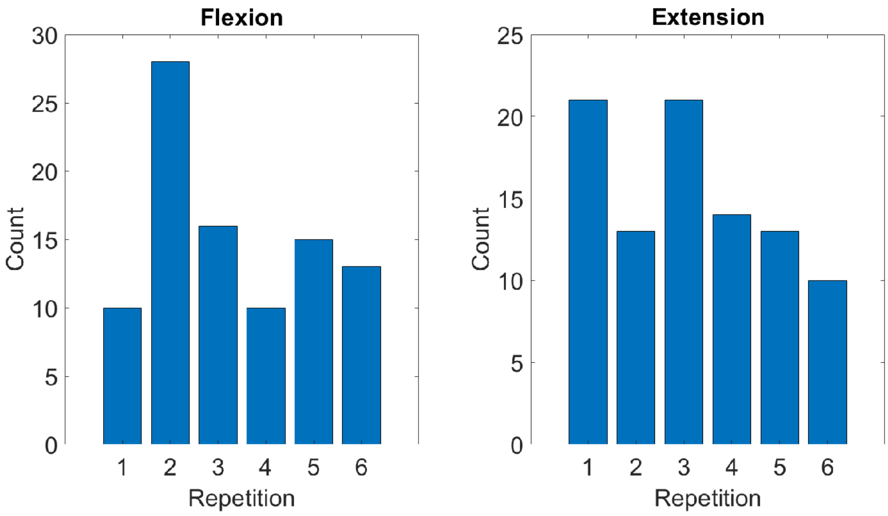


Fig. 3.1: Order of the total peak torque from all repetitions. Subjects performed 4 testing sets (6 repetitions at each set). The repetition's rank of the overall peak torque from each set is shown in the graph above. Left: flexion, right:extension.

By flexion movement, the overall peak torque was mostly observed during the second repetition. The most frequent repetitions for extension movement were the first and the third one. Other repetitions were represented approximately equally.

3.2 Research issue 2

Question 2: "Do the quadriceps and hamstring muscle groups of professional athletes produce higher strength values compared to amateur athletes?"

Torque values were compared between groups of professional and amateur athletes. The female group confirmed that professionals athletes achieved higher torque values. However, the male group showed the opposite as can be seen in Tables 3.1 and 3.2. Unexpected results at the male group induced further analysis of the parameters of 90% peak torque area. The mean torque and produced work from values reaching above the 90% of the maximum were computed and compared between groups of professionals and non-athletes. Results are presented in Table 3.3.

Tab. 3.1: Comparison of average peak torque values expressed in % of body weight between professional and amateur athletes.

Type of movement	Gender		Torque [Nm/kg] Professionals	Torque [Nm/kg] Non-athletes
Flexion	Male	Mean ± Std	111.1 ± 51.0	146.2 ± 40.1
		Min - Max	$6.3 - 248.5$	$67.8 - 245.9$
	Female	Mean ± Std	99.6 ± 90.8	45.3 ± 14.6
		Min - Max	$22.9 - 434.9$	$14.6 - 76.5$
Extension	Male	Mean ± Std	385.5 ± 177.5	555.3 ± 186.7
		Min - Max	$22.8 - 889.4$	$256.5 - 1147.3$
	Female	Mean ± Std	243.6 ± 119.2	195.7 ± 64.1
		Min - Max	$39.4 - 618.2$	$66.7 - 353.0$

It can be seen that significant differences ($p < 0.05$) were observed the same for the original and the normalised values. The only exception was the non-normalised parameter mean90 for the extension at the female group. Parameter work90 for the flexion did not show statistically significant differences between professionals and non-athletes. The results of one-sided tests of mean90 showed that the female athletic group performed higher values for both movements than the non-athletic group. In the male group, both parameters for the extension revealed higher values for amateurs than for professionals.

Tab. 3.2: Results of the Wilcoxon rank sum test. Evaluation of differences of normalized peak torque between professional and non-athlete groups. (** p-value < 0.001).

Type of movement	Gender	z-statistic	p-value
Flexion	Male	-6.766	1.00
	Female	8.778	< 0.001**
Extension	Male	-7.135	1.00
	Female	3.245	< 0.001**

Tab. 3.3: Results of the Wilcoxon rank sum test. Comparison of mean90 and work90 between professional and non-athletes. Values are shown 1) original 2) normalised to body weight. both: two sided test, right: one-sided right-tailed test, left: one-sided left-tailed test. (*p-value < 0.05, ** p-value < 0.001).

Parameter	Type of movement	Gender	z-statistic	p-value both	p-value right	p-value left
work90 [J]	Flexion	Male	-0.15	0.88	0.56	0.44
		Female	0.36	0.72	0.36	0.64
work90 [J]	Extension	Male	-3.70	< 0.001**	1.00	< 0.001**
		Female	-0.1	0.92	0.54	0.46
work90 [J/kg]	Flexion	Male	0.42	0.67	0.34	0.66
		Female	0.54	0.59	0.30	0.71
work90 [J/kg]	Extension	Male	-3.51	< 0.001**	1.00	< 0.001**
		Female	-0.03	0.98	0.51	0.49
mean90 [Nm]	Flexion	Male	-6.4	< 0.001**	1.00	< 0.001**
		Female	8.35	< 0.001**	< 0.001**	1.00
mean90 [Nm]	Extension	Male	-6.88	< 0.001**	1.00	< 0.001**
		Female	1.81	0.07	0.04*	0.97
mean90 [Nm/kg]	Flexion	Male	-6.37	< 0.001**	1.00	< 0.001**
		Female	8.36	< 0.001**	< 0.001**	1.00
mean90 [Nm/kg]	Extension	Male	-6.98	< 0.001**	1.00	< 0.001**
		Female	2.18	0.03*	0.01*	0.99

3.3 Research issue 3

Question 3.1: "How the designed set of parameters such as time, angle or surface mutually correlate?"

All extracted parameters were subjected to the correlation analysis. Spearman correlation coefficient was calculated for each movement and gender separately. Some parameters did not show any significant relations and therefore, were not evaluated and used for interpretation. Examination of relationship directly between the peak torque value and its particular angle did not prove to be notably potent ($r < 0.42$). The most significant relations were observed among time elapsed from reaching the maximum until the end of the movement, angle of the peak and the ratio of work (before maximum/whole work). Specific results are presented in Table 3.4. Visual representation of correlated data can be seen in Fig. 3.2.

Question 3.2: "What is the relation between parameters of flexion and extension movement?"

It can be noticed that correlation of parameters has the opposite trend for flexion and extension movements for both genders. The male group demonstrated a stronger correlation relationship compared to females. The results for flexion showed the reaching of the smaller peak torque angle corresponding to a longer duration of time to the end of the movement. Decrease of the work ratio applied when the angle of peak torque was smaller. On the contrary, extension movement showed a positive correlation between the peak torque angle and the time to the end of the motion. The ratio of work until maximum then raised with the smaller peak torque angle values.

Distribution of the peak torque angles of all individuals data is represented in the histogram shown in Fig. 3.3. Distributions of extension angles (light blue) seem to be similar for both genders having the most observed peaks within 50°- 60°. Looking at the flexion (dark blue) distribution, a peak corresponding to 30°- 37° can be observed at the male group. The female group demonstrates approximately equal distribution throughout the range of motion.

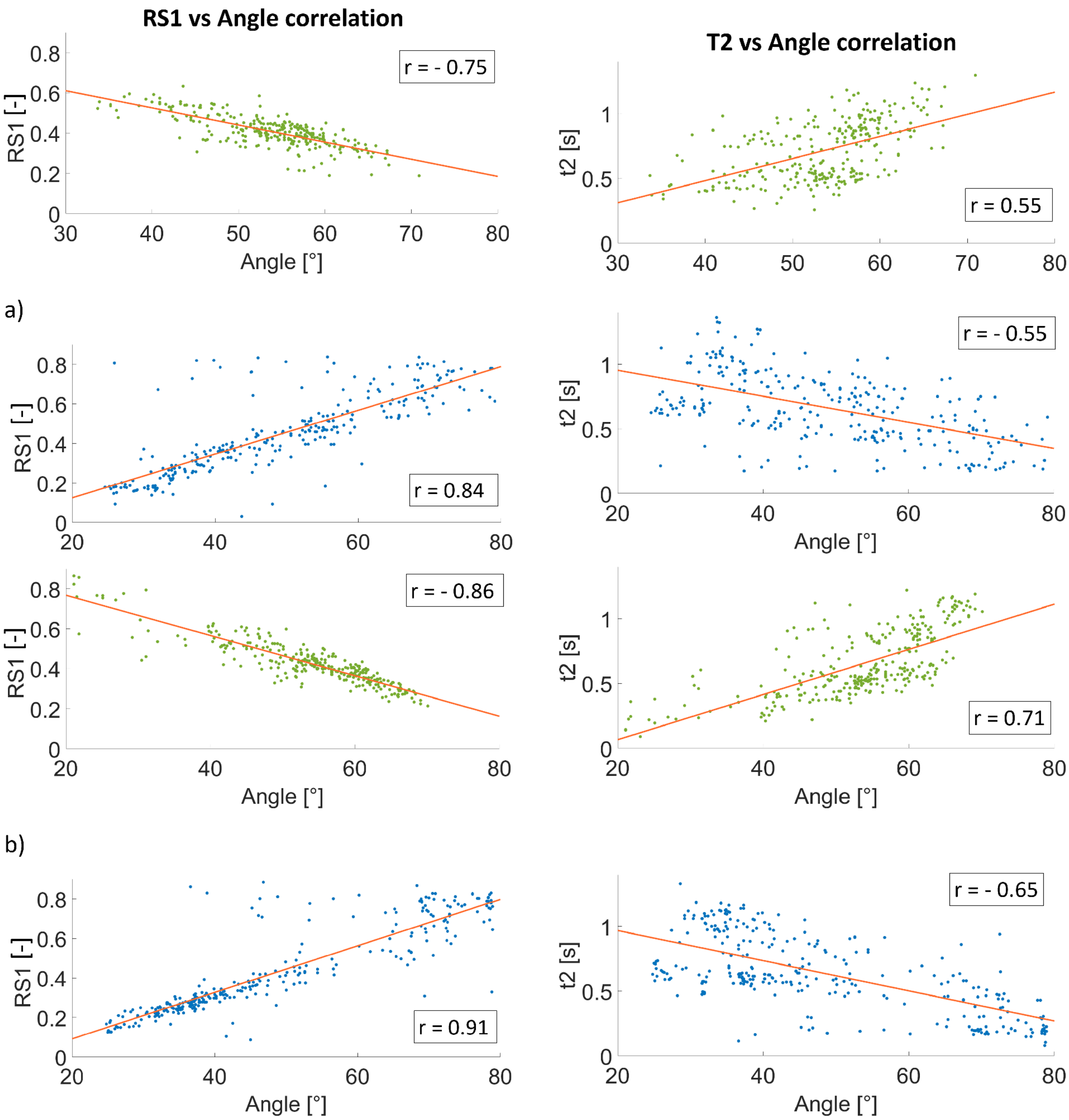


Fig. 3.2: Spearman correlation coefficient between: 1) RS1 and angle - left 2) angle and t2 - right. a) women - top four figures b) men - bottom four figures. Green dots: parameters of the extension movement; Blue dots: parameters of the flexion movement.

Tab. 3.4: Results of the correlation analysis among chosen parameters. r: Spearman correlation coefficient, p: p-value.

Type of movement	Gender	angle-t2	angle-RS1	t2-RS1
Flexion	Male	$r = -0.65$	$r = 0.91$	$r = -0.69$
		$p < 0.001$	$p < 0.001$	$p < 0.001$
	Female	$r = -0.55$	$r = 0.84$	$r = -0.56$
		$p < 0.001$	$p < 0.001$	$p < 0.001$
Extension	Male	$r = 0.71$	$r = -0.86$	$r = -0.64$
		$p < 0.001$	$p < 0.001$	$p < 0.001$
	Female	$r = 0.55$	$r = -0.75$	$r = -0.55$
		$p < 0.001$	$p < 0.001$	$p < 0.001$

Parameters: angle of reaching the peak torque, t2- time period from reaching the peak torque until the end of the movement, RS1- ratio between the work produced from the start of a movement to the peak torque and the work produced in the whole movement.

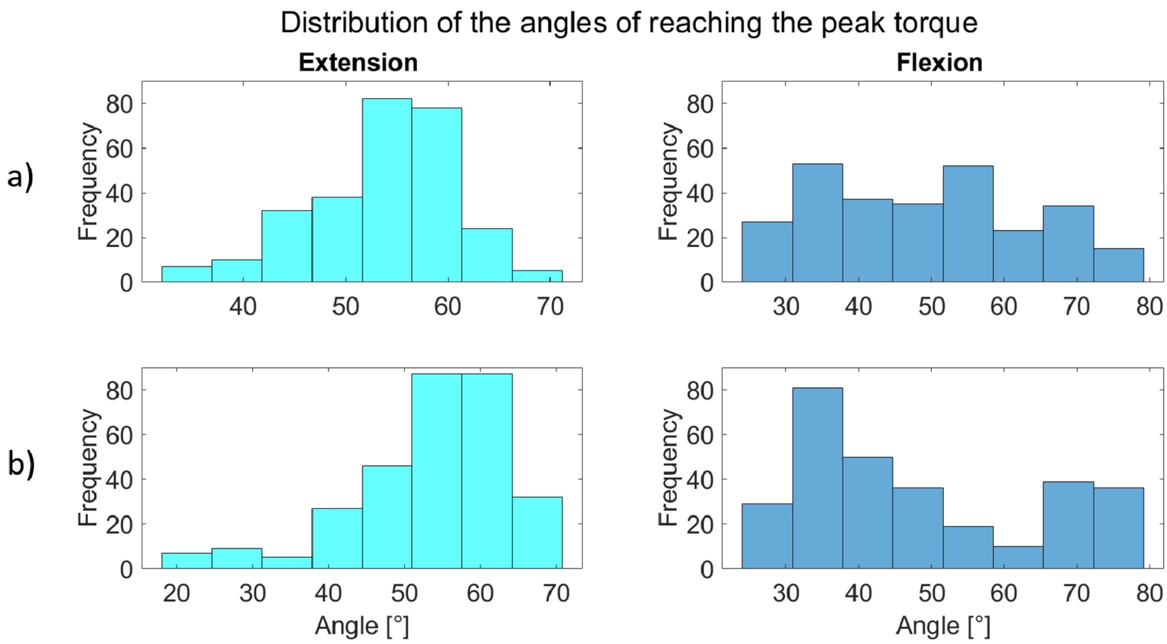


Fig. 3.3: Distribution of the angles at which the peak torque was reached. a) women b) men. Left: angle of the peak torque of the extension movement. Right: angle of the peak torque of the flexion movement.

3.4 Research issue 4

Question 4: "Can surface parameters of the submaximal area be used for muscle strength evaluation?"

Areas covering above 90% and 80% of the maximal reached torque were examined. Specifically, it was the surface of the torque curve top and angle range which the limb moved on. The results are presented in Tables 3.5 and 3.6.

Tab. 3.5: Descriptive statistics of 90% area of the peak torque.

Type of movement	Gender	angle90 [°]	surf90 [J]
Flexion	Male	$med = 36.3$ $Q_{25} - Q_{75} = 29.3 - 44.6$	$med = 2.6$ $Q_{25} - Q_{75} = 1.6 - 4.2$
Flexion	Female	$med = 37.3$ $Q_{25} - Q_{75} = 30.0 - 49.9$	$med = 1.9$ $Q_{25} - Q_{75} = 1.1 - 2.7$
Extension	Male	$med = 25.8$ $Q_{25} - Q_{75} = 22.5 - 28.9$	$med = 3.0$ $Q_{25} - Q_{75} = 2.4 - 5.1$
Extension	Female	$med = 25.4$ $Q_{25} - Q_{75} = 21.5 - 28.4$	$med = 2.0$ $Q_{25} - Q_{75} = 1.5 - 3.1$

Tab. 3.6: Descriptive statistics of 80% area of the peak torque.

Type of movement	Gender	angle80 [°]	surf80 [J]
Flexion	Male	$med = 53.1$ $Q_{25} - Q_{75} = 46.1 - 60.1$	$med = 7.6$ $Q_{25} - Q_{75} = 5.0 - 12.4$
Flexion	Female	$med = 55.8$ $Q_{25} - Q_{75} = 47.8 - 63.5$	$med = 5.5$ $Q_{25} - Q_{75} = 3.6 - 8.0$
Extension	Male	$med = 38.3$ $Q_{25} - Q_{75} = 34.4 - 42.1$	$med = 8.9$ $Q_{25} - Q_{75} = 7.1 - 14.9$
Extension	Female	$med = 37.9$ $Q_{25} - Q_{75} = 34.0 - 41.7$	$med = 6.2$ $Q_{25} - Q_{75} = 4.6 - 9.2$

med: median, Q_{25}: 25% quartile, Q_{75}: 75% quartile, angle90, angle80: angle range of 90%/80% maximal torque, surf90, surf80: work at the 90%/80% maximal torque (only the peak surface).

The extent of angle range was bigger during flexion movements. Differences between men/women and professionals/non-athletes were tested. For flexion movement, male athletes had a longer angle range than non-athletes ($p = 0.019$). The opposite applied for female group ($p < 0.001$). Angle range of extension did not differ in the male group ($p = 0.774$), and in the female group, it was again longer for non-athletes ($p = 0.009$). Comparison between men and women showed for flexion in the non-athletic group longer range for women ($p < 0.001$) and in the athletic group for men ($p = 0.009$). The length of the extension angle range did not differ between men and women ($p = 0.55$) in the athletic group, and in the non-athletic group, it was observed longer for women ($p = 0.021$).

Larger 90% surface could be observed for extension movements compared to the flexion ($p < 0.05$) in all groups. Similar findings were observed for the area of 80% of the maximum.

Another parameter suggested rather for injury investigation was the ratio of 90% and 80% top surfaces. Observed values are shown in Table 3.7.

It can be seen that the female group and the male group achieved almost identical values, thus median around 33-34% for both types of movement. That was verified by the Wilcoxon rank-sum test (see Table 3.8). Men and women were compared within the professional/amateur group for both movements separately. Median of this parameter for flexion movement differed between men and women in the non-athletic group. Other comparisons proved the median to be equivalent for both genders.

Tab. 3.7: Statistical values describing the ratio of work at 90-80% of the peak torque area.

Type of movement	Gender	RS90-80 [%]
Flexion	Male	$med = 33$ $Q_{25} - Q_{75} = 30 - 36$
Flexion	Female	$med = 34$ $Q_{25} - Q_{75} = 31 - 38$
Extension	Male	$med = 34$ $Q_{25} - Q_{75} = 33 - 36$
Extension	Female	$med = 34$ $Q_{25} - Q_{75} = 32 - 35$

Tab. 3.8: Results of the Wilcoxon rank sum test. Comparison of RS80-90 median between men and women. (*p-value < 0.05).

Type of movement	Group	z-statistic	p-value
Flexion	Professionals	0.532	0.595
	Non-athletes	2.511	0.012*
Extension	Professionals	−1.295	0.195
	Non-athletes	−1.285	0.199

The majority of tested subjects have never suffered any knee-joint-related injury. However, when data were visualised, in few cases, fast torque fluctuations around the peak could be noticed. That is demonstrated in Fig. 3.4. It is the example of the extension motion during the second repetition for both limbs (left:injured left leg, right: uninjured right leg). Apart from more than double torque values, we can observe the fluctuations and the flatter shape of the curve missing the distinctive edge slope.

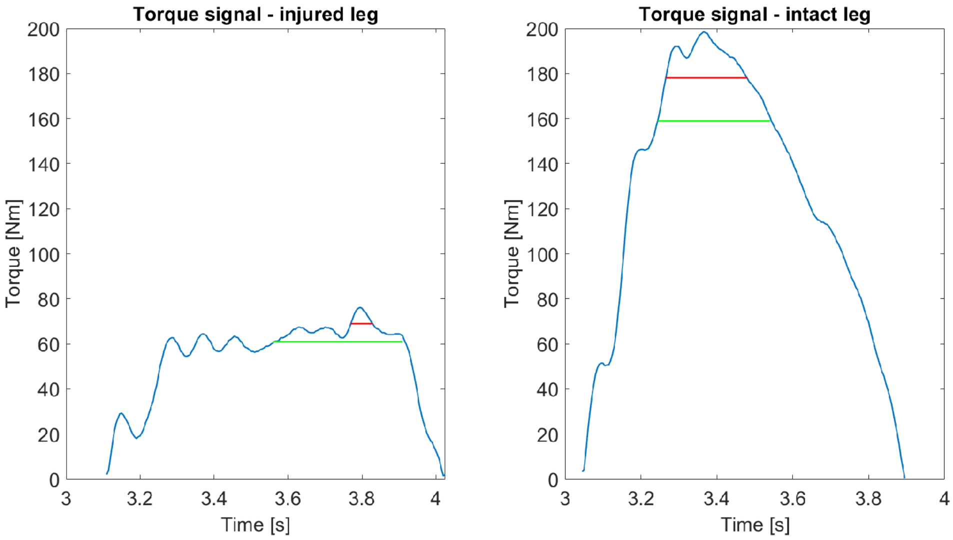


Fig. 3.4: Comparison of the injured limb (left) and the uninjured limb (right). Red line: 90% peak torque surface. Green line: 80% peak torque surface.

Boxplot in Fig. 3.5 shows the RS90-80 ratio values of all groups. The extension movement demonstrates a compact range of values compared to the flexion in which boxes are more extended. The outlying values marked in red doted circles mostly corresponded to values of subjects reporting previous lower limb injuries. Those ratios reached maximally only about 15% for the flexion and 27% for the extension. It can be seen that outlying extension values do not differ a lot from the typically observed values of this study (see Table 3.7).

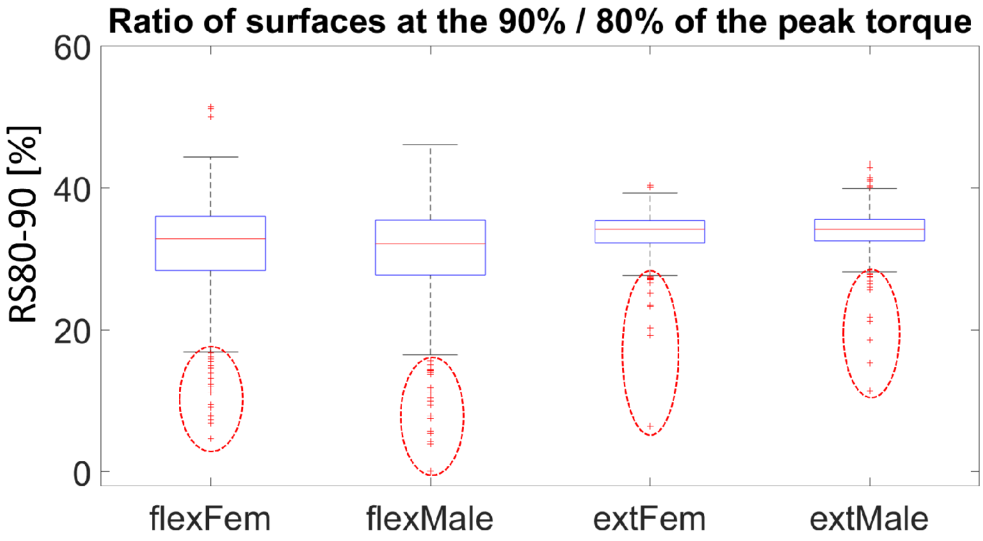


Fig. 3.5: Boxplots of the ratios of work at the 90-80% of the peak torque. From the left: female's flexion, male's flexion, female's extension, male's extension. Red circles: outlying values (smaller ratios) indicating irregularities at the top of the torque curve.

In order to determine the strength of the relationship between the peak torque and the average torque of 90% and 80% area, the Spearman correlation coefficient was computed. The coefficients for all groups were higher than 0.90, proving a strong relationship between these parameters.

4 DISCUSSION

This work was focused on the utilization of isokinetic dynamometer and evaluation of its data. Chosen methods were designed in two ways: 1) according to the current standards to validate their usability 2) aiming to propose innovative parameters which could broaden the current spectrum of methods used for muscle strength evaluation. This chapter presents answers to questions stated in 1.7 regarding the aforementioned aims and the interpretation of obtained results.

Selection of data for processing

The occurrence of torque overshoot in the acceleration or deceleration phase is reported as a limitation of isokinetic dynamometry (10). Some parameters were then extracted from the whole range of motion and compared to the parameters of the same motion observed within reduced range (VIS-valid isokinetic sector). Results of Hypothesis 1 (section 3.1) confirm that the parameters can differ. That supports previous findings of other researchers (7)(30) .

Another question was related to the number of repetitions during testing. Six repetitions of each movement were performed according to currently used testing protocols (see section 1.5.8). In order to see whether subjects were less likely to perform maximal effort at the first or last repetition, the repetition of the total maximal torque of the whole testing set was determined. As can be seen in Fig. 3.1, both of the mentioned repetitions were represented as the maximal. In case of extension movement, the first repetition was even the most observed together with the third one. Therefore, the results indicate to include all six repetitions when determining the maximal strength. Contrarily, if the endurance testing evaluating the effect of fatigue is desired, six repetitions are insufficient since the last repetition could still be the maximal.

Evaluation of the strength between professional and amateur athletes

The comparison of the torque measured in professional and amateur athletes was done using VIS data. Hypothesis 2 (section 3.2) assumed that regular practising led to an increase of the muscle mass and to exerting greater strength. The comparison of averaged peak torque between professionals and non-athletes confirmed this hypothesis only in the female group. Contrary to expectations, the male group of professional athletes achieved lower peak torque values than amateurs. That can be explained by two main factors limiting this study. The first one is a relatively small number of individuals representing each group. The second one is the issue of motivation. During measurement, subjects were encouraged to perform their best. However, that does not assure their actual voluntary ultimate performance. Therefore, highly motivated individuals of non-athletes could strive more and reach higher torque values. Together with the aforementioned low number of participants, it could be the reason for the obtained unexpected results.

Since the method of peak torque determination revealed in the men group unforeseen results, parameters of 90% peak torque area (see Fig. 2.6a) were evaluated. Professionals and non-athletes were tested for parameters work90 and mean90. Specific results are presented in Table 3.3. Parameter work90 showed significant differences only for extension movement at the male group, and so it does not seem to be suitable for comparison relating to the maximal strength. Parameter mean90 showed significant differences for both genders and both movements. The results of comparisons between groups are in agreement with previous findings regarding the peak torque. Considering the issue of motivation to perform maximal effort, parameter mean90 can be a good alternative to evaluate strength. It could be used, for example, to differentiate between athletes belonging to one team to see the effect of training on the individual team members. Another use could be to compare athletes from independent training groups as one of the criteria to get promoted to a higher league or the national team.

Results of correlation

Hypothesis 3 (section 3.3) dealt with correlation analysis and differences in parameters between flexion and extension movement. Time elapsed after reaching the maximum until the end of motion (further called as t2) correlated with the angle of the peak torque and parameter RS1 expressing the ratio of work produced before reaching the maximum to total work per movement. That induced further considerations.

1) **Flexion**

Peak torque angle at the male group was found to be around 30°- 37°, which corresponded to the earlier phase of the motion and might provide information about the capability of faster muscle contractions. Reaching the maximum at smaller angles also corresponded to longer duration of t2. A positive correlation between the peak angle and RS1 indicates a smaller amount of work until the maximum exerted and more work production needed to finish the movement. In the female group, the peak torque was observed at angles throughout the whole range of motion. That emphasises the fact of gender difference and calls up the need to interpret the data separately, as stated in section 1.5.6.

Determination of the peak angle might carry information about different muscle contribution at specific movements. The presumptive peak position was the angle at which the knee joint is exceptionally loaded during training. That could induce the occurrence of higher torque values. Since the subjects for this study were randomly selected, their dedication to particular sport training could not be controlled. That led to creating of study sample where all athletes represented various types of sport. It seemed convenient to relate interpretation of peak angle results to running as it is a fundamental of most of the sport activities.

The review of the knee biomechanics studies by Zhang *et al.*(40) provided peak torque values and its particular angles for walking, running, stair climbing and sit-to-stand move. The results of them reviewed studies present quite various range. The flexion peak angle between 36°- 48° was found for the stance phase while running. Results obtained from our testing mostly support those findings. However, dynamometry testing does not simulate quite the same load on the knee joint and muscles as when running. Besides, as mentioned, most of the participants do not dedicate directly to running. Therefore, the interpretation of the results must be treated with caution.

2) **Extension**

A specific value of the peak angle was achieved at 50°- 60° for both genders. Since the extension motion started at approximately 90°, it took around 30 to 40 degrees to reach the peak, which is more than observed at the flexion (20-30 degrees). That can indicate slower involvement of muscle fibres with corresponding shorter t2. RS1 was about half of the total work. The knee biomechanics review (40) summarised peak angle for extension while running at low angles (10°- 20°). That is in contradiction with our observations and suggests that dynamometry might not be an appropriate method for evaluation of the extension phase of the running cycle and would be better suitable for a different sport.

Above mentioned considerations regarding the peak angle apply to the most frequently observed values. However, the overall peak angle distribution consisted of values throughout almost the whole range of movement. That could be influenced by inconsistency in the examined sports activities. That leads to an idea that every sport task may require an athlete to evoke the maximal strength at a specific angle. Further experimental investigations are needed to establish the specificity of torque-angle-time relation to the particular sport training.

Parameters of the submaximal area

Hypothesis 4 (section 3.4) was focused on evaluation of parameters from 90% and 80% area of the maximal torque. The first reason for analysing this area was the issue of motivation during testing. Concurrently the muscle function impairment was to be examined. These areas are represented in Fig. 2.6 (t_{90} delineate 90% area - red, t_{80} delineate 80% area - green).

Since some individuals might not be able to perform the maximal effort, there was an interest to examine the submaximal area covering broader torque production. One intention was to observe the angle range of the limb movement, in which the subject was able to reach the strength above 90% of the maximum (parameter angle90). That was found to be approximately 30°- 50° for the flexion and 21°- 28° for the extension (Table 3.5). This parameter did not induce clear findings. Surprisingly, female non-athletes showed a longer extent of angle90 than professionals, and non-athletic women showed higher values than non-athletic men. Regarding extension movement, there was no statistically significant difference between professional men and women and between male professionals vs amateurs. The only expected result was observed for flexion movement when male professionals reached longer extent than non-athletes, and professional men reached a longer extent than professional women. Evaluation of parameter surf90 revealed higher values for extension movement. That indicates the production of higher torque in less time (smaller trajectory) compared to the flexion movement. This finding might contribute when examining the balance between knee flexors and extensors, similarily as H-Q ratio (section 1.6).

As far as it is known, no other authors have focused on a similar approach, and it might be useful for other investigators to repeat the procedure with subjects dedicating to the same sport, and clarify these findings.

Injury potential

The ratio between 90% and 80% surfaces (RS90-80) at the top of the torque curve was calculated. The results show that for extension it equaled approximately 32%-36% and for flexion 30%-38% (see Table 3.7). The values were for the male group approximately the same as for the female group.

Ayalon *et al.*(26) presented in their qualitative study the shape of the torque curve of soccer players after the ACL injury. Those resembled the curves of one subject of this study who has suffered ACL and menisci injury and undergone surgery (see Fig. 3.4). Very small ratio RS90-80 was represented at the torque curves of this subject together with the fast fluctuations in the submaximal area. This quantitative evaluation could point out the potential of injury of ligaments, muscles or the joint. On the other hand, it might be useful when assessing the effect of rehabilitation. Additionally, the flatness/skewness parameter could be determined and examined at the torque curves of healthy/injured athletes. There were not enough subjects with the recent injury to perform more complex analysis of the fluctuating curves.

Further experimental investigations focused on the specific injury are needed to verify the use of RS90-80 parameter or its modification. Another approach that could be applied regarding injury examination is based on the frequency content in the power spectrum presented by Tsepis *et al.*(35). Since this study consisted of mostly healthy athletes, appropriate data to confirm this approach were missing, and therefore it was not investigated. Nevertheless, it might worth to combine both methods to study the injury nature.

CONCLUSION

This thesis was focused on the utilisation of the isokinetic dynamometer in the sport field, specifically on the evaluation of muscle strength acting on the knee joint. The main objective was to propose and examine methods that could validate and augment today's conventional methods. The analysis of acquired data has led to the following conclusions. When designing a sport-related experiment, selected participants should dedicate to the same sport activity. Six repetitions are the appropriate number when the maximal strength assessment is desired, and all repetitions should be included for evaluation. When processing data, acceleration and deceleration phases should not be included for interpretation as they can misrepresent the torque curve. Determination of the angle of the peak torque specific for a particular sport can help to design a training targeting on strengthening the muscles of interest. The main contribution of this work is the proposal of alternative parameters which could be useful for physiotherapists or biomechanists when examining the knee-related muscles' function. Other suggested parameter might help to predict potential injury or to assess rehabilitation effect. Finally, the proposed parameters could be beneficial for comparison between athletes reducing the influence of an individual's motivation.

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LIST OF SYMBOLS, PHYSICAL CONSTANTS AND ABBREVIATIONS

ACL	Anterior cruciate ligament
b	Allometric parameter
fROM	Full range of motion
F	Force
g	Gravitational acceleration
H-Q	Hamstring to quadriceps ratio
m	Mass
M	Moment, torque
MET	Metabolic equivalent of task
P	Power
r	Distance
ROM	Range of motion
S_n	Normalised torque index
VIS	Valid isokinetic sector
W	Work

LIST OF APPENDICES

A QUESTIONNAIRE

A.1 English version

General information

Name:

Gender: Body mass [kg]:

Age: BMI:

Dominant lower extremity*: Height [m]:

Sport

Which sports activities do you regularly do?

1. Type of sport:
   Level of sport: [recreational/professional]
   Average number of training units [hours per week]**:
2. Type of sport:
   Level of sport: [recreational/professional]
   Average number of training units [hours per week]**:

Average number of training units of all activities [hours per week]**:

Injuries

Have you ever had any injury? [Yes/No]
If yes, please provide specific information about all injuries you ever suffered.

1. Year (month):

   Injury site:

   Type of injury (e.g. fracture, dislocation, sprain, tear):

   Did the injury happened during sports activity? [Yes/No]
   If yes, please describe in detail the sports activity and how the injury happened:

2. Year (month):

   Injury site:

   Type of injury (e.g. fracture, dislocation, sprain, tear):

   Did the injury happened during sports activity? [Yes/No]
   If yes, please describe in detail the sports activity and how the injury happened:

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* Subjective opinion
**In last 3 months

A.2 Czech version

Obecné informace

Jméno:

Pohlaví:

Věk:

Dominantní dolní končetina*:

Tělesná hmotnost [kg]:

BMI:

Výška [m]:

Sport

Jakým sportovním aktivitám se věnujete?

1. Druh sportu:
   Úroveň sportu: [rekreační/výkonnostní]
   Průměrný počet tréninkových jednotek v příslušném sportu [počet hodin za týden]**:
2. Druh sportu:
   Úroveň sportu: [rekreační/výkonnostní]
   Průměrný počet tréninkových jednotek v příslušném sportu [počet hodin za týden]**:

Průměrný počet tréninkových jednotek všech aktivit [počet hodin za týden]**:

Zranění

Měl(a) jste někdy nějaké zranění? [Ano/Ne]
Pokud ano, uveďte prosím konkrétní informace o všech zraněních, které jste kdy utrpěl(a).

1. Rok (měsíc):

   Místo zranění:

   Druh zranění (např. zlomenina, vykloubení, vymknutí):

   Došlo ke zranění během sportovní aktivity? [Ano/Ne]
   Pokud ano, popište prosím podrobně sportovní aktivitu a způsob, jakým k úrazu došlo:

2. Rok (měsíc):

   Místo zranění:

   Druh zranění (např. zlomenina, vykloubení, vymknutí):

   Došlo ke zranění během sportovní aktivity? [Ano/Ne]
   Pokud ano, popište prosím podrobně sportovní aktivitu a způsob, jakým k úrazu došlo:

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* Subjektivní pocit
**V posledních 3 měsících