Biomechanical analysis of groin related strength training exercises for injury prevention

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Abstract

Purpose: Groin injuries in soccer are a widespread problem in sports medicine. One certain strength exercise, the Copenhagen adductor exercise, has shown an injury preventing effect. But there are still many groin injuries, and even better preventive measures are needed. The aim of this study was to investigate the load on groin structures during the performance of the Copenhagen adductor and three other exercises designed with a hypothesis of having a greater load. All are one-foot dynamic plank exercises. The Copenhagen adductor exercise is conducted by hip adduction, while the others have hip adduction, hip flexion, and a combination of both to resemble a soccer pass. More specific, muscle activation of the adductor longus muscle and the rectus femoris muscle were examined as well as torque exerted on the hip joint.

Methods: 18 footballers (10 men and 8 women) at varying playing levels in the Oslo region performed the four plank exercises, while electromyography activity, motion capture and forces were recorded. Muscle activations were found from the electromyography data and normalized to a player's maximum activation for the given muscle. By motion capture, the position of hip joints and force direction were determined. Together with measured forces, this was used to calculate torque and further normalized to the player's weight. Both average of mean values and peak values were calculated and used for comparison analysis.

Results: With a p-value set to 0.05, all exercises with hip adduction achieved significantly higher muscular activation of adductor longus than the exercise without. Exercise including only flexion of the leg showed significantly higher activation of rectus femoris than exercises including only adduction and both adduction and flexion. The muscle activation seemed to be higher during concentric muscle work rather than eccentric muscle work. None significantly differences were found in torque between the exercises, but it showed that torque was greatest early in the concentric phase for all exercises.

Conclusion: Four exercises were investigated, and a trend was shown of greater total load on one exercise intending to resemble a soccer pass compared to the Copenhagen adductor exercise. It should be investigated further whether this more sport-specific exercise has greater preventive potential. To ensure high activation on both adductor longus and rectus femoris, one single exercise does not seem to be sufficient, a combination of several exercises should be performed.

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1. Introduction

In Norway, soccer is by far the biggest sport – for both genders. There were almost 360,000 members in the Norwegian Football Federation in 2019, which corresponded to 21% of all active Norwegians [1]. It is also the most popular team sport in the world [2]. According to a FIFA Big Count survey from 2006, 265 million people worldwide were involved in playing soccer. Together with referees and other officials, the total number of people directly involved in soccer was 270 million, accounting for 4% of the world's population. Among registered footballers, the number had increased by 54% for women and 21% for men, since FIFA's previous report in 2000. This is a significant increase for women, yet there were over eight times as many men [3].

High intensity, sudden changes of directions, many short sprints, accelerations, and decelerations are typical in soccer play [4-7]. These characteristics places a high demand on muscles in the hip area [7]. In general, the injury rate in soccer is high [8-16]. Lower extremities are particularly prone to injuries, among them are injuries in the groin [10, 17-20]. The groin is the junction where the upper part of the thigh meets the lowest part of the abdomen [10]. The high injury rate applies to both genders and at all levels, although studies on injury epidemiology in women's soccer is far behind studies investigating the problem for men. In addition to its prevalence, the groin injury problem also includes risk of chronicity [20] and recurrence [7, 19-24]. It is also problematic that the injuries are difficult to both diagnose and treat [19]. Adductor longus has been reported as the muscle most often affected by groin injuries [25]. Injuries are also common in the rectus femoris muscle [25, 26], in addition to iliopsoas-related [25-27] and abdominal-related injuries [26, 27].

Apart from the risk of injury, playing soccer can contribute to several positive health effects [7, 8, 26, 28-30]. Public health is therefore one reason to put an effort into reducing injuries. With many active footballers and a high rate of groin injuries, successful injury prevention work will be beneficial for many people. Absence from participation over time will also affect the opportunity to develop as an athlete. From a team or club point of view, it becomes difficult for a coach to assemble a team for match play, which further gives the team poorer conditions for sporting success. Since one of the biggest risk factors for groin injuries is a previous injury to the groin, reducing the number of index injuries with prevention work could potentially help to avoid many injuries.

Injury prevention work based on strength training in soccer has shown effectiveness for several types of injuries [2, 31, 32], including groin injuries [33]. A common exercise used to prevent groin injuries today is the Copenhagen adductor exercise [34], which is a one-foot dynamic side-lying plank exercise [24]. This exercise has shown to have high adductor longus activation [24], large increase in eccentric hip adduction strength [35], and a significant increase in adductor longus muscle thickness [36]. A prevention study have shown a 41% lower risk of reporting groin problems, defined as any physical complaints in the groin area, by conducting this exercise [33]. These are positive results, but a similar study [37] using a strengthening programme with the Nordic hamstring exercise to prevent acute hamstring injuries showed an even better result. The injury rate per 100 players over a season was 13.1 in a control group (n = 481) and 3.8 in an intervention group (n = 461), meaning the number of injuries in a group of 100 footballers was reduced to less than a third for them performing the Nordic hamstring exercise. A review of the effects of including the Nordic hamstring exercise as part of different injury prevention interventions, presented a reduction in hamstrings injuries by over 50% [38]. This shows great preventive potential for a single exercise that matches injury mechanisms and has high muscle activation [24].

1.1 Project objectives

The Copenhagen adductor exercise has proven to be very effective in reducing groin problems in soccer, but there may be other exercises that are even more effective. The aim of this thesis is to conduct a biomechanical analysis of the Copenhagen adductor exercise, in addition to three other one-foot dynamic plank strength exercises. The exercises are performed by lying sideways, straight, and obliquely to examine motion in multiple planes. The original Copenhagen adductor exercise is probably not heavy enough to ensure a greater reduction of groin injuries. The other exercises are therefor designed with a hypothesis that they are heavier. One of the exercises is also designed to be sports specific as the movement intends to resemble a soccer pass. The analysis will include measurements of hip joint torque and muscle activation of the adductor longus and the rectus femoris muscle. Further, the project will investigate how the variables differ between exercises and through the exercises. And lastly, the result will be used to determine whether or which of the exercises are appropriate to use in groin injury prevention work.

2. Theory

2.1 Biomechanics

Biomechanics is the study of the mechanical principles that act on biological systems and is based on Isaac Newton's laws of motion [39]. Knowledge in physics, anatomy and physiology is used to describe movements of the body and calculate forces present during static positions and dynamic movements [40]. Forces create motion. By signal from the nervous system, muscles can create forces, as the muscles are attached to bones via tendons [41]. Most movements of the human body are rotations about joints, which means that torque is a common term within biomechanics. Torque is the ability of a force to chance a rotation about an axis. Decisive for whether movements are created or changed is the ratio between internal and external moment. If net moment of a joint is zero, the angular velocity is constant. To change or initiate a rotational movement, it must be a mismatch between torque created inside and outside of the body. Muscle forces usually contribute to internal torque [40], although internal forces also come in tendons, ligament, and connective tissue [41]. The internal lever arm is determined by the distance between the joint and muscle attachment. Gravitation forces are the origin of external forces. This can be your own body weight, for example when walking, but also the weight of a dumbbell lifted during strength training [42].

Biomechanical measurements methods can be divided into four main areas, these are anthropometry, kinematics, kinetics and kinesiological EMG. In other words, the methods measure the body, movements, forces, and muscle activation [43]. A biomechanical analysis can use one of the methods, two, three or of a combination of all. For the purpose of this project, all methods were used, and the next sections describes some of the important principals for this study.

Measurements of human motion can be done in many ways by several working principle, such as optoelectronic measurement systems, electromagnetic systems, image processing systems, ultrasonic localization systems and intertial sensory systems. Optoelectronic measurement systems have shown to be the most accurate of these and is often regarded as “gold standard” for motion capture. These systems estimate positions of small markers, attached to a human or object of interest, in three dimensions by a time-of-flight triangulation. Several cameras in fixed positions captures light, which means the system are both sensitive to sunlight and is limited to measuring within a specific area. Another limitation of this system is the need of line-of-sight, the markers must be visible at all times to get sufficiently good measurements. Even with an overall high accuracy, there are several things that can affect this, such as the distance between and the location of cameras relative to each other and the number, type, position, and motion of the markers. The optoelectronic system can further be divided into two groups based on which markers are used. This is passive and active markers. The passive markers reflect light back to the cameras, while active markers contain light sources and emit light. Cables and batteries are required for the active markers and lead to restrictions regarding movements but are still the most robust [44]. LED lights is common to use for passive reflective markers, but the radiation is not considered dangerous [45].

Measurements of outer forces can vary widely based on what is to be investigated. For example, if the force comes from an object being lifted, only the weight of the object needs to be measured. There are many other instruments that can measure forces, one of them is the load cell. A load cell is a kind of transducer which converts forces into a measurable electrical output. Different kinds of load cells exist, distinguished by their type of output signal and the way they detect forces. Some are hydraulic, pneumatic, strain-gauge, piezoresistive, inductive and magneto strictive load cell [46]. Not all these kinds of load cells are suitable for biomechanical analysis, but one that is, is the tension load cell. This measure force when pulling in the cell, as the load cell and strain gauges bonded to the load cell, slightly deforms. The electrical resistance is alternated and generates a voltage signal proportional to the applied force [47].

EMG, or electromyography, is a common use in biomechanical analysis and to our knowledge the only method used in studies on specific groin related strength exercises.

EMG is an experimental technique used to record and analyse electrical signals emanated from skeletal muscles [43, 48, 49]. Muscles are important for the internal forces created during movements, but EMG is not a measure of force, of muscle strength or of effort given. Just electrical activity [50]. An EMG signal can tell when a muscle is active or not [43]. The force a muscle can exert depends on several things, such as how stretched it is, and the extent of overlap between the proteins aktin and myosin in the muscle cells [42]. Studies and research using EMG are widespread, with applications such as medical research, ergonomics, rehabilitation and sports science. The latter includes biomechanics, movement analysis, athletes strength training and sports rehabilitation [43]. Mainly there are two types of EMG being used, these are intramuscular EMG and surface EMG. By the intracellular method, needles are inserted into muscle tissue. Only a few muscle fibres are observed at a time, and measurements must therefore be made with the needle in multiple positions to get enough information. This is a quite invasive method, and when a more general picture of muscle activity is sufficient, the surface EMG is often preferred [49]. The surface EMG technique attach electrodes to a person's skin without penetrating it (hence surface), which as opposed to the needles are non-invasive. Furthermore, the method is safe and easy to handle [50, 51]. The method is commonly used in biomechanics. The main limitation is though the fact that only superficial muscles can be recorded [43]. Intramuscular EMG can measure internal muscles, but for biomechanical analysis during movement this is very impractical and impossible without affecting the course of movement. Correct palpation of the muscles and proper interpretation of the data are crucial to extract the information of what is intended to be investigated [50]. Silver/silver chloride pre-gelled electrodes are the most common to use, and the recommended one. These are disposable, which greatly reduces necessary hygiene measures [43]. The desired size of the surface electrodes depends on the properties of the muscles being examined. The largest are used for the large muscles and often has a diameter (conductive area) of 1 cm. When a greater selectivity is necessary, for example for small facial muscles, smaller electrodes are selected because these allow a closer interelectrode distance. The size can be of 0.5 cm with an interelectrode spacing of 1 cm [50]. There are limited recommendations for electrode placement and studies investigated the same muscle may have different locations, making it difficult to compare. To establish guidelines for standard electrode placement is challenging as important measures can be at the expense of each other. It requires a balancing of several factors to get the best reading possible. Fridlund and Cacioppo [51] have highlighted some elements to consider: minimize intermediate tissue between muscle and electrodes, paired electrodes should be placed parallel to the muscle fibres to maximize selectivity, avoid the region of the muscle's endplate, use easily identifiable anatomical landmarks to secure consistency of sites within and across subjects, choose electrode sites without problems from skin folds, and minimize crosstalk as much as possible. It is recommended to prepare the skin before electrode positioning. Hair removal and cleansing with abrasive and conductive cleaning plates, very find sandpaper or alcohol is common procedure. The skin usually gets a light red colour when the preparations are done properly [43, 50]. Figure 2-1 is an example of a raw (unprocessed) EMG signal, where surface electrodes measured activation of the rectus femoris muscle. The image first shows a rest period (the muscle is relaxed), followed by an active burst from an isometric contraction and finally another rest period. The signal from the rest periods are so-called baselines and are almost noise-free but are influenced by noise from the environment and quality of the detection conditions. Mean value of the EMG signal is zero and the pikes from the signal burst are of random shape. There is a constant variation in which motor units are recruited through the muscle and the strongest pikes is a result of the simultaneously firing of several motor units close to the electrodes. This, in addition to the fact that connective tissue and skin layers acts as a low-pass filter, means that the signal being measured is not the same as the original nor can it be reproduced. Typical processing of EMG signal includes rectifying and a smoothing algorithm [43]. The signal is measured in microvolt, but it is normal to normalize the captured values to a reference value to eliminate influence of given detection condition. The amplitude of signal varies a lot between electrode sites, muscle mass and subjects. The reference value is typically found by a maximum voluntary contraction, which is contractions of full effort. The motivation for this is to rescale data and present it as percentage of the reference value [43]. By normalization one can compare data across muscle groups [50]. Most common the reference value is found by a *isometric* contraction test, called a maximum voluntary isometric contraction (MVIC) [52]. That is to push all you can against a fixed object, without there being any movement in the joint. Different studies may use different tests to normalize their results, and one must therefore be careful in making direct comparison.

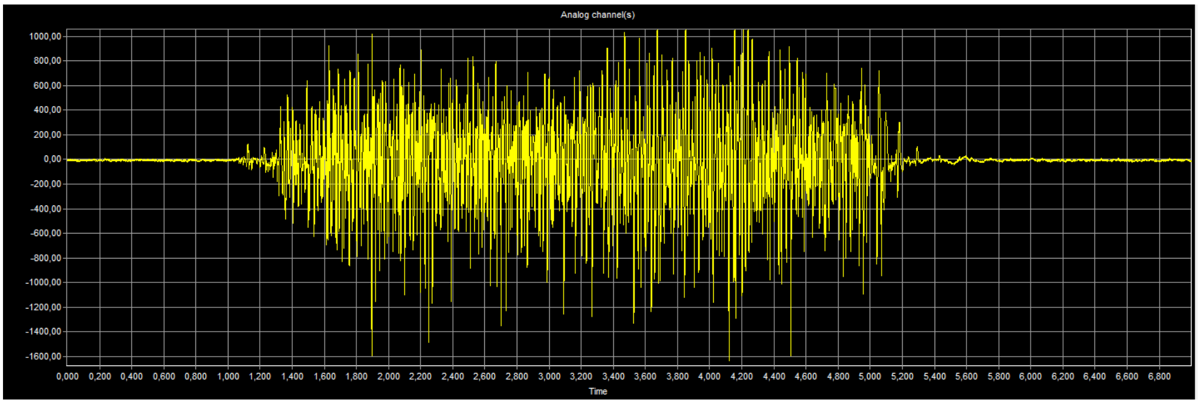

Figure 2-1: Raw EMG signal as an example for a contraction in the rectus femoris muscle. In the first and last part of the figure, the muscle is relaxed, and a baseline is shown. The middle section shows a signal burst because of contraction in the muscle.

2.2 Health Perspective on Physical Activity and Soccer

Physical activity can be defined as body movements produced by skeletal muscles, leading to increased energy consumption significantly exceeding the level at rest [17]. It is one of the most important measures to stay healthy [26]. In addition to the absence of disease and weaknesses, the World Health Organization's definition of health also includes a state of physical, mental and social well-being [53]. Based on this definition, Clarsen et. al [54] have derived a definition where any condition of reduced state of full health is considered a health problem for athletes. This may include injury, illness, mental illness, pain and other, regardless of its consequences for participation and performance in sports.

Physical activity reduces the risk of cardiovascular diseases, high blood pressure, type 2 diabetes, and some types of cancer. Ultimately, it reduces the risk of premature death.

On the other hand, lack of physical activity is an important risk factor for serious illness. Physical inactivity can be just as dangerous as smoking, obesity, high cholesterol and high blood pressure when it comes to disease development [26]. Physical activity can also delay the development of osteoporosis [28]. Soccer has been shown to have several positive effects, such as improvement of cardiovascular health, metabolic fitness, muscular performance, postural balance, as well as reduction of adiposity. Soccer is, together with running, recognized as one of the best activities to improve health [29]. However, one does not have to be an elite athlete to achieve health effects. Many of the health effects can be achieved through moderate physical activity [26]. Based on all the health effects associated with physical activity, it is beneficial to be active throughout life. Being active as a child gives a greater likelihood of remaining active as an adult, although many also quit in adolescence [55]. As many as 9 out of 10 children in Norway have taken part in organized sports [56]. 12% of young boys and girls named in a study injury and illness as the reason for dropping out. The proportion was twice as large for girls than for boys[57].

Playing soccer has also been shown to have psychological benefits [30]. Nevertheless, it is no clear evidence that soccer improves mental health. A study by Heun and Pringle [58] on mental health in active and retired professional footballers and referees showed similar or more psychological problems than in the general population, including anxiety and depression. One of the reasons for this may be severe injuries. Players with high competitive anxiety may also have a greater chance of sustaining an injury [59]. Although it has not been proven that soccer improves mental health in the mentioned study, Heun and Pringle [58] state that it does not mean that no individuals get mental benefits from the sport.

Being physically active also has its side effects, especially related to the risk of injury. Injuries occur in all sports, but the nature of the sports is decisive for which injuries are typical [17, 26]. The injuries can be overuse injuries or acute injuries and can lead to permanent injuries or death, but fortunately, deaths rarely occur in sports. The injuries have different severity, but there is an increase in injuries that pose a risk of early osteoarthritis [26]. An injury can be very challenging for the player and their club, it can even be a problem for det society because of its popularity [2]. As much as 17% of all injuries treated at the emergency room in Norway are caused by participation in sports and is, therefore, a significant problem from a socio-economic perspective as well. However, traffic accidents and serious occupational accidents are responsible for the heaviest burden on society [26]. According to Bahr and Mæhlum [26], the health benefits of physical activity exceeds the health risks associated with injuries. Former Finnish elite athletes in endurance and team sports have been shown to have a lower incidence of cancer, lung disease and cardiovascular disease, and increased life expectancy. Former elite athletes are also less likely to be hospitalized, but the increased risk of osteoarthritis of the knees and hips makes them more likely to be hospitalized due to musculoskeletal injuries than others. However, it is important to emphasize injury prevention work when it comes to sports and physical activity, although net health gain is positive [26].

2.3 Injury Definitions

Many definitions of injuries have been used in epidemiological studies, which makes it difficult to compare data across studies and further determine the severity and risk of developing injury problems. For this reason, the IOC convened an expert panel in 2019 to develop recommendations in sports epidemiology. The group defined a sports injury as follows:

> *"Injury is tissue damage or other derangement of normal physical function due to participation in sports, resulting from rapid or repetitive transfer of kinetic energy". [53].*

A similar consensus report [60] was published in 2006, but this time an expert group was gathered under the auspices of FIFA Medical Assessment and Research Centre with a focus on soccer injuries. This research team agreed on three alternative definitions of injury in soccer, suggesting there is no one-size-fits-all definition. They came to the following conclusion of an injury:

> *"Any physical complaints sustained by a player that results from a football match or football training, irrespective of the need for medical attention or time loss from football activities. An injury that results in a player receiving medical attention is referred to as 'medical attention' injury, and an injury that results in a player being unable to take a full part in future football training or match play as a 'time loss' injury" [60].*

One injury can be in need of "medical attention" *and* lead to "time loss", belong to one or none of the terms, but anyway be part of "any physical complaints" [61]. A goal of the consensus statement was to enable interstudy comparison. Establishing definitions is an important step, but there may still be differences in reported injuries. This is affected by the player's threshold of pain, access to and normal practice of medical support, whether the player is selected to play the next match and whether there is a game/training session in the following days at all [60].

Although the wording is different, both the above definitions intends to be inclusive and cover a wide range of injury-related problems in soccer [60] and sports [53]. The definition developed through IOC covers more. The pain threshold allows tissue to be damaged for a period before pain is felt [17]. A player can thus be injured before the person is aware of it. In most cases the chances of it being registered are small, so in practice, the two definitions will probably capture about the same number of injuries – those of "any complaints". To get an overview of the total burden, this broad definition may be appropriate. The downside of this approach is lack of reliability. One person responsible for registering injuries can interpret a complaint only as a response to hard training and thus not register it, while others take note of it. In addition, it has been common in surveillance studies for medical staff to register injuries, but it is not certain that they are made aware of injuries that do not require medical attention [61]. The definition most used in studies is the time loss approach, and this is much narrower. This is a relative reliable method, as it is easy to identify when athletes are absent from their sport [61]. The most severe injuries are likely to be captured, but many physical problems are overlooked, this especially applies to overuse injuries. It is well documented that athletes participate as usual in sports despite the presence of overuse problems, pain and reduced performance [10, 17, 18, 20, 61, 62]. This is particularly common in the early stages of an overuse injury, probably partly due to misinterpretation of gradually onset of pain and functional limitations, as it may be transient. Athletes may continue to participate as usual, but when the problems get worse, some will participate with limitations, such as avoiding certain exercises and partially train alternatively. This is not necessarily registered as an injury. If possible, some will postpone the "time-loss" to the off-season and use this period to rest and recover from an injury. If, on the other hand, the overuse injury worsens significantly, it may nevertheless become necessary to seek medical attention [62]. Athletes can also return to sport before the injury is completely healed, although performance is reduced [53].

Injuries have traditionally been divided into acute (or traumatic) and overuse injuries [17, 26], although many surveillance studies cover the latter to a small extent. Injury mechanism and time of onset determine which it is. When symptoms and loss of function occur suddenly from a specific and definable event, it is an acute injury. An overuse injury develops over time. The symptoms gradually worsen, and no single event can be identified as the cause. Athletes sustain injuries when there is a mismatch between the load on the tissue and its tolerability. In the case of an acute injury, a single load will exceed the maximum strength of the tissue. Repetitive microtraumas over time that together form a load beyond tissue tolerance are the mechanism of an overuse injury. The risk increases with increased training load (duration of sessions, intensity and/or training frequency) [17, 26]. The definition of injury to the IOC's expert group [53] covers both injury definitions, where “rapid” and “repetitive” transfer of kinetic energy refers to acute and overuse injuries, respectively. It is often easy to define which of the two an injury belongs to, but not always. Sometimes the symptoms occur acutely, but the injury is a result of overload over time [26, 53]. When an acute injury occurs, the athlete is usually forced to immediately stop ongoing activity. Common symptoms are pain, swelling, redness, increased temperature at site of injury and loss of function. The first symptoms of an overuse injury can be pain, tenderness, and swelling. Since the injury develops over time, weeks and months can pass by before functional capacity is significantly impaired. In the beginning, pain can be provoked only by specific kinds of stress and disappear after warm-up [17].

There are also differences in the severity assessment of injuries. Fuller et. al [60] defined the severity of injuries in soccer as the number of days between onset and fully return to training and match selection. The purpose of a study should determine how severity is measured, by considering the strengths and limitations of each method. Use of time loss from normal training and competition as a measure of severity is very common in sports medicine and is also relatively simple [53]. With this approach, Bahr et. al [53] recommends to start counting the day after injury onset. This is day 1. 0 days should be noted if athletes don't complete a session but is able to participate as usual the next day. Furthermore, they recommend to categories injury based on number of days in following way: 0, 1-7, 8-28 or >28 days. Disadvantages with this method include underestimation or overestimation when athletes return to play before the injury is healed or after the injury is clinically resolved. The method also leads to an underestimation of injuries reducing performance without effected participation, nor is it appropriate for the most serious injuries leading to retirement, permanent disability, or death. Other possible approaches are athlete-reported symptoms and consequences which can be conducted with questionnaires, recordings based on clinical assessment, or based on functional measures and sports-related performance measures [53].

2.3.1 Groin Injury Definition

As with sports injuries in general, groin injuries have also been defined and diagnosed very differently. In the literature, groin injuries have often been defined as a single injury. Hölmich et. al [27] have used a definition that corresponded to the consensus rapport from FIFA's initiative [60]. However, this does not consider the many structures that can be injured. The groin region has a complex anatomy, leading to many possible injuries and many causes of pain. Ultimately this makes diagnosis difficult [17, 27, 63, 64]. To add to the problem, injuries elsewhere can cause pain reminiscent of groin injuries [17], there is a high prevalence of “abnormal findings” and variations in the use and interpretation of terminology among clinicals [63]. An example of this problem’s complexity is found in a systematic review by Serner et. al [64]. They investigated the treatment of groin injuries through 72 articles, which in total had 33 different diagnosis of groin pain. It is normal for the injuries to include an inflammatory condition in muscle tissue and muscle tendon junction [17].

To simplify groin injuries in clinical practice and research, a group of experts gathered in Doha in 2014 to agree on definitions and terminologies based on history and physical examinations. The result was a classification system for groin pain in athletes with the following three main categories: 1) defined clinical entities for groin pain (including adductor-, iliopsoas-, inguinal-, and pubic-related groin pain), 2) hip-related groin pain (pain from the hip joint), and 3) other causes of groin pain. Multiple diagnoses can be given when athletes experience pain in more than one entity. Moreover, several popular terms were not included in the recommendations for various reasons [63]. This agreement acknowledges that pain from the hip joint can be a possible cause of groin pain. As part of the complex problem, groin injuries are sometimes referred to as *hip and groin injuries* and other times just as *groin injuries*. Further in this thesis, the term groin injury is consistently used.

2.4 Groin Anatomy and Function

Although the groin is not unambiguously defined, it usually refers to the junction between the abdomen and the anteromedial (in front and toward the middle) part of the thigh [10]. That is the area where the upper part of the thigh meets the lowest part of the abdomen. A wall of muscles and tissue separates the groin and abdomen, but the wall has small openings, called the inguinal and femoral canals, which allow structures like blood vessels and nerves to pass [65]. Three large groups of muscles make up the groin. This is the abdominal, iliopsoas and adductor muscle group [66]. All groups can be injured, but most groin injuries in soccer are adductor-related, followed by iliopsoas-related and abdominal-related injuries [27]. The next sections focus on some of the important structures that make up the complex anatomy of the groin region.

2.4.1 The Pelvis

The pelvis (Figure 2-2) consists of two hipbones which are connected behind by the sacrum and in front by the pubic symphysis. Each hipbone consists of three bones that grow together in early adulthood: the ilium, the ischium and the pubis. The ilium is blade-shaped, located above and to either side and accounts for the width of the hips. The ischium is behind and below and this is where the weight falls while sitting. In front is the pubis. The bones are united in the acetabulum, which forms the hip joint with the head of the thighbone called the femur. The pelvis thus connects the trunk with the legs. The intestines, urinary bladder and internal sex organs are all supported by the pelvis. The pelvis is responsible for the support and balance of the trunk. Muscles that contribute to this, as well as movements of the legs, the hips and the trunk, are attached to the pelvis [67].

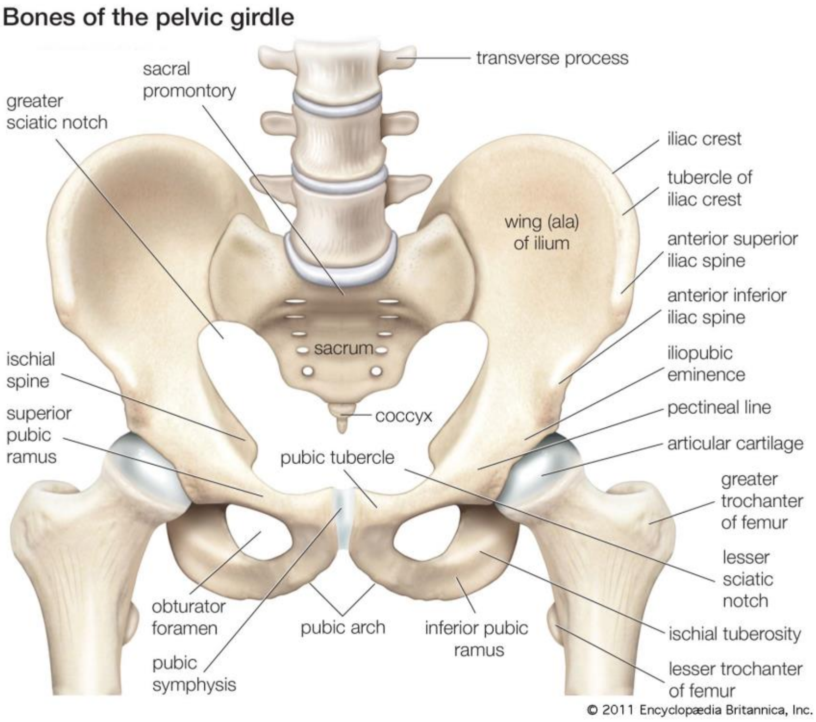

Figure 2-2: Bones that make up the pelvis. Retrieved from [67].

2.4.2 The Hip Joints

The hip joints, and the shoulder joints, are ball and socket joints which allow movement in three planes and make them triaxial and multiaxial [68]. The joints also belong to the group of synovial joints, which are the mobile joints of the body and account for most joints [68]. The hip joints are located on the right and left side of the human body and connect the thigh bones to the hip bones (Figure 2-3), allowing movement between them. There are three sets of opposite possible movements in the hip joints (six degrees of freedom), these are flexion and extension, abduction and adduction and internal and external rotation. Orientation planes and axis used to describe human movements are shown in Figure 2-4. Flexion (or bending) in the hip joint is to bring the thigh forward, and extension is to bring the thigh backwards. This happens in the sagittal plane around a frontal axis. The foot is moved outwards (away from the body) during abduction and inward (towards the body) during adduction, this movement is in the frontal plane around a sagittal axis. Rotation means that the leg is rotated about an imaginary line (a longitudinal axis) from the hip to the knee. This takes place in the transversal plane. When the patella points more medially the rotation is internal, and when the patella points more laterally the rotation is external [69]. The rotations can also be called medial and lateral rotations [68].

Figure 2-3: The highlighted hip joint connects the femur to the hipbone allowing movement between them. Retrieved from [70].

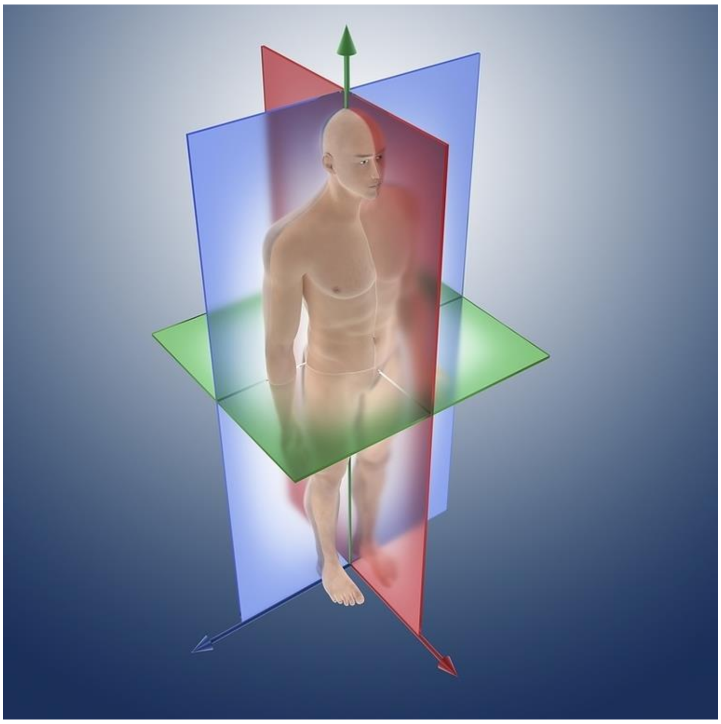

Figure 2-4: The three different orientation planes and axis for reference in human anatomy. Red: sagittal plane (divides the body into a left and right part) and sagittal axis. Blue: frontal plane (divides the body in a back/posterior and front/anterior part) and frontal axis. Green: transversal plane (divides the body into an upper/superior and a lower/inferior part) and longitudinal axis. Retrieved from [71].

The hip joints have two functions: mobility and stability. To fulfill the task of stability, mobility is restricted, and the hip joints are less mobile than the shoulder joints. The acetabulum (meaning “little vinegar cup”) makes up the socket of the joint. It is a deep outward-facing cup surrounded by a labrum, which is a rim of fibrocartilage. The ball of the ball and socket joint is the head of the femur with the shape of a two-thirds sphere. The labrum curves inwards to grip around the femur and hold it in place. Further on is most of the femoral neck surrounded by a strong capsule strengthened by ligaments anteriorly and posteriorly by small half rotator cuff muscles. One important ligament is the iliofemoral ligament, and this is the strongest ligament in the body. It passes across the front of the joint and is used to support the trunk on the lower limb by limiting the range of extension of the hip. Circular fibres, called the orbicular fibres, in the capsule also contribute to stability [68]. As many as twenty-two muscles cross each hip joint and help two both stabilize the joint and move the femur [72].

2.4.3 The Adductors

On the inside of the thigh lies the adductors (Figure 2-5). This is a muscle group whose main action is to adduct the femur and are composed of the muscles m. adductor magnus, m. adductor longus, m. adductor brevis, m. gracilis and m. pectineus. These muscles pass the hip joint from multiple directions, which functionally means they can create torque in all three planes [40]. This gives the adductor muscle group several functions. In addition to adducting the femur in relation to the pelvis in the frontal plane, the group also contributes to flexion and extension of the femur along the sagittal plane and rotation along the transverse plane. But there is no universal agreement to what kind of rotation. Some have described the action as internal rotation, some as external rotation, and others as both [73]. These disagreements further emphasize that the groin anatomy is complicated.

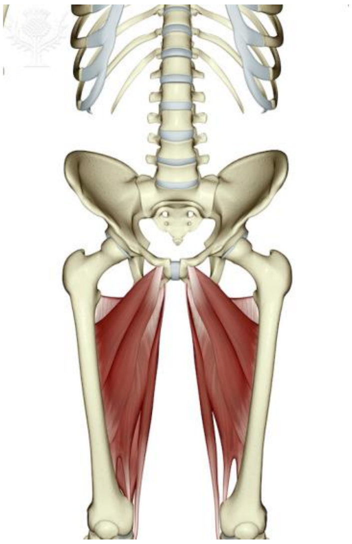

Figure 2-5: The muscles forming the adductor muscle group lies on the inside of the thigh. Retrieved form [74]

Together with the lower abdominal muscles, the adductors also act to stabilize the pelvis [75]. The muscles are therefore at risk of injury due to overloading, if the stabilization of the hip joint is disturbed [76], as it often is in sports like soccer. In most everyday activities, however, *strong* adductor muscles are not particularly important. But they are important, together with the abductors, to keep the bodyweight over the feet when standing on unstable ground [68].

Some of the muscle's function changes depending on the position of the body. M. adductor longus, for instance, is a flexor when det hip joint is extended, and an extensor when the hip joint is flexed. Another example of a muscle changing its function is the m. adductor magnus. This muscle is a good hip extensor in a flexed position, but the moment arm is so short when the hip is extended that its contribution to extension is minimal [40].

2.4.4 The Adductor longus

As one of the muscles in the adductor group, the adductor longus muscle is in the medial aspect of the thigh (Figure 2-6). The muscle is triangular and fan-shaped. In addition to its primary function to adduct the thigh at the hip joint, it also contributes to flexion, extension, and external rotation of the thigh as well as pelvis stabilization both during walking and while standing. The origin of the adductor longus is the anterior surface of the body of the pupis, inferior to the pubic crest and lateral to the pubic symphysis, while the insertion is the middle third of the medial lip of the linea aspera [40, 77].

Figure 2-6: The adductor longus muscle lies in the medial compartment of the thigh. Retrieved form [78].

2.4.5 The Iliopsoas

The iliopsoas (Figure 2-7) is the main hip flexor, composed of the iliacus and the psoas muscle [68]. The origin of the iliopsoas is extensive. The psoas (major) originates from the twelfth thoracic vertebrae and all five lumbar vertebrae. The iliacus originates mainly from the iliac fossa of the pelvis. They emerge into a muscle belly and insert into the lesser trochanter of the femur [79]. From the origins to the insertion the muscle passes under the inguinal ligament and over the hip joint [68], which makes sure the muscle can produce a moment to flex the hip. In addition, the muscle has more functions such as external rotation of the thigh and flexion of the trunk. The psoas major can also flex the trunk laterally [79].

Figure 2-7: The iliopsoas muscle group. Retrieved from [80].

2.4.6 The Rectus femoris

The rectus femoris (Figure 2-8) is one of four individual muscles that are part of the anterior located quadriceps femoris muscle on the thigh, which is a powerful extensor of the knee. The other muscles are vastus medialis, vastus lateralis and vastus intermedius. All four muscles pass the knee joint and share a common tendon which inserts into the patella [81]. The rectus femoris also acts as a weak hip flexor as it, as the only one of the quadriceps muscles, passes the hip joint. It consists of two heads, with origins from the anterior inferior iliac spine and from just above the acetabulum. It is also the most superficial muscle in the midline [68].

Figure 2-8: The rectus femoris muscle. Retrieved from [78].

2.5 Epidemiology

2.5.1 Injuries in Sports and Soccer

Despite several documented positive health effects of engaging in sports [7, 8, 26, 28, 29], there is also a real risk of sustaining injuries during physical leisure activities [26]. It has been reported that only in the United States, 3.5 million people under the age of 15 receive medical care for sports-related injuries annually [9]. A study in Canada that examined sports injuries over a year in a sample of 1466 junior high school students, aged 12 to 15 years, reported a sports injury rate over 60 injuries/100 students. 93.39% of the students participated in at least one of the more than 80 identified sports and activities. Over 40% of the adolescents suffered multiple injuries. Near three-tenths of the students got injuries that required medical attention and 12.28% of them were sent to the emergency room with an injury. 36.3 injuries/100 youth annually resulted in at least one day of time loss from sport. It was also reported that soccer contributed to the second most injuries, after basketball [8]. Another study, carried out in Spain, reported soccer to have the highest injury rate among 492 adolescent athletes on both amateur and professional level. More than two-thirds of the injuries occurred in the lower extremities, and the incidence of injuries was 5.11% higher for the professionals [9]. In general, the injury rate in soccer is high [10] and injuries have proven to be more common in soccer than in many other types of sports [8, 9, 11, 12]. As a complex contact sport, soccer has according to Pfirrmann et. al [13] a relatively high injury rate for male professionals, amateurs and adolescents both during match and practice activities. Junge and Dvorak [82] reviewed several studies on incidence of soccer injuries, and estimated that every elite male footballer incur, on average, one injury limiting their performance every year. There are significantly fewer injury studies on female soccer players, but there are nonetheless multiple studies that show a high risk of injuries for females as well. Including Junge and Dvorak [14] who reported 2.2 injuries/match for female footballers in seven top-level international tournaments, and Engström et al. [15] who investigated injuries in two elite teams during one year and found that 33 of 41 players (80%) sustained 78 injuries. It was further reported that the majority of the injuries occurred in the lower extremity, with respectively 65% [14] and 88% evenly distributed on both legs [15]. Another prospective study, done on 123 male players over the age of 16 at various senior levels in a Danish football club, found that 84% of the injuries in one season were in the lower extremities. Of all the injuries, injuries to the ankle were the most common, accounting for over two-thirds [16]. It seems to be clear evidence that the lower extremities are most prone to injuries in soccer, as this is supported by all studies found in the field. Wong and Hong [12] did a review study on injuries in the lower extremities. From 22 selected articles, knee, ankle, upper leg, groin and hip were pointed out as the anatomical areas with the most injuries. The first three areas appear to be most prone to injury, although the various studies reported different areas as the most common site of injury. The authors concluded that adolescents suffered the most injuries to the knee, while the upper leg was most often injured among the professionals. There were also gender differences, where male players had the most ankle injuries and women more knee injuries. In terms of type of injury, contusion was most common, followed by sprains and strains. Nevertheless, it is difficult to draw any conclusions, as the articles used different injury definitions and classified the severity of injuries differently. This is a common problem when looking at previous injury studies in soccer. Injuries are defined in many ways, and one must therefore be careful when comparing studies as they can examine completely different things. The differences in definitions here, revolve mostly around when and for how long players must be out of play and need of medical attention.

2.5.2 Groin injuries in Soccer

Groin injuries contributes to a relatively large proportion of injuries in soccer [10, 17, 18]. Waldén et. al [10] published a review in 2015 comparing literature from 34 articles on the epidemiology of groin injuries in different senior soccer levels – from professional to amateurs. This included injury surveillance studies on both genders, in international tournaments and European club soccer for at least one season. Most of the studies used different time-loss variations to define an injury, and it was found that groin injuries accounted for approximately every eighth and fourteenth time-loss injury, for male and female, respectively. The injury rate seemed to be lower in international tournaments compared with most studies on clubs. The main findings were that groin injuries are common in senior soccer and that it is more frequent for men than women. This gender difference was shown in the proportion of groin injuries among all injuries, as well as the number of injuries based on player-exposure time. For club-seasonal play the proportion of groin injuries for men was 4-19% and they had an injury rate ranging from 0.2 to 2.1/1000 h. For women the numbers were 2-11% and 0.1 to 0.6/1000 h. It can also be mentioned that there were significantly more studies on club soccer than international tournament, and twice as many studies on men than women in club-seasonal soccer. One of the studies in the review by Werner et. al [19] investigated the incidence of groin injuries in European professional soccer over seven consecutive seasons (a total of 88 club seasons spread over 23 teams). The survey showed a consistent incidence of groin injuries between seasons, with a selection of results as follows: a percentage number of all injuries ranging from 12-16%, an average number of injuries per club per season ranging from 7.2 (SD = 5.5) to 8.0 (SD = 3.6) and the number of players injured varied from 19% to 22%. That the incidence does not change over time was part of the conclusion. However, the study was conducted during the seasons 2001/02-2007/08, which is a while ago. More recent numbers should be examined to determine whether the prevalence remains the same today. Nearly all of the previously mentioned studies in this section have used time-loss and definitions of injuries, meaning players need to be unable to participate in practise or matches for an injury to be registered. This way of recording injuries presents probably only the "tip-of-the-iceberg" when it comes to groin problems because many continue to play after symptoms have appeared, despite reduced performance [10, 17, 18, 20, 61, 62]. In a descriptive epidemiology study, Harøy et al. [18] investigated the prevalence of groin injuries in Norwegians footballers using injury definitions based on all physical complaints of the groin. Groin problems were recorded weekly using a questionnaire developed by the Oslo Sports Trauma Research Center. This was carried out over a period of six weeks with a high match load. The players were part of 15 different teams where there were three teams in each of the following five groups: male elite, male subelite, male amateur, under-19 male elite and female elite. Of results, the study presented that 59% of the men and 45% of the women experienced problems in the groin on at least one occasion. 29% of the males had on average groin problems every week. Of all groin problems, only 34% of the problems for men and 20% of the problems for women led to absence from soccer participation. This indicates that only one-third and one-fifth of all groin problems would have been registered with the more traditional time-loss definitions, and that this type of definition underestimates the magnitude of the problem. Further, the study concluded that elite men had groin problems more frequently than women, with an odds ratio of 3.1. It was, however, no difference in risk of sustaining groin problems between the different male groups, and no differences between the sexes in substantial problems. A study on females only (434 Dutch amateur players between 18 and 40 years) [20], compared injuries with and without time-loss. Of reported injuries through an online questionnaire during one season, groin injuries turned out to be the most common non-time-loss injury. In comparison, it was the fifth most common time-loss injury, after ankle, knee, hamstring, and thigh.

The study mentioned above by Werner et al. [19], on professional soccer players over seven consecutive seasons, classified 53% of all hip and groin injuries (both acute and overuse injuries) as moderate or severe, meaning an absence of 8-28 days and more than 28 days from training and match play. 15 days of absence was the average per injury. The distribution of traumatic injuries and overuse injuries was for one season shown to be 27% and 73%, respectively The same study also reported a higher groin injury rate for matches than for training [19]. In general, most soccer injuries occur in match play [13], and most severe injuries typically occur during matches [83], but re-injuries are more likely to happen during training [84]. Video analysis of acute adductor longus injuries concluded that 71% of the injuries occurred in non-contact situations [85].

There are many risk factors associated with a groin strain. Several studies show an association between previous injuries and new ones [7, 19-24]. Hägglund et. al [86] investigated how previous injuries affected risk of injury among 197 Swedish male elite players and found that players with previous groin injury were two to three times more likely to suffer a new identical injury. In the study, medical staff documented all injuries over to consecutive seasons, and recurrence injuries were defined as an identical injury to an index injury that occurred after medical staff cleared for full participation. Another study of nine to seventeen clubs over seven seasons reported that 15% of all registered groin injuries were re-injuries, which was defined as an injury of same type and at the same location as an earlier injury occurring within two months of full return to soccer participation [19]. Some re-injuries can result from inadequate rehabilitation or premature return to sports, but injuries can also be recurrent regardless of time interval [60]. It is nevertheless important to focus on sufficiently good rehabilitation before players return fully, as it turns out that re-injuries often have a longer absence than the index injury [19]. Other presented risk factors for groin injury in soccer are kicking (mostly in the kicking leg) [23, 25, 85, 87], core muscle weakness, delayed onset of transverse abdominal muscle recruitment [22], weak adductor muscles [21, 35], change of direction, reaching, jumping [85, 87] and too short recovery time

[13]. A correlation has been shown between a reduced hip range of movement and adductor injury [7, 88]. There is also debate about the role of certain factors, such as age, sports experience/playing level [22, 89] and playing position [13]. As many of the risk factors above indicates, most acute adductor longus injuries occurs in non-contact situations [85].

Muscles in the groin area of athletes most often affected by acute groin injuries are adductor longus, rectus femoris, rectus abdominis and iliopsoas [26]. In a cross-sectional study [25] of 110 adult male athletes with acute sports-related groin pain, two-thirds of the injuries were related to the adductors, with the highest injury rate for the adductor longus. Injuries to the iliopsoas and proximal rectus femoris were also quite common. Another study [27] investigating both acute and overuse groin injuries, in a sample of 998 sub-elite male footballers, also found adductor-related injuries to be most common. Iliopsoas-related and abdominal-related injuries were the second and third most common types of groin injuries. A more accurate description of injury location for acute adductor injuries has been carried out by MRI examination of 71 athletes within seven days of injury onset. Over half of the recorded injuries was in adductor longus, which seems to have three main injury locations, this was proximal insertion (26%), and intramuscular musculo-tendinous junction of the proximal tendon (26%) and of the distal tendon (37%). 25 of the athletes had multiple adductor injuries. Adductor longus was the most frequent injured adductor muscle both in isolation and in combination with other adducting muscles [87].

2.6 Physical demands of soccer

One of the physical demands of soccer is running. An overview article by Taylor et al. [4] analyzed running characteristics in several ball sports, including soccer. Several results were presented. Elite male players ran on average between 9,000 and 12,000 meters during a match, while elite female players on average travelled a distance between 9,600 and 10,000 meters. The distance was generally lower and more variable for junior players. The frequency of sprinting was quite similar across ages and sexes, but the distance of sprinting was longer for men than females and seniors compared with juniors. 4.0-12.3% of total distance travelled and 0.3-3.4% of total game time was conducted as a sprint, and each sprint lasted for approximately 2.0 s on average. More time and a longer distance were generally spent in high-speed/intensity running than sprinting. High-intensity running accounted for 5.1-18.2% of the total distance and 2.1-6.1% of total game time and lasted for 1.3-4.4 s on average for males. Numbers for females are 4.8% of the total time with a duration of 2.3 s on average. It was 1379 to 1459 activity changes during a match. That is a new activity movement about every four seconds, indicating many accelerations and decelerations. The number of directional changes varies depending on playing position, where midfielders have the most cutting throughout a game [5]. An analysis of directional changes by Bloomfield et al. [6] showed that elite male players over 600 times during a match turned at angles <90°. A similar analysis conducted by Robinson et al. [5] found that elite male footballers had 35-40 cuts in both directions at an angle in the range of 45° to 135°, and just over 20 cuts at angles >135°. Change of direction is one of the main actions resulting in acute adductor longus injury [85].

2.7 Prevention and Treatment of Groin injuries

Since there are many active players [1-3] and a high groin injury rate [10, 17-20, 25, 27], a relatively large number of people are affected by groin injuries worldwide. The sport is evolving, which entails greater training volume and greater physical demands on elite players [90]. The tempo in contemporary professional soccer increases, the players are running more than before, and the fitness level must then be increased correspondingly. The players must be able to both accelerate over short distances and quickly change the direction of movement. Several young players start earlier with intense training than before [11]. This development leads to an increased risk of injury as there is a correlation between the training load applied to a player and the incidence of injury and illness [91]. Being able to prevent injuries will therefore be helpful for individuals and soccer teams. Injury prevention strength training continues to show its effect on multiple types of injuries in soccer [2, 31-33, 92].

2.7.1 Research on common exercises in groin injury prevention

Several exercises are used to target the hip adductors in prevention and treatment of adductor-related groin injuries. Delmore et. al [93] investigated peak and average normalized electromyographic (EMG) activity of adductor longus in the dominant leg (the leg preferred for kicking) during six common hip-adductor rehabilitation exercises. Twenty-four physically active college-age students performed the following six exercises: side-lying hip adduction, ball squeezes (Swiss ball at the knees), rotational squats, sumo squats, standing hip adduction on a Swiss ball and side lunges. The exercises that produced most peak activation was the side-lying hip adduction (60.1 ± 16.2 %MVIC) and ball squeezes (36.0 ± 18.0 %MVIC), the same exercises also produced the most average activation with (22.2 ± 5.5 %MVIC) for the side-lying hip adduction and (14.3 ± 6.0 %MVIC) for the ball squeezes. MVIC is a reference value from a maximum contraction in adductor longus. Serner et. al [24] conducted a similar study around the same time. For forty healthy male elite soccer players, they investigated bilaterally muscle activation in eight hip adduction exercises, six traditional and two new ones at the time. However, they only studied peak activation but instead of only focusing on adductor longus they also measured activity for gluteus medius, external abdominal oblique and rectus femoris. Isometric adduction with a soccer ball between the ankles, isometric adduction with a soccer ball between the knees, side lying hip adduction, sliding hip abduction/adduction, hip adduction with an elastic band and hip adductor machine were the traditional exercises, while subine bilateral hip adduction and Copenhagen adduction (described in section 3.6.1) were the new suggested exercises. All exercises, except from supine hip adduction had higher peak values of adductor than the exercises in Delmore et. al’s study [93]. The side-lying hip adduction exercise were the only exercise included in both studies. It was ranked with highest activation in [93], but ranked number seven in the study of Serner et. al [24]. The activation of the dominant leg was nevertheless quite similar, with 64

± 6 percent of reference value in the latter study. Even though the exercise had similar values in both exercises, the results cannot be compared directly as the procedure of finding maximum reference contraction to normalize the EMG were different. The isometric adduction with a soccer ball between the knees (108 ± 6 %MVIC) were similar to the ball squeeze exercise in the first study but had a much higher peak activation. The main difference in these exercises is the hip angle (the Swiss ball is larger) and the fact that the Swiss ball is softer which means the contraction is not isometric. An interesting finding in the latter study is the high adductor longus activation of the new suggested Copenhagen adductor exercise. Normalized peak activation was 108 ± 5 %MVIC in the dominant leg and 69 ± 6 %MCIV in the non-dominant leg, which was a significantly higher activation in the dominant leg. Serner et. al [24] concluded their study with statement saying it seemed relevant to include the Copenhagen adductor exercise in future prevention and treatment programme, not only because of high intensity but also because it can be performed at any facility.

The Copenhagen adductor exercise has become popular in the community of sports medicine [34]. In addition to high documented adductor longus activation [24], an 8-week supervised progressive training program using the Copenhagen adductor exercise among sub-elite soccer players, showed a significant increase in both eccentric hip adduction strength (EHAD) and surprisingly also in eccentric hip abduction strength (EHAB) [35]. The strength programme was conducted by ten players and data was compared with an intervention group, also of ten players, who were instructed not to perform resistance training of the hip adductors during the period. A prevention study on 34 Norwegian male semiprofessional soccer teams by Harøy et. al [33] investigated the effect of an adductor strengthening programme including the Copenhagen adduction exercise as its only exercise and found a 41% lower risk of reporting groin problems (all physical complaints in the groin area) in an intervention group than in a control group. The control group trained as normal, while the intervention group performed the Copenhagen adduction exercise progressively two to three times a week in the preseason and once a week during the competitive season.

3. Methods and Equipment

This master project was carried out as a biomechanical experimental study. Subjects performed four standardized dynamic plank strength exercises. Quantitative data were extracted by examining the dependent variables torque in hip joints, and muscle activation in the two muscles adductor longus and rectus femoris during the exercises. To collect the necessary data, an optical motion capture and 3D positioning tracking system from Qualisys, a surface EMG system from Myon and a tension/compression load cell from HBM were used. All trials were conducted in the biomechanical laboratory at the Norwegian School of Sport Science in February 2022.

Further in this chapter, basic principles and specific settings for the equipment will be presented, in addition to a description of the experimental procedure, as well as data processing, analysis methods and ethical considerations.

3.1 Motion Capture

An optical motion capture system consisting of multiple cameras connected in a loop recorded three-dimensional position data with a sampling frequency of 200 Hz (Oqus 400/700; Qualisys AB, Gothenburg, Sweden). The cameras were connected to a data acquisition software called Qualisys Motion Capture (QTM) (version 2019.3; Qualisys AB, Gothenburg, Sweden) through a 16-bit analog-to-digital conversion board (USB-2533; Measurement Computing Corporation, Norton, MA, USA). The peripherals EMG system and the load cell were also connected to the system through the conversion board and were recorded by QTM, simultaneously as the software captured motion data. The cameras recorded movements of 25 retro-reflective markers attached to anatomical landmarks on the subjects and to the load cell. This was passive markers reflecting light from the cameras. 20 of the markers were positioned on the subjects' skin and the other 5 to the load cell. The load cell measured forces the subject exerted on it, and the markers were attached to determine the direction of the force. All markers were attached with double-sided tape. Table 3-1 shows a list of all markers on the subjects, which is based on [94]. On the load cell it was placed one marker on the top and to pairs of markers further down on each side at different heights. Figure 3-1 illustrates the location of the markers. By playing the recordings in QTM, all the markers contributed to make a good visualization of the movements to the participants. But only some of the markers were used for further analysis. This applied to the markers on the pelvis (number 11 to 14) and markers on the load cell, which was used to find the hip joint center, line of force and moment arm.

Table 3-1: List of anatomical landmarks of which the marker set contained. The anatomical landmarks are shown illustratively in Figure 3-1 using the same numbering as in this table.

Right foot	**Right femur**	**Shoulder**
1. Head of the first metatarsal	8. Middle of the tight, in front	15. Right acromion
2. Head of the fifth metatarsal	9. Middle of the tight, lateral	16. Left acromion
Right Ankle	10. Greater trochanter of the femur	**Neck**
3. Lateral malleoli of the ankle		17. C7 spinous process
4. Medial malleoli of the ankle	**Pelvis**	18. Proximal of the sternum
Right knee	11. Right anterior superior iliac spine	**Back**
5. Tibial tuberosity		19. Midway between 17. and the middle of 13. And 14.
6. Lateral femoral condyle of knee	12. Left anterior superior iliac spine	20. Midway between 19. and the middle of 13. and 14.
7. Medial femoral condyle of knee	13. Right posterior superior iliac spine	
	14. Left posterior superior Iliac spine	

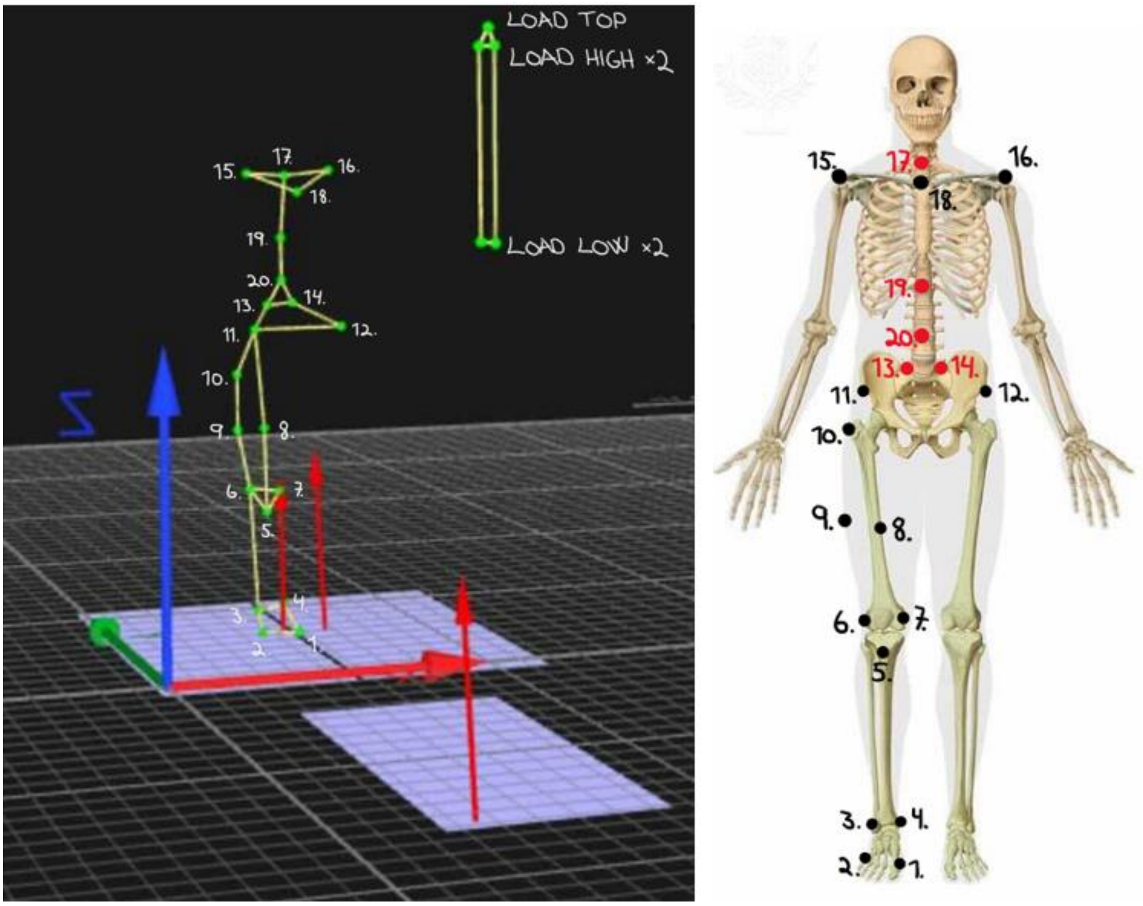

Figure 3-1: The locations of the markers. The numbers 1-20 refer to names of the anatomical landmarks stated in Table 3-1. *Left*: Screenshot of a static trial in QTM. The markers, for both anatomical landmarks and on the load cell, appear as green dots. The numbers and names are added afterwards. *Right*: A picture of a human skeleton retrieved from [95], marked with dots to illustrate the position of the markers in relation to the skeleton. The black markers can be seen from the front, while the red markers are only visible from behind.

On the first day of testing, there were eleven cameras. Three participants attended this day. For the rest of the test period, twelve cameras were used. The cameras were placed at different heights and angles around the capture volume (the area of the lab where the subjects are during the recordings). Figure 3-2 shows the two different camera setups with the capture volume in the middle. As the figure shows, it was down to the right the changes with camera positions were made and here the twelfth camera was added. The changes were made after assessments along the way to ensure better angles to improve the quality of the recordings. A closer look at det capture volume can be seen in Figure 3-3. The three blue rectangles are floor mounted force plates. These plates measure ground reaction forces when a body or other objects are standing on or moving across them. Data from the plates were recorded but not extracted in this project. During motion capture recordings the subjects were always on or above the plates, thus the plates formed the base area of the capture volume. Figure 3-3 also shows the origin and the directions of the x-, y- and z-axis which constitutes the global coordinate system of the lab.

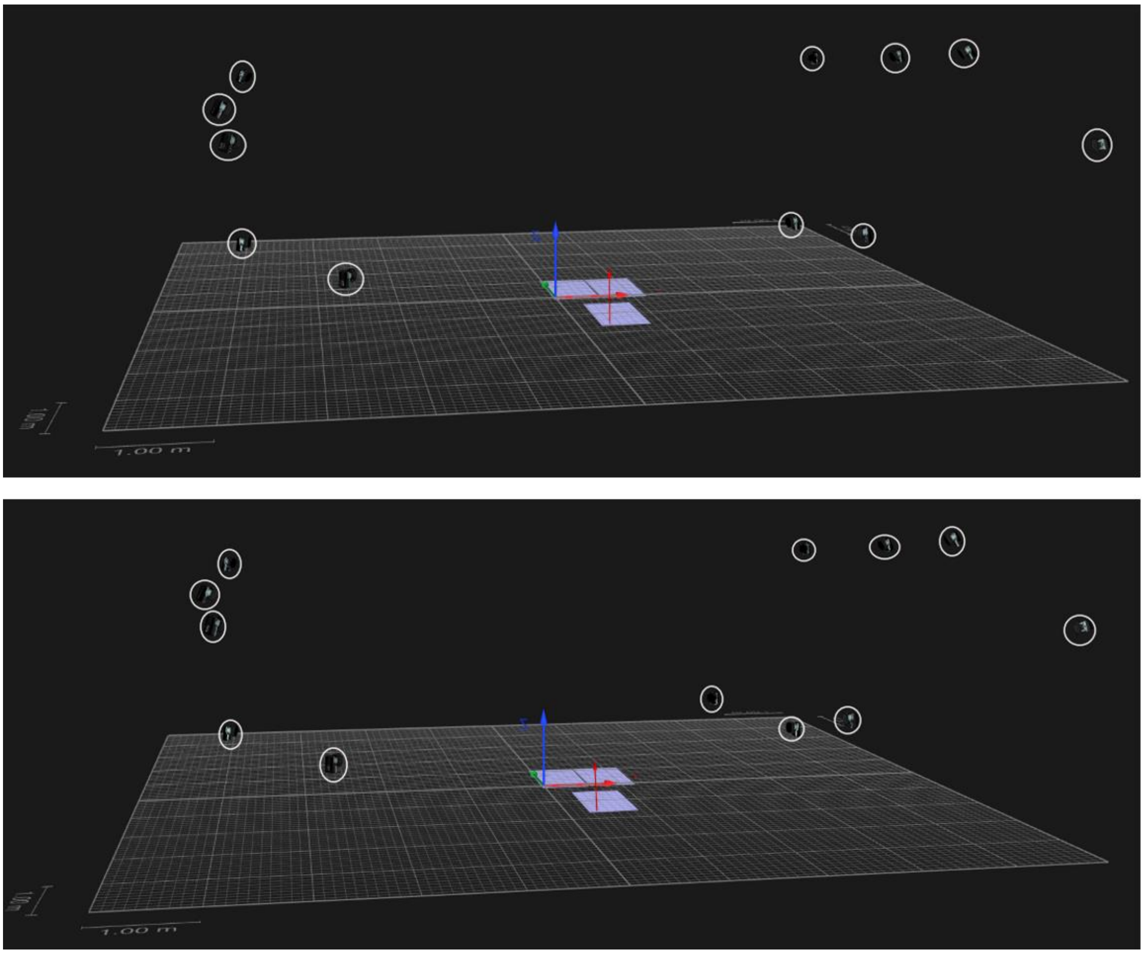

Figure 3-2: Camera set up of 11 cameras (upper picture) and 12 cameras (lower picture) surrounding the capture volume in the middle. The figure are edited screenshots from QTM where white circles are added to highlight the cameras.

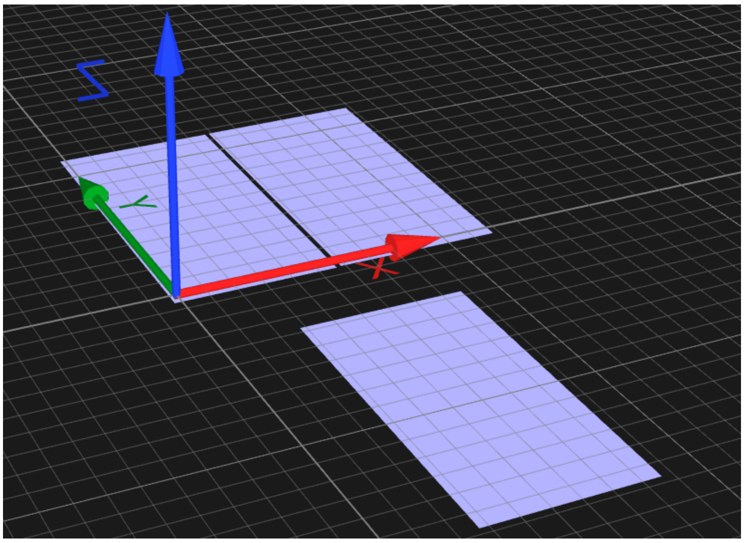

Figure 3-3: Global coordinate system in the biomechanical lab and the capture volume of motion capture recordings.

Two different camera models, called Oqus 400 and Oqus 700 (Oqus 400/700; Qualisys AB, Gothenburg, Sweden), were used interchangeably. In general, the Oqus 700-cameras were used furthest away from the test area as they are more sensitive to light and have better resolution. The Oqus 400-cameras were thus used more closely to the position of the subjects. The cameras use short and strong infrared flashes, generated by LED lights, to illuminate the retro-reflective markers on the subjects and on the load cell. The markers were spherical with a diameter of 12 mm.

All cameras can detect light from other cameras. Ideally, no cameras would point at each other, but this was not possible to avoid for the recordings in this project. To prevent the cameras from capturing light from other cameras and register it as phantom markers, they were divided into two groups that flashed slightly out of phase with each other. While the cameras in one group flashed, the other group were inactive. The data will not be out of sync, but the highest possible capture frequency is reduced. From the perspective of the lab in Figure 3-2, the cameras were grouped so that one was to the right and the other to the left of the capture volume. In this way, none of the cameras in the same group pointed at each other.

For QTM to know where the cameras were positioned in relation to each other and in which direction they were pointing, calibrations were made. Besides a few exceptions, the camera system was calibrated before the attendance of each participant. It was only when there was a very short time between two participants that calibration was not carried out, but there were never more than two subjects before re-calibration. A T-wand and L-frame (Figure 3-4) were used to perform the calibrations. Both had spherical markers attached, respectively 2 and 4 in number. The distance between the markers on the wand was 750 mm. The corner of the L-frame determined the origin of the global coordinate system in the lab. It was placed in the corner of one of the force plates (as shown in Figure 3-3 and Figure 3-4). The longer arm of the frame defined the x-axis, the shorter arm defined the y-axis, with the z-axis perpendicular to these. The frame was placed in a predefined position, commonly used in previous projects in the lab, with the axes matching those of the force plates. Markings on the floor showed the exact position for the frame. Since data from the force plates were not used, the coordinate system could have been defined in any way within the volume of interest. Using the markings that were already on the floor, however, made it easy to find the same position every time for consistency, also, the possibility of using the force plates for analyses was still there, which was considered beforehand. The actual calibration was performed by holding the T-wand by its handle and moving it through all the capture volume. This was done over 30 seconds with controlled and continuous movements in all three planes. It was impossible not to occlude some cameras with the body, so it was important to move around so that the markers on the T-wand and L-frame were seen by all cameras for approximately the same amount of time. After the half minute a popup window displayed «Calibration passed» if approved. Calibration was redone in failed cases.

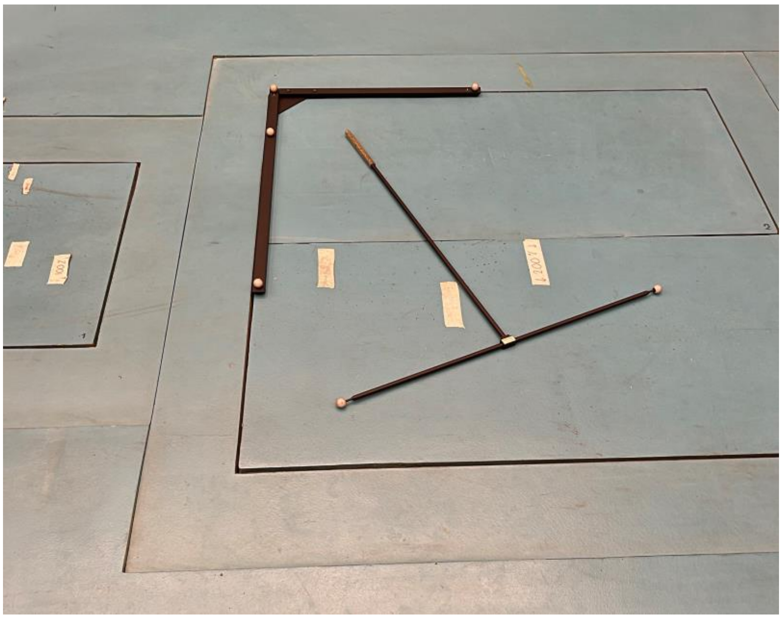

Figure 3-4: A T-wand and L-frame used to calibrate the camera system. The corner of the L-frame defines the origin of the global coordinate system in the lab, while the longer side defines the x-axis, and the shorter side defines the y-axis.

3.2 Measures of muscle activity

Using surface electrodes, raw EMG data were acquired at 2000 Hz by an EMG system (Aktos, Myon, Schwarzenberg, Switzerland). Disposable pre-gelled adhesive Ag/AgCl surface electrodes with a circular conductive area of 12 mm diameter were utilized (Kendall Arbo H124SG electrode, Clinton Township, MI, USA). Two electrodes were attached on the skin above the two muscles of interest. For the rectus femoris muscle, the electrodes were positioned and oriented according to recommendations from SENIAM (Surface Electromyography for the Non-Invasive Assessment of Muscles) [96]. For the adductor longus, electrodes were placed in the upper third of the muscle belly parallel to the muscle fibres. Short cables run from the paired electrodes to a lightweight transmitter attached to the skin, with double-sided tape, a few centimetres away. Wireless signal was sent to a receiver connected to the conversion board. The signals are captured quickly allowing real-time feedback. The data was retrieved via QTM and further processed in MATLAB.

3.3 Force Measurments

With a sampling frequency of 1000 Hz, force data was measured with a tension/compression load cell with a maximum capacity of 500 kg (U2A 500 Hottinger Baldwin Mestechnik, Darmstadt, Germany). The cell had bi-directional sensitivity and could measure force by pushing and pulling it. For all measurements in this trial, only tension force was applied to the cell. The subjects performed the exercises with one foot in a sling that hung freely from the cell. The external force in biomechanical analyses comes from gravitational forces, as all exercises were body weight exercises only the subjects' mass where origin of the forces. The weight of the subjects is distributed over the contact surfaces in the sling and over supporting arms. The foot rests on the sling and pulls it and the load cell downward, while the load cell pulls upwards with equal force. A voltage signal, proportional to applied force, was captured in the QTM software. After the test session, the data was converted to force (N) in MATLAB and used to calculate torque (Nm) applied to the leg causing rotation in the hip joint. The calculation was carried out based on a calibration performed by another master student in prior to the test period (Appendix F).

3.4 Subjects

Twenty-one people agreed to join the study. Two of them had to withdraw during the test period due to covid-related reasons, and one person was excluded from the study because of inconclusive data collection. Thus, data from 18 subjects, including 10 men and 8 women, were analysed (Table 3-2 and Figure 3-5). All subjects were soccer players or had until recently been. Apart from one female participant, all the women played for clubs in the top division in Norway (Toppserien). The exception did not play soccer at the time of data collection but had also played at the top level until recently. The playing level for the male participants was lower and more varied, with a range from level 3 to 7. There was also one male subject who did not play at the time but quit a few months earlier. The player position was not considered as a study by Hölmich et.

al [27] found no significant difference between playing positions in risk of groin injury. Both goalkeepers and field players participated. Due to difficulties in recruiting subjects and the corona situation in the previous two years, the inclusion criteria were relatively flexible. At the time of testing, the subjects had to play soccer or have played until recently, be over 16 years old and not have an ongoing groin injury. Not everyone had normal training and match load in recent years due to coronavirus restrictions, especially those at lower levels.

Table 3-2: Subject characteristics.

Descriptive	**Mean ± SD (all n = 18)**	**Mean ± SD (men n = 10)**	**Mean ± SD (women n = 8)**
Age (years)	22.0 ± 3.9	23.9 ± 3.7	19.6 ± 2.6
Height (cm)	173.5 ± 5.2	176.0 ± 5.1	170.4 ± 3.2
Body mass (kg)	72.2 ± 5.9	75.9 ± 4.9	67.6 ± 3.3

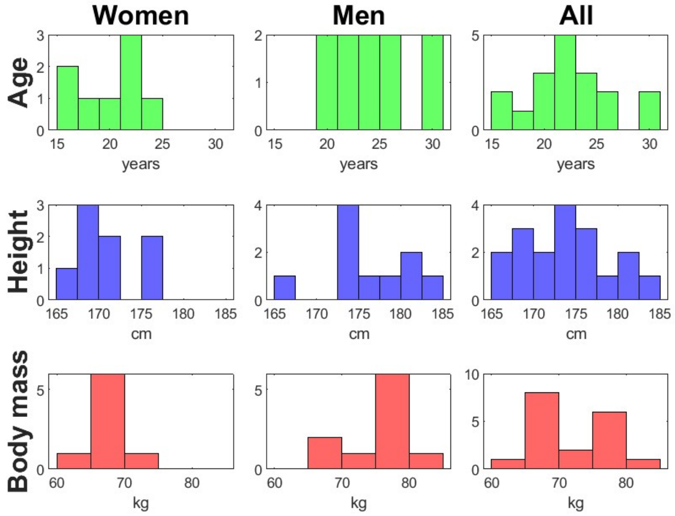

Figure 3-5: Histogram of subject characteristics.

3.5 Test Procedure

Each subject participated in one test session in the biomechanical laboratory at the Norwegian School of Sport Science. One to two hours was allocated each participant.

The testing sessions started by attaching electrodes and markers to the subject's skin. Due to all the electrodes and markers, the men wore a boxer, and the women wore shorts and sports bras. A validation check was then made of the raw EMG signal. It was done by looking at baselines and signal burst in real-time for each muscle while the subjects performed a few repetitive contractions in the current muscle. All participants completed a warm-up routine, consisting of approximately 5 minutes of cycling and some repetitions of air squats and adduction and flexion of the hip with an elastic band. Then the data collection began.

The first recording was a static trial, shown in Figure 3-6. The participants stood straight and had their hands horizontal to the sides, as a T-pose. The feet pointed straight ahead and with approximately shoulder width apart. This recording with the subject standing stationary lasted for 2 seconds and is later used to define segments and determine anatomical coordinate systems of the pelvis.

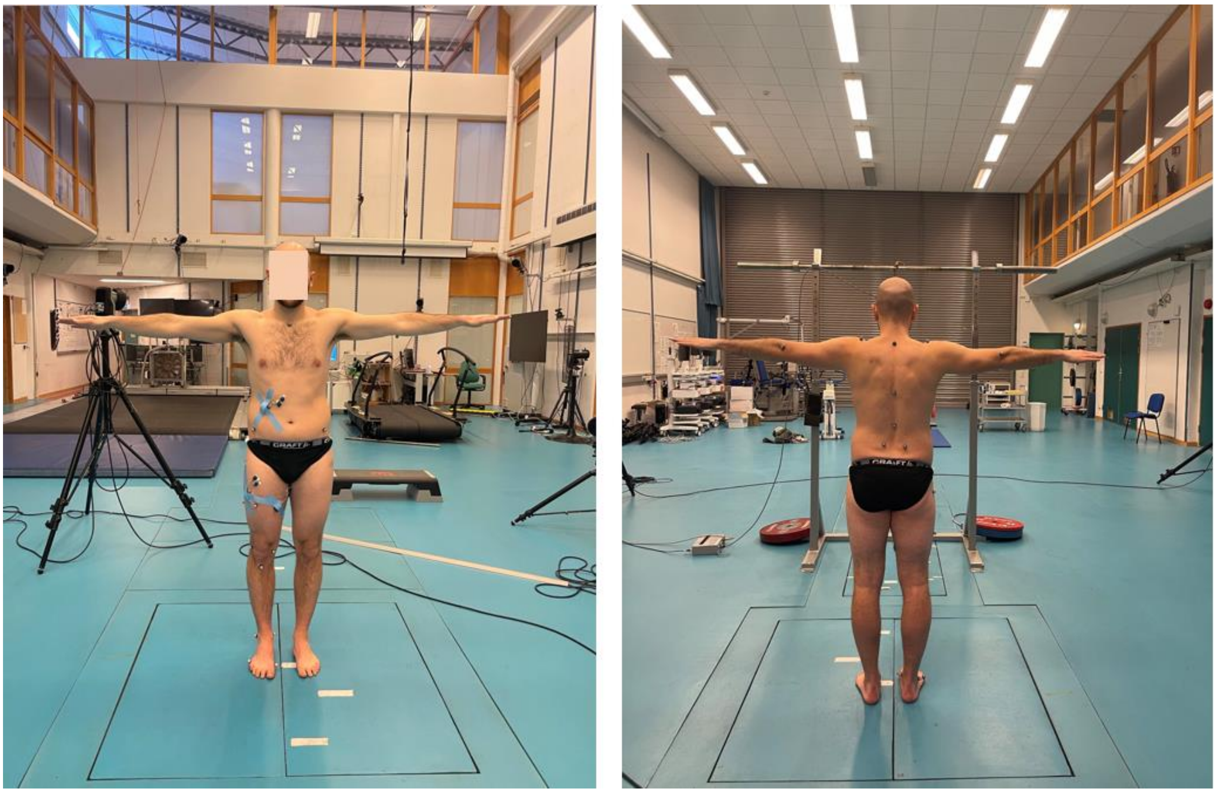

Figure 3-6: A subject standing in the capture volume performing the static trial, with all markers and electrodes attached to the skin.

Then the four dynamic plank exercises were conducted. This is the Copenhagen adduction variant 1 exercise (CA1), Copenhagen adduction variant 2 exercise (CA2), one leg pike exercise (OLP) and oblique plank with hip flexion and adduction exercise (OPHFA). The first is a side-lying exercise suggested by Serner et. al [24] in 2013 and has become common practice in the field of sports medicine today [34]. CA2 is a modified version of CA1, and both these exercises include an adduction of the leg in the frontal plane about a sagittal axis. The main action of the OLP is leg flexion in the sagittal plane around a frontal horizontal axis. This is performed with the anterior part of the body pointing down towards the floor. OPHFA is an intermediate of CA2 and OLP, it intends to resemble a soccer pass, and is performed in a titled position including both adduction and flexion of the leg. The exercises are described in more detail in section 3.6. For practical reasons (settings on the equipment), all subjects started with CA1. The other three exercises were done in a random order, determined before each subject arrived at the lab. Instructions of the exercises were given during warm-up, and the individual exercises were explained again before they were to be completed. The subjects were also shown videos of the execution of the exercises and received instructions during recordings if necessary. The exercises were not standardized by time, and the participants could decide for themselves how long they spent on each repetition. The recordings lasted 30 seconds. The duration and the ability to perform the exercises was decisive for the number of repetitions that were performed. However, the most common was between 3 and 5 repetitions. After each recording, a quick check was made of the acquired data. Sometimes the check revealed errors, such that markers had fallen off or strange EMG signal indicating that the transmitters were out of power. In such cases, new recordings of the exercises were made. If everything looked fine, it was on to the next exercise.

After all the exercises had been performed, anthropometric data, including weight and height, was collected. Finally, maximum voluntary isometric contraction (MVIC) tests were conducted for both muscles of interest. The test was performed in the same order for everyone, with first a test for adductor longus, then a test for rectus femoris. Section

3.7 describes the two tests. Recordings of these tests did not have a common time span but was manually stopped after the tests was completed.

In summary, 7 types of recordings were made after fixating the markers and electrodes. First, one static trial, then the four exercises and lastly two MVIC tests. All equipment recorded data for all recordings, but not all data was extracted for further processing. From the static trial only motion capture data was needed and used to calculate coordinate system of the pelvis. For recordings of the exercises, both movements of the markers, force data and EMG were relevant. This to be able to calculate torque and analyze muscle activation during the exercises. The MVIC tests do not require information about the markers position and are the only recordings where the subjects were not in capture volume. Force data is not relevant either, therefore only EMG data is extracted from these recordings. The result of the tests was used as a reference value, to normalize the EMG signal acquired from the exercises.

The tests were carried out by the undersigned master student, with assistance of a master student in sports science and a qualified orthopedic surgeon. The latter person was responsible for palpating to the anatomical landmarks to attach the markers and electrodes.

3.6 Exercise Description

To perform the four exercises, a sling and a step platform was used. The set-up of the sling is shown in Figure 3-7, and the step is shown is use in Figure 3-8, Figure 3-9, Figure 3-10 and Figure 3-11. The subject’s right leg was placed in the sling and the step was used to place one or two hands on. The sling hung from the load cell that hung from a barbell placed on a squat rack. The rack could be adjusted up and down leading to different heights for the sling. In this project, two heights were used. The distance from the ground to the inside of the sling (where the subject’s leg was placed) was measured to be approximately 55 cm for the lowest position and 80 cm for the highest position. The step had three levels, which were 15 cm (low), 20 cm (middle) and 25 cm (high). The sling and step adjustment varied between exercises, but all subjects used the same heights. Table 3-2 shows the settings for the various exercises. The exercises Copenhagen adduction variant 1 (CA1), Copenhagen adduction variant 2 (CA2), one-leg pike (OLP) and oblique plank with hip flexion and adduction (OPHFA) are described in the following sections.

Table 3-3: Height settings for the sling and the step for the different exercises.

Exercise	**Height level sling (low/high)**	**Height level step (low/middle/high)**
CA1	high	-
CA1	low	low
OLP	low	high
OPHFA	low	middle

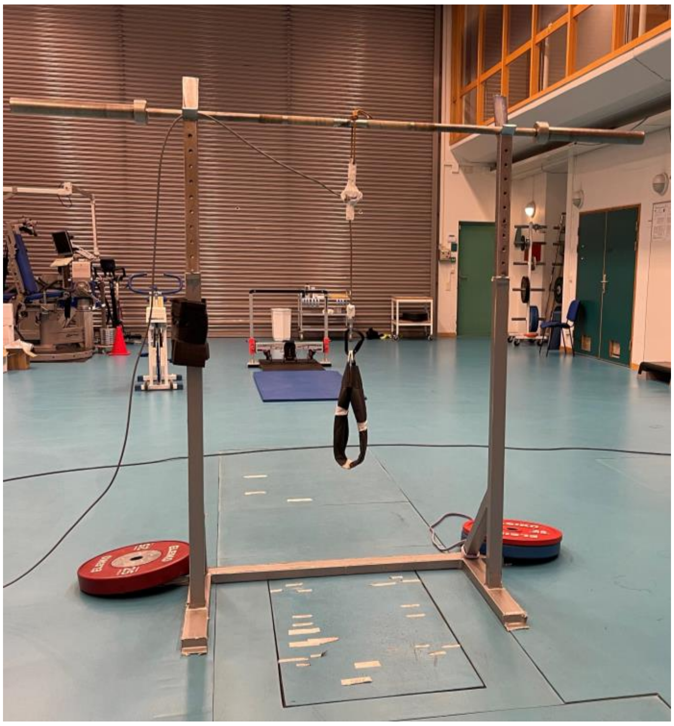

Figure 3-7: Set-up of the sling used to perform the exercises. The sling is attached to the load cell, which hangs from a barbell on a squat rack. The load cell is covered in white tape to prevent it from being registered as a phantom marker by the cameras. Some weight plates lie on the legs of the rack for safety reason to prevent the setup from falling over.

3.6.1 Copenhagen adductor variant 1 (CA1)

The CA1 exercise is shown in Figure 3-8 and intendeds to resemble the original version of the Copenhagen adductor exercise described by Serner et. al [24] as follows:

> *"A partner exercise where the player is lying on the side of the non-dominant leg with one forearm as support on the floor and the other arm placed along the body. The dominant leg is held at approximately the height of the hip of the partner, who is holding the leg with one hand supporting the ankle and the other supporting the knee. The player then raises the body from the floor and the non-dominant leg is adducted so that the feet touch each other and the body is in a straight line. The body is then lowered halfway to the ground while the foot of the non-dominant leg is lowered so that it just touches the floor without using it for support."*

The exercise was, however, modified for this project. Because of load measurements, a person couldn't hold the foot, which instead were supported by the sling. Nevertheless, it was desirable to keep the foot in the sling as still as possible. Therefore, a person stood holding his hand against the foot and was to make sure that the foot did not go further back. However, this did not prevent the foot from moving forward. The knee was not supported either. All subjects had their right foot in the sling, whether it was their dominant or non-dominant leg. The height in the description is very dependent on the partner's body proportion. In this project, the sling was about 80 cm above the floor for all. In order not to disturb markers on the foot, the sling was moved slightly above the ankle. Serner et. al [24] described the position and movement of the free arm and foot, but the participants in this project received no instruction about these limbs - except that the arm should not cover any markers. This exercise was the only one with the high position of the sling. It was decided that CA1 should be performed first, and afterwards the sling was moved down.

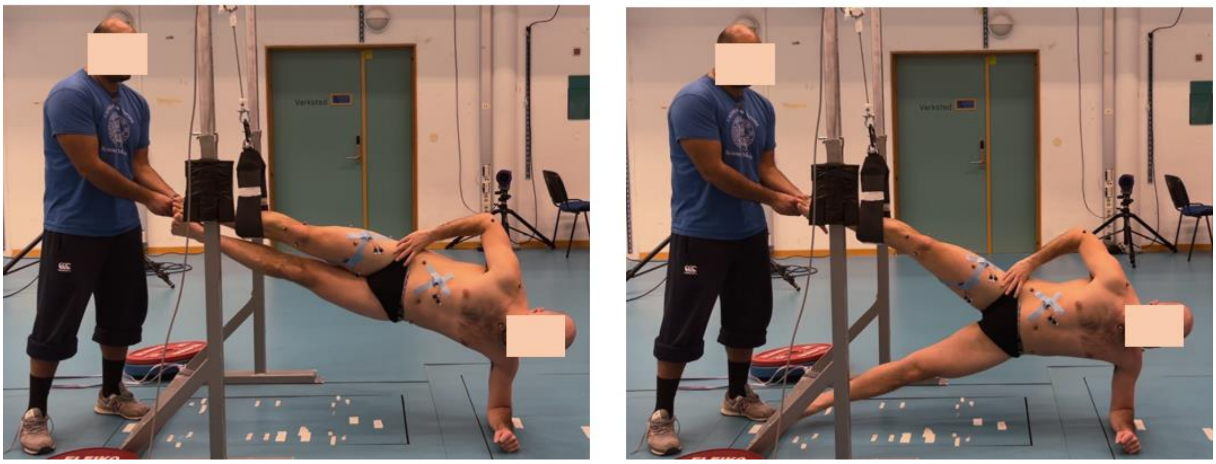

Figure 3-8: A subject performing the Copenhagen variant 1 exercise, and a person from the test personnel holding his hand against the subject’s right foot to prevent it from going backwards. *Left*: top position of the exercise, also the start and stop position. *Right*: bottom position, which is halfway through the exercise.

3.6.2 Copenhagen adductor variant 2 (CA2)

The CA2 exercise is shown in Figure 3-9. This is also a side-lying exercise and is similar to CA1, but with some adjustments. The sling is lower, and the supporting forearm is raised with the step. This means that the height difference between the foot in the sling and the supporting forearm is quite much smaller than in CA1, and it allows for a greater range of motion of the pelvis. The sling is placed on the middle of the calf. The exercise starts when the left shoulder is directly above the left elbow and the body is in a straight line. The body is then lowered simultaneously as the arm on the step pushes the body backwards. The body is lowered and moved backwards as far as the person can do so in a controlled manner. Then the body is lifted back to the top position in a controlled manner. The whole exercise should be done with a straight body, without flexion in the hip joint. As in the CA1 exercise, the subjects received no specific instructions about the left foot and right hand, except to not cover any markers.

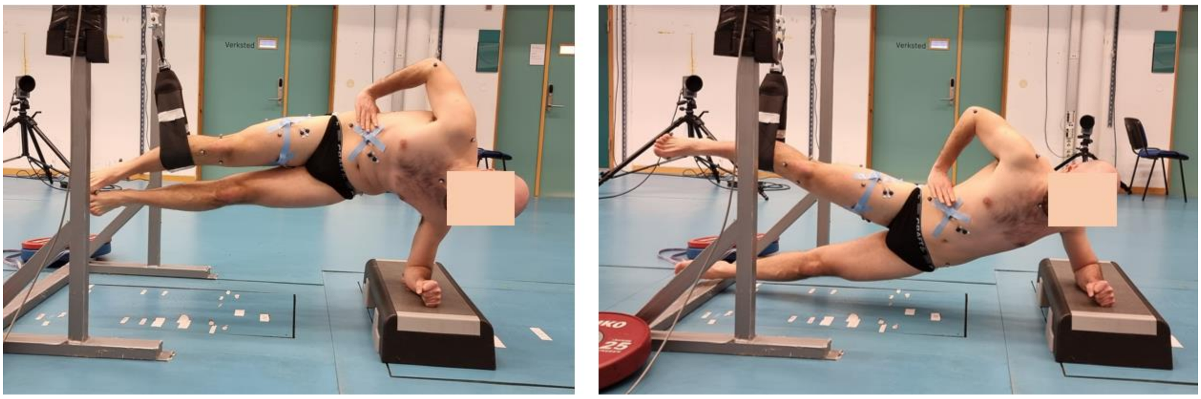

Figure 3-9: A subject performing the Copenhagen variant 2 exercise. *Left*: top position of the exercise, also the start and stop position. *Right*: bottom position, which is halfway through the exercise.

3.6.3 One leg pike (OLP)

Figure 3-10 shows the OLP exercise. This starts as an elbow plank, with both forearms on the step and the right foot in the sling. The sling is placed on the middle of the calf. The highest level of the step is used to have the right foot and shoulders of approximately the same height in the starting position. The body is pushed backwards, as far as the subject can. Then the foot is pulled in towards the rest of the body by making a flexion in the hip and at the same time lifting the backside towards the ceiling. From here is there an extension in the hip and the body is lowered to the starting position – and directly pushed backwards into the next repetition. The whole movement should be controlled. The subjects were asked to keep their left foot apart from their right foot to not cover the marker medially on the knee. For the subsequent analyses, the top position was defined as start and stop of one repetition. This was done to simplify the analyzes by dividing the exercise into a downward (eccentric) phase and an upward (concentric) phase.

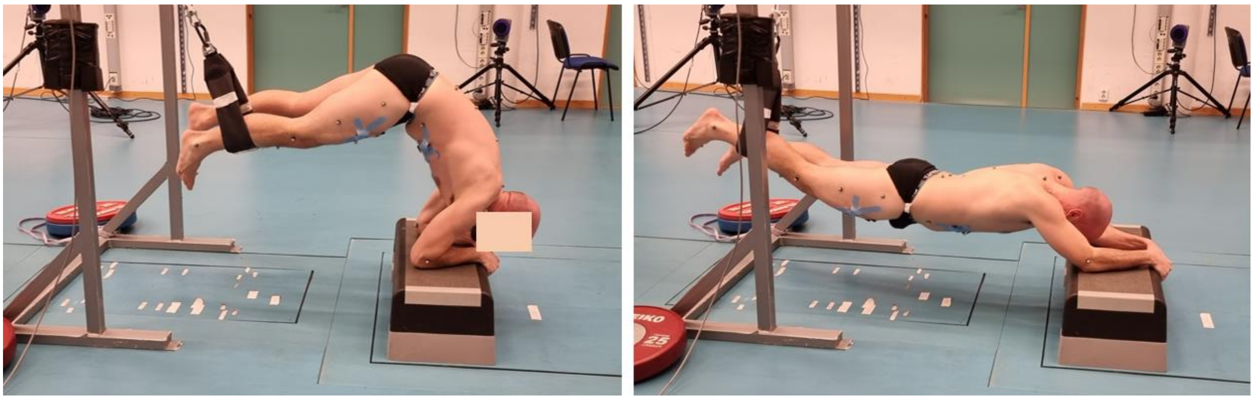

Figure 3-10: A subject performing the one leg pike exercise. *Left*: top position of the exercise, which is defined as the start and stop position for analysis purposes. *Right*: bottom position, which is defined as halfway through the exercise for analysis purposes.

3.6.4 Oblique plank with hip flexion and adducton (OPHFA)

The OPHFA exercise is demonstrated in Figure 3-11. It is something in between CA2 and OLP and intends to resemble a soccer pass. This exercise is performed with the body at an angle of approximately 45 degrees to the floor. The sling is placed on the middle of the right calf. The left forearm and right hand are used as support on the step. The starting position is like that of the CA2 exercise, but the body is rotated 45 degrees about its longitudinal axis. The exercise starts with lowering the body and at the same time pushing it backwards, just like in CA2, but the movement is oblique. From here the body is raised obliquely towards the ceiling by flexion and adduction in the right leg. The body is then lowered back to the starting position. The free left foot should be behind the right foot during the upward phase (like the standing foot during an inside pass is behind the kicking leg). As with the OLP, the top position is defined as the position of start and stop for the analyses afterwards.

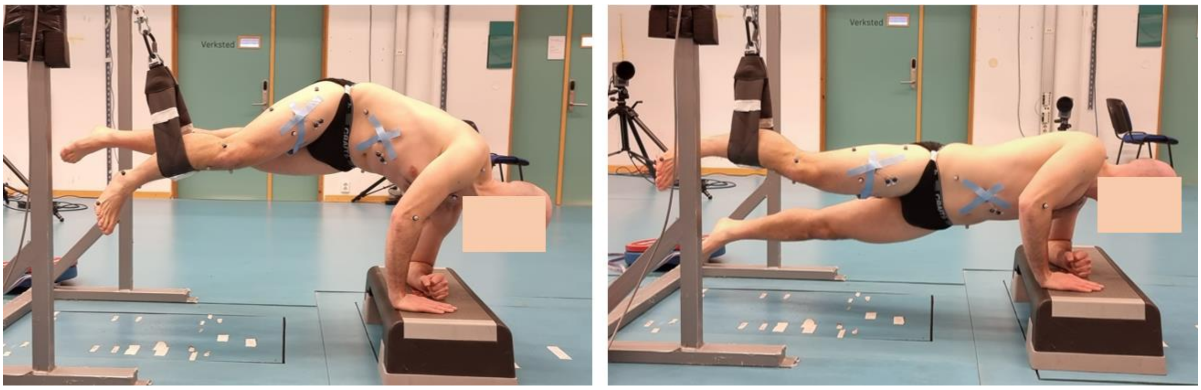

Figure 3-11: A subject performing the oblique plank with hip flection and adduction exercise. *Left*: top position of the exercise, which is defined as the start and stop position for analysis purposes. *Right*: bottom position, which is defined as halfway through the exercise for analysis purposes.

3.7 Maximum Voluntary Isometric Contraction (MVIC) test

MVIC tests were performed to define a reference contraction to normalize the EMG recordings from the four exercises. Two isometric tests were conducted, one for each of the muscles. As the term MVIC implies, the tests consist of maximum contractions against a fixed object by a static muscular work. This is conducted to normalize EMG signal to a reference value, which enables comparison between exercises and subjects. The following sections describe the test procedure for the MVIC tests of the adductor longus and the rectus femoris. One person in the test personal counted seconds during the test but did that without a timer. It also varied who was responsible for this, leading to an uncertainty as to whether maximum contraction was actually performed over the time it was supposed to.

3.7.1 Adductor longus MVIC

The MVIC test for the adductor longus muscle were performed supine with the hip and knees straight and the arms placed next to the body, as shown in Figure 3-12. The ankles were placed in a ForceFrame (Vald Performance, Alboin, Australia). The subjects were instructed to do maximum bilateral hip adduction for 5 seconds, go straight to maximum bilateral hip abduction for 5 seconds, followed by a 10-second break. This was repeated three times. The distance between the ankles of the adduction was measured to be 18 cm. The ForceFrame measures the force that the subjects exert on it, but data from this is not relevant for this project. Nor is the abduction part of the test. The force results were however used to determine which of the repetition to use for analysis.

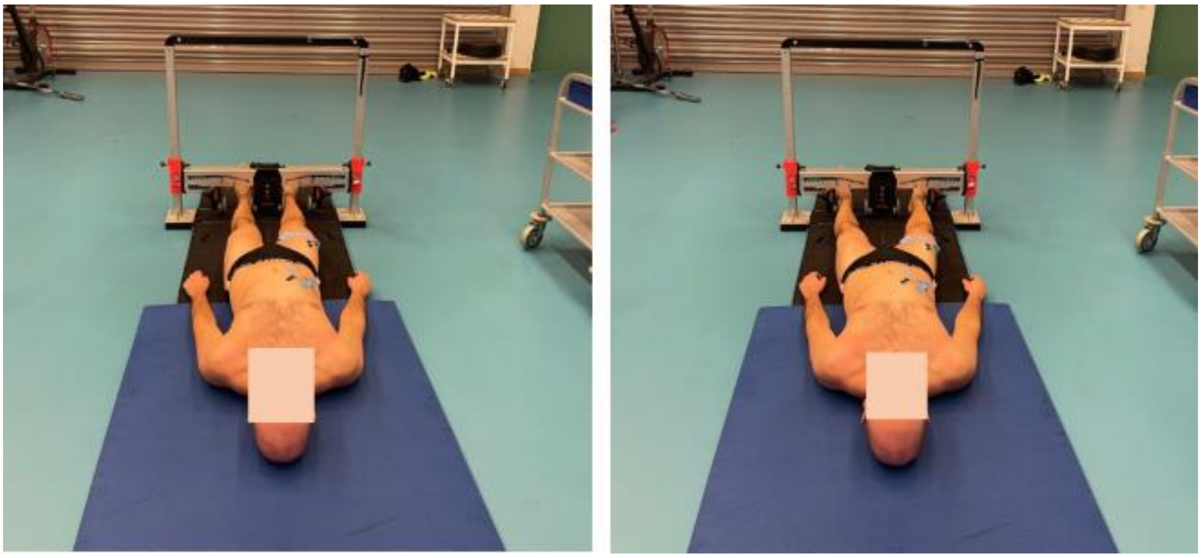

Figure 3-12: A subject performing the MVIC test for the adductor longus muscle. *Right*: a maximum bilateral hip adduction contraction. *Left*: a maximum bilateral hip abduction contraction.

3.7.2 Rectus femoris MVIC

Figure 3-13 shows the MVIC test of the rectus femoris muscle. This test was performed sitting on a chair. An object was placed slightly above the subjects' thighs. With a knee flexion, the subjects lifted their right foot slightly above the ground and pushed all they could against the object one time for 5 seconds. The subjects could hold on to the sides of the chair while pushing.

Figure 3-13: A subject performing the MVIC test of the rectus femoris muscle, by doing a maximum contraction against an object above his right thigh.

3.8 Data Processing

First step of the data processing was to go through each recording in QTM in order to decide which part was to be used further in the analyses. For the MVIC test, only raw EMG data was reviewed. One second of maximum contraction was chosen. In general, this time was approximately in the middle of the contraction. But if raw EMG signal showed a clearly greater burst earlier or towards the end of the test, then this affected the choice. The MVIC test of rectus femoris included only one repetition and thus part of this repetition was analyzed. MVIC of adductor longus had three repetitions. The repetition with the greatest force output on the ForceFrame was chosen, since recruited motor units gradually increases in an isometric contraction [41]. For the static trial, also one second, the first second, was selected. Before the selection was made, a labeling list was made with names of all markers, and each marker was identified based on this list. In addition, lines, so-called “bones” were made between markers. This is not anatomical bones but made it possible to visual the connection between markers. The bones are shown as yellow lines between the green markers in the left part of Figure 3-1. The identification of the markers and creation of bones was also done for each recording of the exercises. This made it easier to visual the movements and to detect any errors during the performances, such as markers disappearing. One repetition of each exercise was selected for further analysis. The choice was made based on several factors: the important markers (on the load cell and the pelvis) should be present as much as possible and the EMG signal had to be valid. Time at start position (top), halfway through the exercise (bottom) and stop position (top) of the exercises were manually selected. For every recording, the marker frames (from 200 Hz samplings frequency) that constituted the selected period was noted.

The one selected second from the MVIC test was rectified and processed using root mean square, and this value was defined as reference value for a given muscle and subject. For the exercises, raw EMG data was rectified and smoothed with a window length of 200 (100 ms) based on recommendations by Konrad [43]. The processed EMG signal was divided by the reference value to find normalized signal as %MVIC. Normalized peak value and mean value with the corresponding standard deviation were extracted to use for statistical comparisons, and to calculate average values of all subjects.

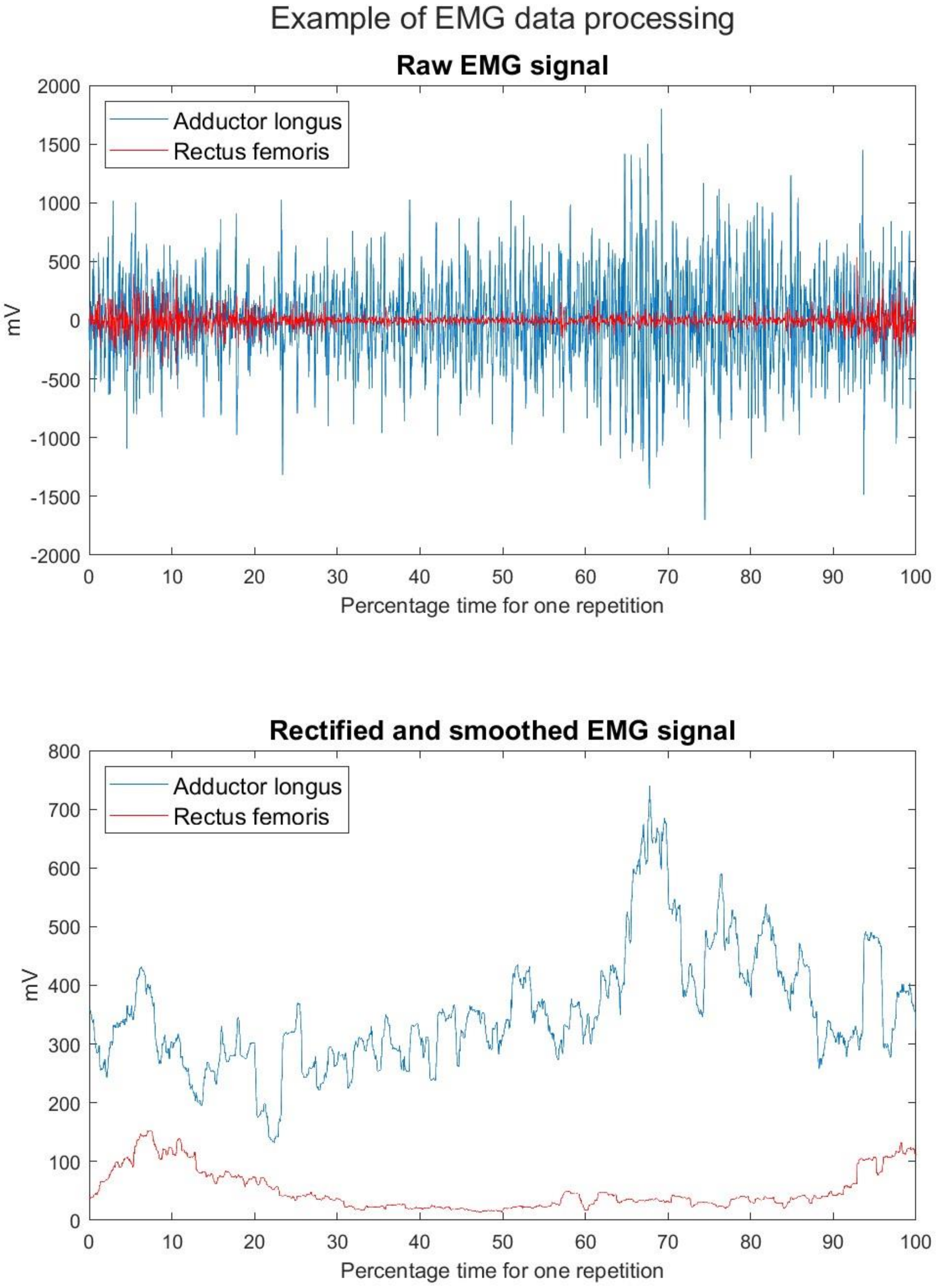

Figure 3-14: An example of how EMG data was processed. This example is from one subjects' performance of the oblique plank with hip flexion and adduction exercise.

Average positions of the markers in the static trial were defined to be the position of the markers in the static pose. Local coordinate system for pelvis was found, for both static trial and throughout the exercises. Origin of the axis cross was midway between right and left anterior superior iliac markers (markers number 11 and 12 in Table 3-1 Figure 3-1), and the y-axis was defined to lie on the line between these markers with positive direction towards the subjects left side. The direction of the x-axis was along a line between the origin and midway between the right and left posterior superior iliac spine (markers number 13 and 14 in Table 3-1 Figure 3-1), with positive direction outwards from the person on the anterior side. Perpendicular to these the z-axis was found. For recordings where one of the markers on the pelvis was missing, that markers was interpolated based on the three other pelvis markers. A gap limit was set to 100 samples (0.5 seconds), any recordings with greater gap were discarded. Right hip centers were found by the local coordinate system of pelvis and the distance between right and left anterior superior iliac markers (the two markers in the front of pelvis). The joint was calculated to be at 19% av the distance in negative x-direction, 36% in negative y-direction and 36% in negative z-direction [97].

Data from the load cell were smoothed by moving average with a window length of 50 (50 ms) (see Figure 3-15), recalculated from Volt to force (F), normalized by the subject's mass (nF), and then resampled to match the samples of the right hip center. The moment arm (r), the shortest distance from the hip center to a line from the top marker on the load through one pair of markers lower on the cell, were determined throughout the exercises. Review of the recordings showed many cases where the high or low markers on the load cell were missing for periods. It was decided to draw a line between the top marker and the middle of the lower markers, when possible, in the other cases the high markers were visible at all times and were used. Normalized torque ($n\tau$) was then calculated using the following formula:

$$n\tau = nF \cdot r$$

Normalized peak and mean value during one repetition, with corresponding standard deviation, were calculated for each subject and extracted for statistical comparison and to find average values of all subjects.

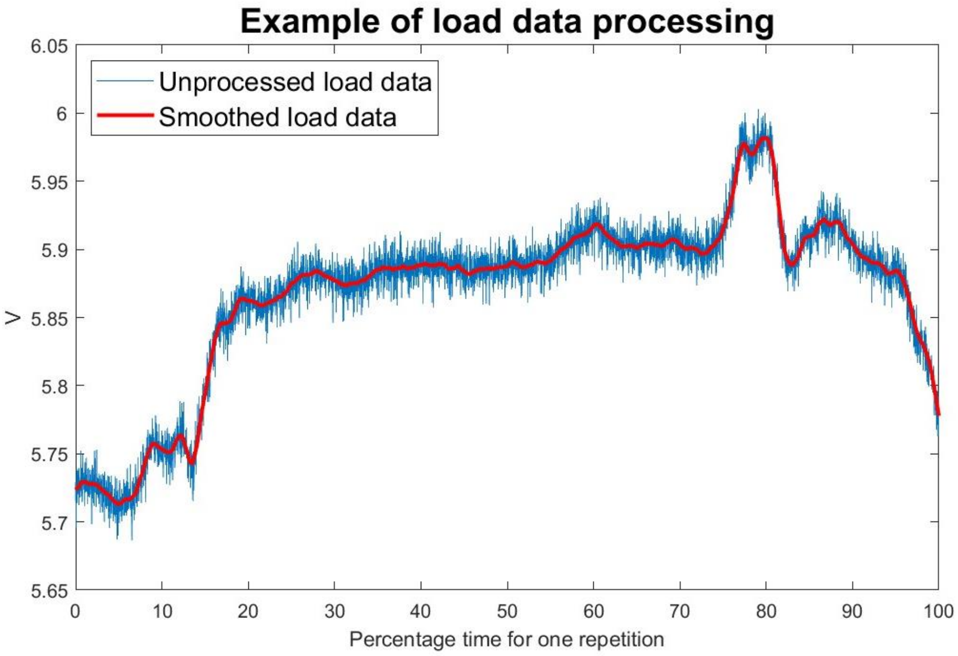

Figure 3-15: An example of how data from the load cell was processed using moving average. This example is from one subjects' performance of the one leg pike exercise.

Figure 3-16 illustrates the motivation behind motion capture and force measurements.

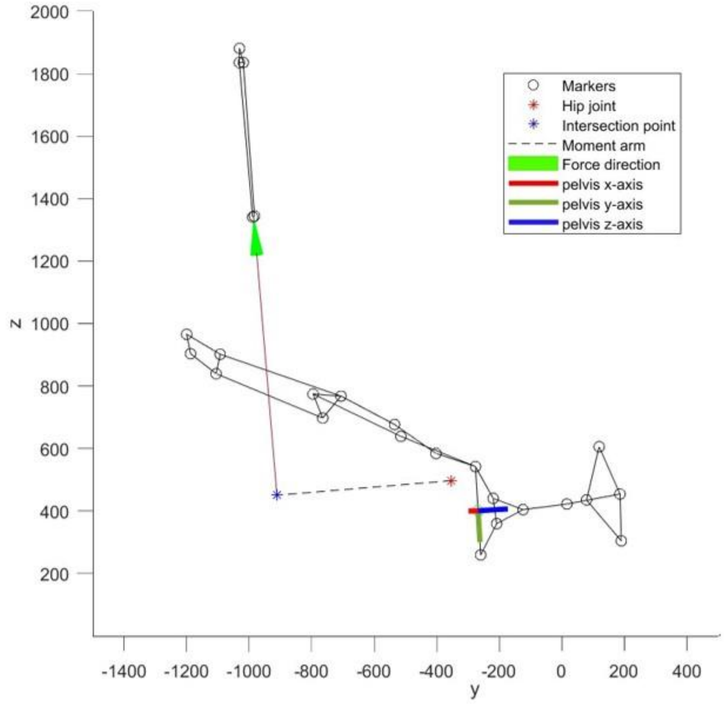

Figure 3-16: Variables of interest from motion capture and force measurements, provided as an example from the bottom position of the Copenhagen adductor variant 1 exercise.

The EMG and torque data for each exercise was also time normalized. The EMG data was first resampled to match the samples of hip center and torque, so that no single point marked the bottom position. Then both data of muscle activation and force were separated into on eccentric phase and one concentric phase and interpolated to 50001 points. The last point of the downward phase and the first point of the upwards phase was equal and defined as the value in the bottom position. The mean data for all participants throughout the exercises was found and plotted.

One-way analysis of variance (ANOVA) was used repeatedly to compare data between the four exercises. Type of exercise were thus the independent variable, and analysis were run for the dependent variables peak %MVIC for each of the two muscles, mean %MVIC for each of the two muscles and peak and mean of normalized torque. With a p-value set to 0.05, the ANOVA tests revealed if there was any significant difference between the exercises. In cases with significant differences, post hoc tests were performed to determine where the differences came from. How the analysis were carried out, and other data processing can be seen in Appendix G and Appendix H.

3.9 Ethics

The ethical committee of the Norwegian School of Sport Sciences and the Norwegian Centre for Research Data approved the study. For applications and approvals see Appendix A, Appendix B, Appendix C and Appendix D. All subjects signed a written informed consent form (Appendix E), where their rights of participation were presented. Participation was voluntary and they could withdraw their consent at any time without having to provide a reason. All collected personal data were non-identifiable. The risk of injury by participating was minimal, the squat rack was secured to avoid accidents, and players could not participate with an ongoing groin injury. All the equipment used for measurements were non-invasive. Photos of one subject was taken and are presented in this thesis, with permission.

4. Results

The analyzes are done based on data from 18 subjects, but some recordings had to be rejected due to absent markers that exceeded the gap limit. This applied to one subject in CA2 and four in OPHFA, thus n = 17 in CA2 and n = 14 in OPHFA remained. The EMG data were nevertheless included in the analysis, as it is independent from motion capture.

4.1 Muscle activity

The extracted and processed EMG data were used to find results of muscle activity. The variables peak %MVIC and mean %MVIC are presented here, and these data were analysed with ANOVA and post-hoc analysis. Peak %MVIC (further abbreviated to "peak") is the average of every subject's maximum EMG value divided by their own reference value for a given exercise and muscle. Mean %MVIC (further abbreviated to "mean" value) is the average of every subject's mean EMG signal divided by their own reference value for a given exercise and muscle.

ANOVA and subsequent post hoc analysis for the adductor longus muscle showed no significant differences between CA1, CA2 and OPHFA in mean nor peak values. OLP had means values significantly lower compared to the three other groups for both peak and mean. With the lowest difference to CA1 for mean on 28.2 (95% CI: 4.5 – 51.9), and the least difference to CA2 for peak on 56.2 (95% CI: 11.0 – 1.01). That OLP is lower is natural, as it is the only one of the exercises that does not include adduction in the frontal plane, which is the main function of the adductor longus. For mean EMG the true difference between CA1 and CA2 was 5.1 (95% CI: -18.6 – 28.7), 5.2 (95% CI: -18.5 – 28.9) between CA1 and OPHFA and 0.1 (95% CI: -22.8 – 23.1) between CA2 and OPHFA. The following applies for peak EMG: 3.3 (95% CI: -43.4 - 49.7) between CA1 and CA2, 2.1 (95% CI: -44.5 – 48.7) between CA1 and OPHFA and -

1.2 (95% CI: -46.3 – 44.1). Between the sexes, a significant difference was found for mean adductor longus in CA1 ($p = 0.009$), with the highest activation for women.

For rectus femoris ANOVA analysis revealed significantly differences ($p < 0.05$) between the groups in both mean and peak. Post hoc analysis showed that OLP had significantly higher values than CA1, CA2 and OPHFA ($p < 0.0001$ for all). No significantly differences were found between CA1, CA2 and OPHFA for mean rectus femoris. For peak values, OPHFA had significantly higher values than CA1 ($p = 0.027$), but significantly differences were not found between OPHFA and CA2 and between CA2 and CA1. Since OLP includes pure flexion of the hip joint, it is not surprising that it has higher values than CA1 and CA2 which does not consist of movement in the sagittal plane. More interesting is the relation between OLP and OPHFA and between OPHFA and CA1/CA2. The execution of OPHFA also includes a flexion of the leg, but significantly lesser activation than OLP, and a %MVIC difference of 145.8 (95% CI: 89.6 – 201.9) for peak and 92.2 (95% CI: 70.2 – 114.2) for mean. This is a difference of almost one and a half and one time a maximum isometric contraction. Between CA2 and OPHFA the differences are 14.3 (95% CI: -7.7 – 36.3) for mean and 50.8 (95% CI: -5.4 – 106.9) for peak. Between CA1 and OPHFA 19.9 (95% CI: -2.1 – 41.9) is the difference for mean and 61.4 (95% CI: 5.2 – 117.2) for peak. The latter is the only Copenhagen-variant significantly different from OPHFA. None significantly differences between the genders were found for rectus femoris.

Table 4-1 and Figure 4-1 shows peak and mean muscle activation for adductor longus and rectus femoris during performance of the four exercises. All peak values of adductor longus is above the reference value from the MVIC test. Although the differences were not significant, CA2 and OPHFA have a slightly higher mean value than CA1 for adductor longus but CA1 has the highest peak value. The greatest peak and mean values of all are found in rectus femoris for OLP. Both mean and peak of adductor longus in OLP is greater than the values for rectus femoris in OPHFA – although OLP do not include adduction, but OPHFA do include flexion of the leg.

Values of adductor longus is higher than the corresponded values of rectus femoris in OPHFA, which means that the performance of the exercise required recruitment of more motor unit in adductor longus than rectus femoris. That OLP has higher values of adductor longus than CA1 and CA2 has for rectus femoris, may be due to the fact that adductor longus helps to stabilize the pelvis and contributes as a flexor while rectus femoris do not act as an adductor. The presented standard deviations are also relatively large, which indicates a large variance among the subjects. Although it was not documented in any way, it was observed a big difference in how challenging and heavy the subjects experienced the exercises, something that could explain this variation.

Table 4-1: Mean and peak electromyographic activation for adductor longus and rectus femoris during performance of the four one-foot dynamic plank exercises.

	CA1	**CA2**	**OLP**	**OPHFA**
Adductor longus, peak ± SD (% MVIC)	160.8 ± 67.3 *	157.6 ± 56.5 *	101.4 ± 29.8 ^☆¤	158.7 ± 47.1 *
Adductor longus, mean ± SD (% MVIC)	78.1 ± 33.1 *	83.2 ± 26.5 *	49.9 ± 19.5 ^☆¤	83.3 ± 25.8 *
Rectus femoris, peak ± SD (% MVIC)	34.9 ± 23.0 *¤	45.5 ± 41.8 *	242.1 ± 100.0 ^☆¤	96.3 ± 63.8 ^*
Rectus femoris, mean ± SD (% MVIC)	14.9 ± 8.8 *	20.5 ± 8.6 *	127.0 ± 43.4 ^☆¤	34.8 ± 25.0 *

^ Significantly different to CA1
☆ Significantly different to CA2
* Significantly different to OLP
¤ Significantly different to OPHFA

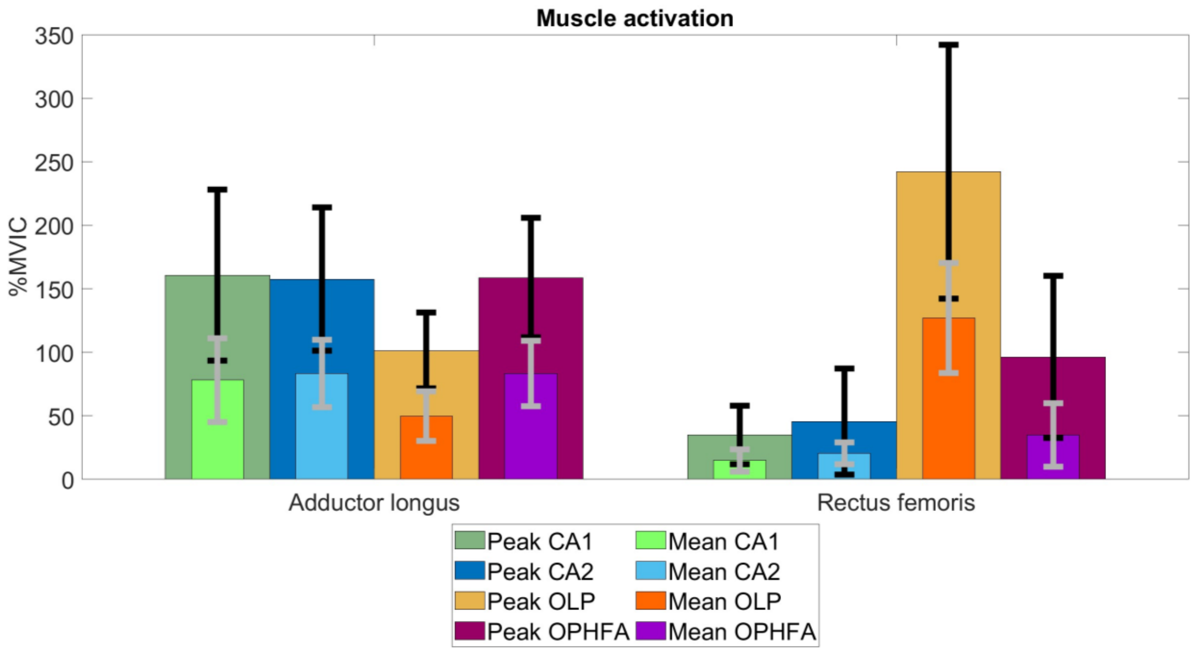

Figure 4-1: Mean and peak electromyographic activation, with error bars, for adductor longus and rectus femoris during performance of the four one-foot dynamic plank exercises.

Figure 4-2 shows how the electromyographic activation changes through the exercises. There are no distinct peaks for any of the exercises or muscles, but it looks like there is a tendency for CA1, CA2 and OPHFA to require more activation of adductor longus and for OLP to have higher rectus femoris activation in the concentric phase than in the eccentric phase. The activation of adductor longus in OLP is quite small at the top position (start and stop), less help is probably required here to stabilize the pelvis as the upper body can contribute more to this (Figure 3-10). CA1 seems to be the exercises with greatest variation of activity, and OLP seems to have a higher activation than CA1 for a small period towards the end of the eccentric phase. The plot of rectus femoris also illustrates well that there is much more activation during performance of OLP than the others, and that OPHFA always lies above CA1 and CA2.

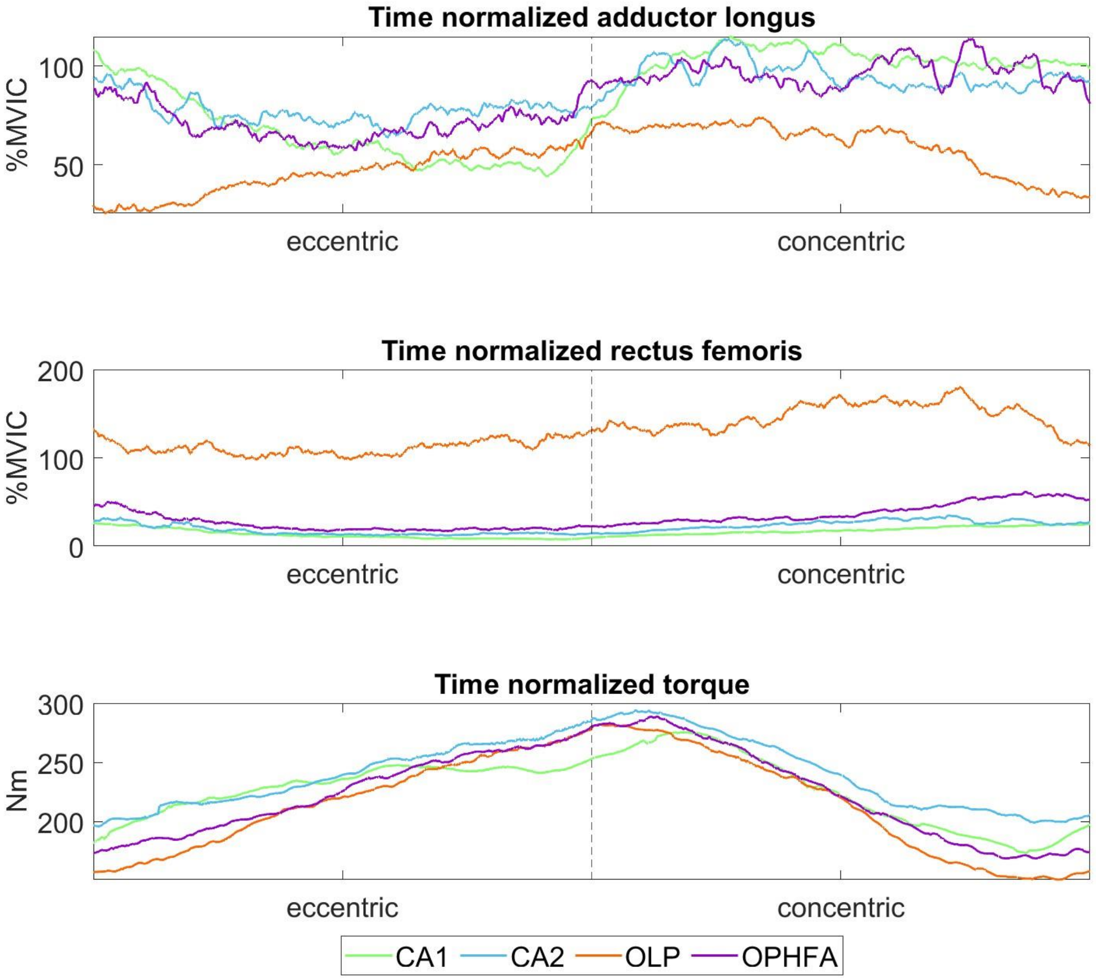

Figure 4-2: Muscle activation of adductor longus and rectus femoris, and torque normalized to time, from start to stop of one repetition. The vertical line represents the bottom position of the exercises. To the left of this line is the eccentric (downward) phase of the exercises, while the concentric (upward) phase is to the right. The plot represents mean values of all subjects.

4.2 Torque

The results for torque were found by a combination of motion capture and force measurements. Presented and analysed peak values are the average of every subject's maximum torque value divided by their mass for a given exercise. Presented analysed mean values are the average of every subject's mean torque value during one repetition, divided by their mass for the given exercise.

ANOVA analysis revealed none significantly differences in mean torque ($p = 0.89 > 0.05$) nor peak torque ($p = 0.91 > 0.05$). The results of peak and mean can be found in Table 4-2, and Figure 4-3 shows the similarities of the values. There were also no significant differences between men and women.

Table 4-2: Mean and peak torque during performance of the four one-foot dynamic plank exercises.

	CA1	**CA2**	**OLP**	**OPHFA**
Torque, peak ± SD (Nm)	281.6 ± 80.5	301.9 ± 88.2	286.4 ± 83.5	294 .5 ± 89.4
Torque, mean ± SD (Nm)	228.4 ± 30.7	238.5 ± 36.0	220.7 ± 80.2	225.5 ± 37.2

^ Significantly different to CA1
☆ Significantly different to CA2
* Significantly different to OLP
¤ Significantly different to OPHFA

How torque changes though the exercises are showed in Figure 4-2. The maximum values seem to be greatest early in the concentric phase, for all exercises. The load seems to increase steadily up to this point and decrease evenly right after. In the bottom position, the CA1 has the lowest value. This exercise has the highest setting of the sling and is performed without the step, leading to the biggest height difference between the foot in the sling and the supporting arm. Of all exercises, this position of CA1 has the greatest adduction angle of the leg. At the beginning and end of the exercises, the load is smallest for OLP. This is probably because a large portion of the subject's weight is above the step. OPHFA is similar to OLP in these positions and is the one with second least torque. Torque for both CA1 and CA2 seems to be quite higher in the top position, and more evenly throughout the exercises.

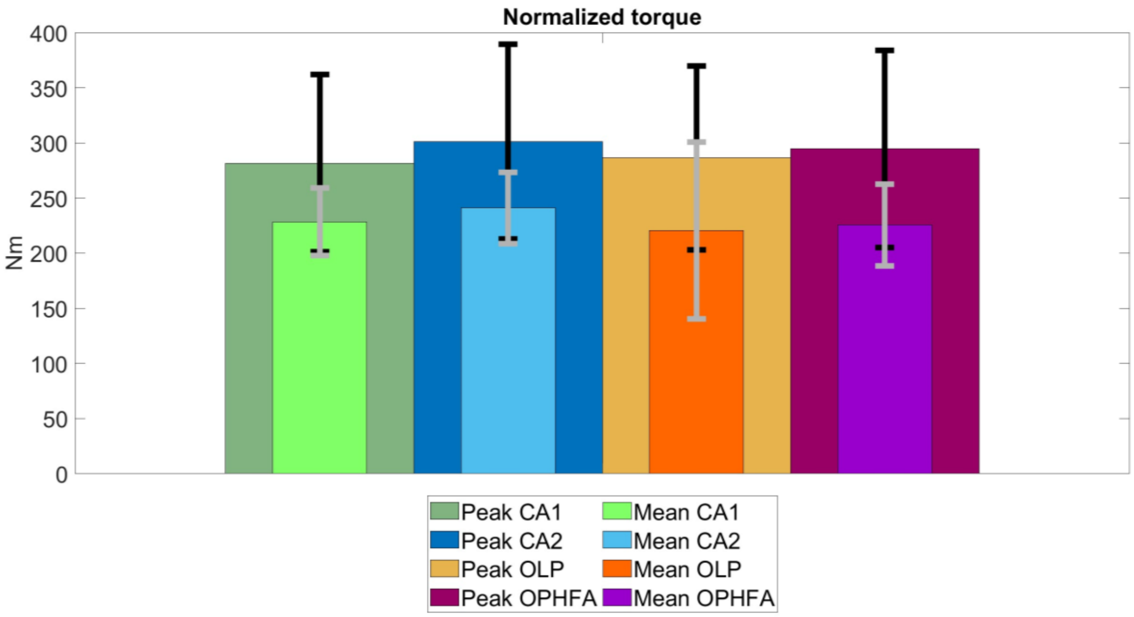

Figure 4-3: Mean and peak torque normalized to the subjects' mass, with error bars, during performance of the four one-foot dynamic plank exercises.

4.3 Execution of the exercises

The exercises were not standardized in terms of time, and the exercises were thus performed over different periods of time, see Table 4-3. The duration of CA1 was the shortest, followed by CA2. OLP and OPHFA lasted the longest. Most of the examined repetitions had a temporally longer eccentric phase than concentric.

Table 4-3: Average time with standard deviation spent on each exercise, the ratio of eccentric versus concentric time, and range of both variables.

	Total time (seconds)		**Eccentric/concentric time**	
Exercise	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**
CA1	2.77 ± 0.61	1.80 – 4.15	1.71 ± 0.37	1.15 – 2.49
CA2	3.92 ± 0.68	2.85 – 5.46	1.47 ± 0.34	0.95 – 2.16
OLP	4.59 ± 1.02	3.25 – 6.40	1.49 ± 0.33	1.12 – 2.57
OPHFA	4.45 ± 1.27	2.65 – 7.20	1.41 ± 0.27	1.00 – 1.95

Figure 4-4, Figure 4-5, Figure 4-6 and Figure 4-7 shows the angle of pelvis in relation to the floor for respectively CA1, CA2, OLP and OPHFA. More specific, they show the angle between the local pelvis y-axis and the global x-axis of the laboratorium. The plots are made mainly to explain how the body is tilted. For CA1 the high sling height will affect the angle, especcialy for those with the shortest legs in top positions. Neverthless, many show to have a consistency around 90 degress. Some of the exceptions are shown in plot 3 and 9, which has a relative constant angle smaller and larger than 90 degrees, and plot 5 with a very unstable pelvis position. For CA2, many had a good angle of approximately 90 degrees throughout the exercise, but also litte rotation of the pelvis for some subjects. The same applies to OLP, but with an angle of 0 relative to the groud. OPHFA had the most rotation of the pelvis, with a tendency for the greatest angle in the middle of the exercise. The angles appears to be more often above 45 degress than it is below 45 degrees, indicating that the exercise is more similar to CA1/CA2 than OLP.

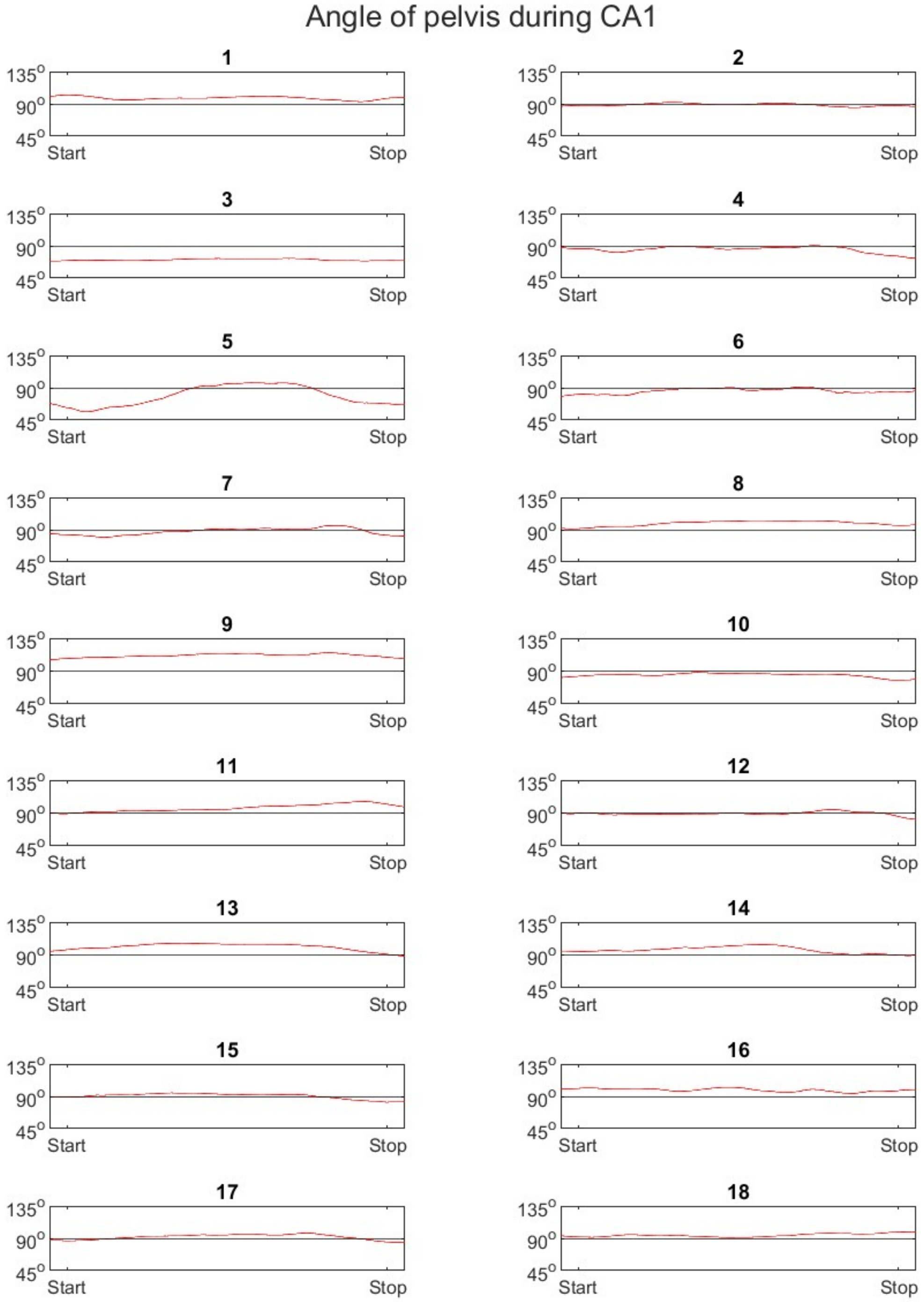

Figure 4-4: Angle of pelvis in relation to the floor during one repetition of the Copenhagen adductor variant 1 exercise.

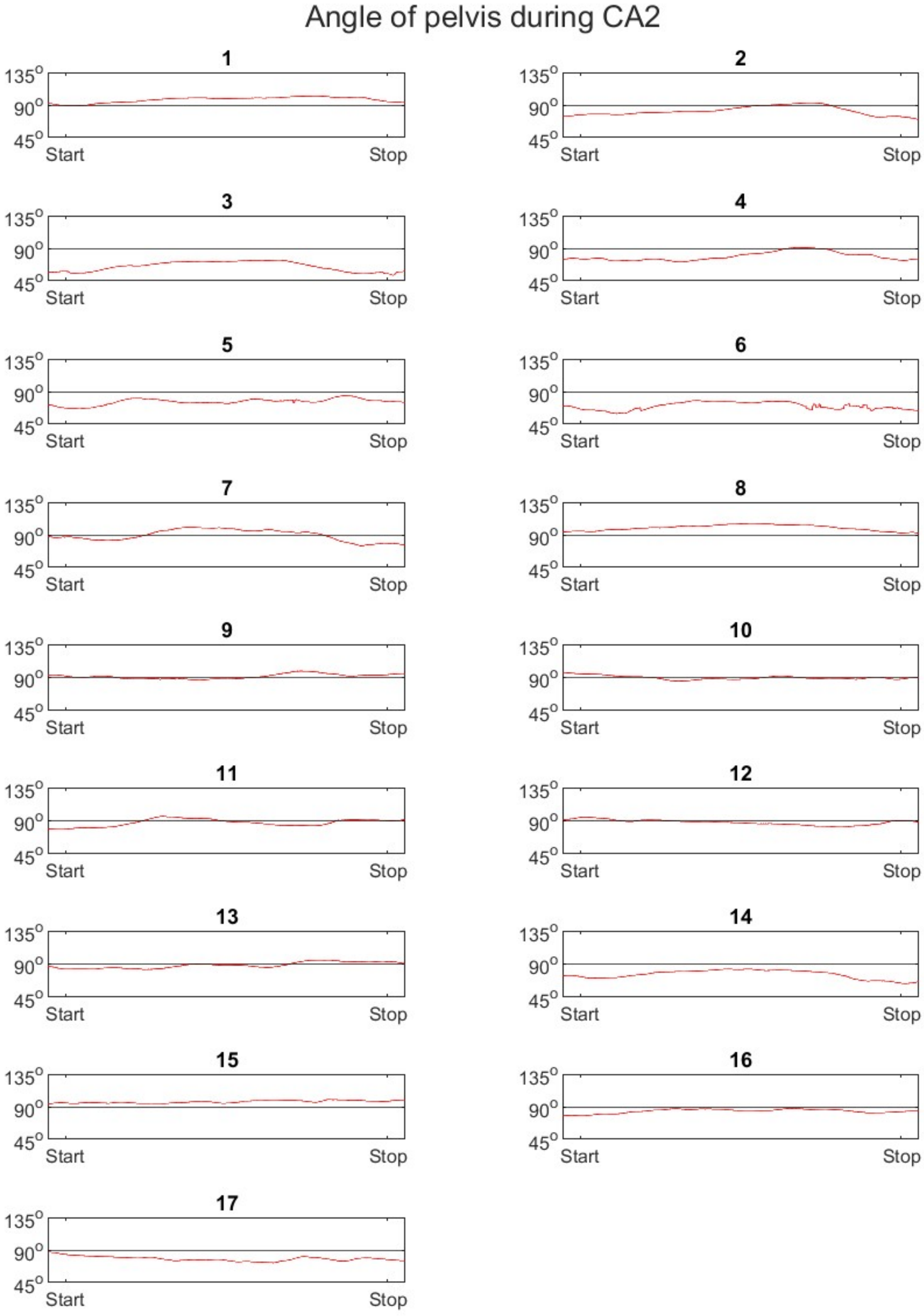

Figure 4-5: Angle of pelvis in relation to the floor during one repetition of the Copenhagen adductor variant 2 exercise.

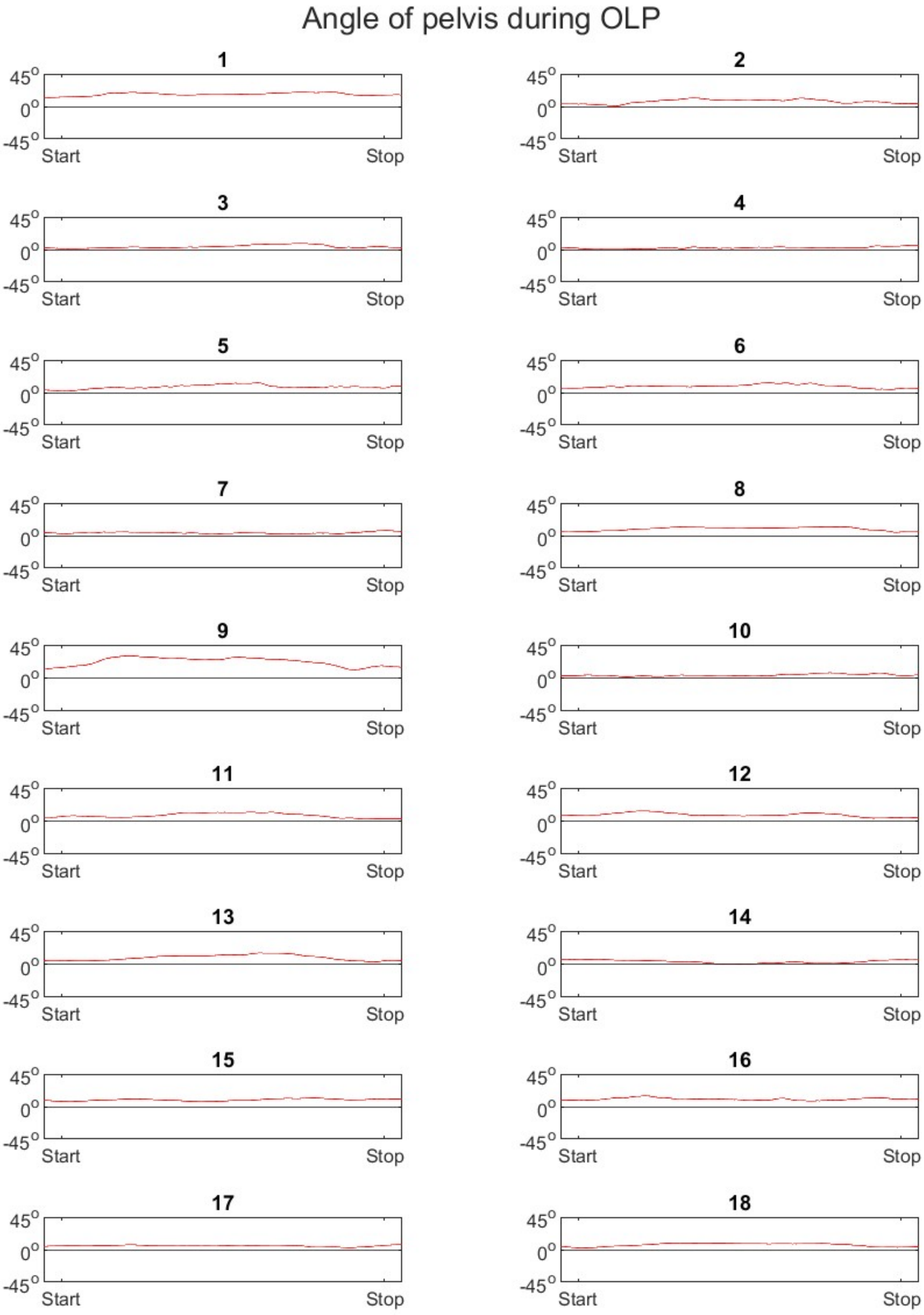

Figure 4-6: Angle of pelvis in relation to the floor during one repetition of the one leg pike exercise.

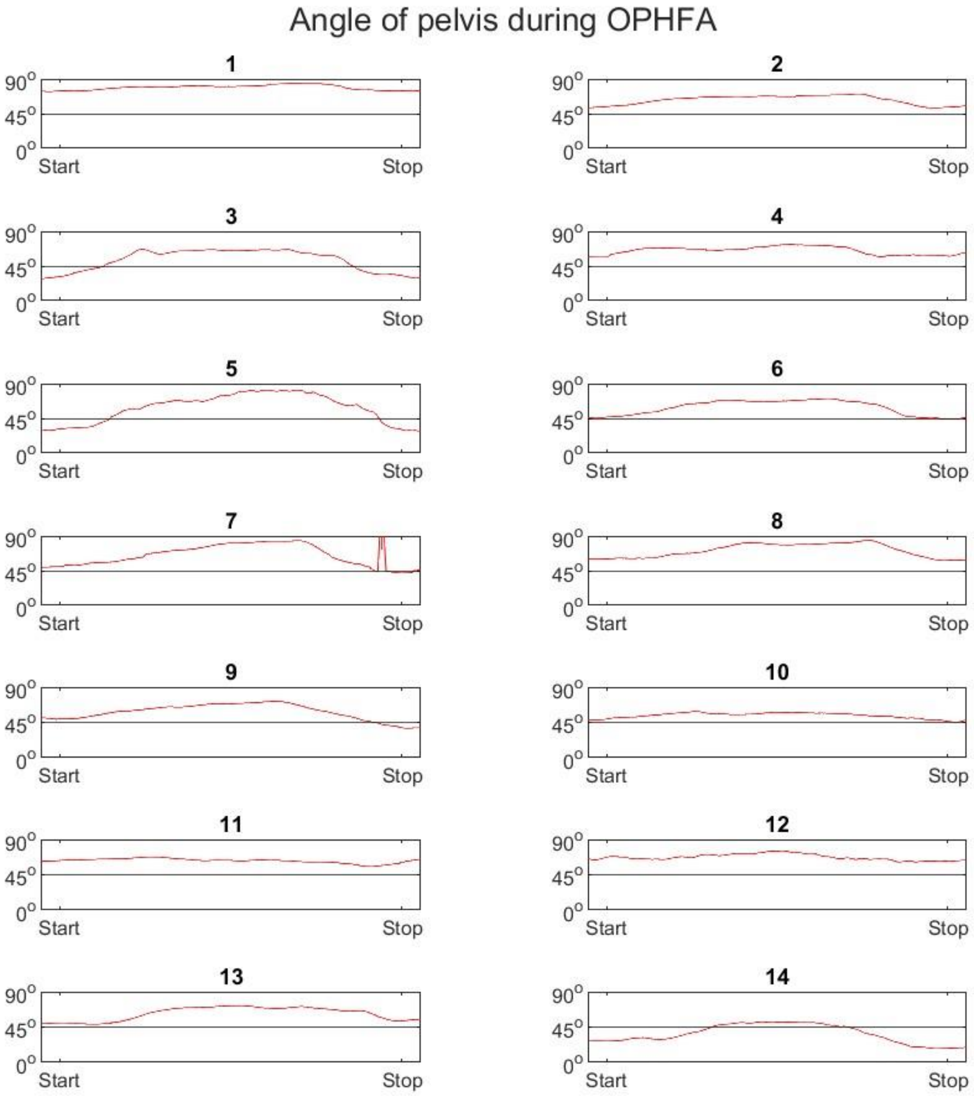

Figure 4-7: Angle of pelvis in relation to the floor during one repetition of the oblique plank with hip flexion and adduction exercise.

4.4 Comparison to other works

Peak normalized EMG of adductor longus in Copenhagen adductor is the only measurement done in this project which has also been investigated in one previous publication, by Serner et. al [24]. This study found a 108 ± 5 %MVIC for the dominant leg, and 69 ± 6 %MVIC for the non-dominant leg. Only the subjects' right foot, regardless of whether it was the preferred foot or not, was tested in this master thesis. The result here, 160.8 ± 67.3 %MVIC, is quite higher, although the execution intended to be as similar as possible to the standardization the exercise described by Serner et. al [24]. Different execution may still be part of the explanation for the difference. Another reason may be due to different procedure of finding reference contractions. In both studies the subjects performed a MVIC test for adductor longus by a bilateral hip adduction with the hips and knee straight in a supine position. In this study a fixed object were placed between the subject's ankle, while a ball was placed between the subject's knees in the previous study. Another difference is the gender of the subjects. In this study both men and women participation, while only men conducted the exercise in the study by Serner et. al. This is probably of little importance as there were none significantly difference between the sexes in peak EMG. Further, CA2 and OPHFA showed no significant difference to CA1, and has also a much higher muscle activation value then the former measurement. Even OLP (101.4 ± 29.8 %MVIC), performed without a hip adduction, had almost the same activation as the dominant foot and a clearly greater value than the non-dominant. To compare with other common hip adductor exercises in another study [93], the greatest value of peak and average EMG was found in a side-lying hip adduction exercise, with peak of 60.1 ± 16.2 %MVIC and average of 22.4 ± 5.5 %MVIC. These are lower values than all results found through this project. The lowest peak and mean value here was for the OLP, with values of respectively 101.4 ± 29.8 %MVIC and 49.9 ± 19.5 %MVIC.

5. Discussion

With a focus on possible groin injury prevention, this study investigated electromyographic activity of the adductor longus and rectus femoris muscles, and hip joint moment during performance of four exercises. To my knowledge this is the first study to examine rectus femoris activation and to integrate measurements of torque in groin related exercises for injury prevention.

5.1 Main Findings

One of the investigated exercises is common practice to include in groin prevention work today, namely the Copenhagen adductor exercise (CA1) [34]. This exercise is feasible almost anywhere, even on the soccer pitch, and can be conducted prior to or after a training session. This opportunity to easy implement the exercise in a soccer player’s training routine, is an advantage of the exercise [24, 33]. Even though the exercise has proven to increase eccentric hip adduction strength over an 8-week period [35], it is a bodyweight exercise where the progression mainly relies on adding repetition and not increase the intensity of the exercise. The ability for these kinds of exercises to elicit large strength gains has been questioned by specialists [34], as it is well documented that progression is important for developing muscle strength [42]. For this project, a new exercise (CA2) very similar to CA1 but with some modifications were designed with the intention of having a greater load. However, the results showed no significant difference either in muscle activation or hip torque between these two exercises. CA2 is also a bodyweight exercise, and therefore have the same limitations when it comes to intensity increase. But if the exercise on the other hand had appeared to have a significantly higher load than CA1, it would be very appropriate to further investigated its effect on groin problem prevention. A significant difference in the intensity of the exercises would have provided useful information regardless of which exercise seemed the heaviest, as it had created a basis for grading the exercises. When it comes to prevention and rehabilitation of injuries, the most challenging exercise is not always the best to choose, because the appropriate exercise intensity should match the different phases of treatment and prevention [24, 93]. If an injury has first occurred, exercise intensity should gradually increase during rehabilitation [26], and therefore knowledge of low-intensity exercises is also useful. OLP had significantly lower adductor longus activation than the other exercises, but still considerable, as the peak value exceeded the reference value. Clinicians should consider using this exercise as part of rehabilitation of groin injuries. The original Copenhagen adductor is a high-intensity exercise [24], and if the load had been different from CA2 it could have been recommended to perform for a period before CA1 or as the next level when CA1 becomes too easy. A limitation with CA2 relative to CA1 is it need for a sling (or something similar) for execution and is thus not as accessible as CA1. In the performance of CA2, the subjects were to push themselves backwards. The hypothesis of greater load came from an assumption of a longer moment arm in the bottom position. It varied whether the moment arm was larger or not compared to the moment arm in CA1. The shorter the legs of the subjects, the larger is generally the hip abduction angle in CA1 in the bottom position, which makes for a smaller moment arm. In the set-up of CA2, the height difference between the supporting arm and the foot is much smaller, and the angles will vary much less. Another difference between the exercises is the location of the sling. In CA1 it was placed slightly above the angle, while it was placed on the middle of the calf in CA2. This also affects the length.

Most preventive groin injury exercises focus mainly on hip adduction movement. This thesis additionally aimed to investigated hip flexion as the rectus femoris muscle is also prone for groin injuries [25, 26]. The two exercises OLP and OPHFA both include hip flexion, the first one as its only movement around the hip and the last in addition to hip adduction. Since adductors are most commonly injured [25-27], it was never an intention of this project to suggest an hip flexion exercise to replace hip adduction in prevention of groin problems. Rather, the purpose of investigating OLP and OPHFA was twofold: to provide information on whether OLP is a good exercise for strengthening rectus femoris, and to compare the load of OPHFA against adductor longus activation in CA1/CA2, rectus femoris activation in OLP and torque off all. By similar adduction results between OPHFA and CA1/CA2, similar flexion result between OPHFA and OLP *and* a high activation of rectus femoris during OLP, it could have been suggested to perform the OPHFA instead of CA1/CA2 and OLP. Which would have saved time, as one exercise is half as many as two. This would have been very advantageous, with one single exercise having “the best of both worlds”. However, this was not the case. OLP did show high activation of rectus femoris, but the activation in OPHFA was significantly lower. Rectus femoris activation of OPHFA was similar to CA2 for mean and peak, and similar to CA1 for mean. A difference was found in peak rectus femoris for OPHFA and CA1, which shows a small trend of OPHFA having a greater loas than CA1. OPHFA was also similar to CA1 and CA2 for all adductor longus results. Figure 4-7 may explain some of the reasons why OPHFA are more like CA1 and CA2, than OLP. The execution of OPHFA seems to be more like the Copenhagen variants, which indicates that the movement for many of the subjects consisted of more adduction than flexion. With none significantly differences between torque in any of the exercises, this study shows clear evidence that CA1, CA2 and OPHFA is better for adductor longus intensity while OLP is the best for rectus femoris. Although OPHFA have similar outcome scores as CA1 and CA2, it has one important characteristic that stands out, namely the sport-specific movement. OPHFA intends to resemble a soccer pass. Kicking is presented as one mechanism commonly resulting in groin injuries [23, 25, 85, 87]. It would be interesting for future studies to investigate the effects of exercises matching common movements and injury mechanisms in the sport.

This work has investigated the amplitude parameters peak and mean for muscle activation. Another parameter that could have been interesting to examine is the EMG area, that is the mathematical integral under the EMG amplitude for the duration of a certain period [43]. This variable also takes the time perspective into account. With a greater range of motion, such as in OLP and OPHFA, the muscles were active for a longer period and the total load may have been greater. An alternative is to standardize exercises by time, for example 3 seconds in concentric phase and 3 seconds in eccentric phase. In the trials in this project, the subjects executed the exercises over the time they found most convenient for them, which probably reflects the time they would use in training.

5.2 Methodological Assessments

The selection consisted of soccer players of both genders with a great variation on playing level. This was determined because groin injuries can incur for all footballers, and this group of subjects represents a great variety among soccer players active today. This also led to a large dispersion of results. CA2, OLP and OPHFA were new suggested exercises for prevention of groin injury, but CA1 was known to many of the players. Some did the exercise regularly, others sometimes while some had never performed it. Not precisely documented, but conversations with the subjects during the test sessions indicated a correlation between higher playing level and frequency of performing the exercise. To ensure better and more equal execution of the exercises, it would have been beneficial if the subjects attended two test sessions, the first to make them familiar with the exercises and the second to do the recordings. However, this had required more time from the participants, of which it was initially difficult to recruit enough.

When it came to muscle selection, it was natural to include adductor longus as this is the muscle most often injured. This study aimed to investigated exercises in which several of the muscles exposed to groin injury were activated to a large extent. The main limitation with surface EMG is the fact that only superficial muscles can be recorded [43], this precluded measurements of iliopsoas. It would not have been practical to use intramuscular EMG either. Rectus femoris, on the other hand, could be examined as a superficial muscle. Since a considerable proportion of groin injuries is abdominal-related, it would have been advantageous to include some abdominal muscles in the project. This was originally intended, and recordings were actually conducted with electrodes on the abdomen, but an unfortunate error meant that the data had to be discarded.

The main reason for including CA1 in the trial was to be able to compare the new exercises with an exercise that is commonly used in prevention work today. In the original Copenhagen adductor exercise [24], the upper foot is held approximately at the height of a partner. The height of the partner will largely determine how high the foot is held, and thus also effect the angle of the body and the possible range of motion. According to the description, the “set-up” for the exercise depends more on the body proportions of the partner rather than the executors. This means that one athlete can perform the partner exercise differently from time by time, if done with different people. It also makes it difficult to standardize one exercise to represent the practice in the best possible way. The height used in this project was nevertheless the same for all. It was reported by almost everyone who were familiar with performing the Copenhagen adductor exercise, that they were used to having their foot lower. This may indicate that the standardization of CA1 failed to represent how the exercise is commonly performed in the soccer community today, and the comparisons with CA1 will not be an accurate comparison of the work done in the field today.

All normalized peak EMG value for adductor longus, and peak and mean for rectus femoris in OLP exceed the maximum voluntary isometric contraction value. This is not totally uncommon, but it means that the contraction in the MVIC test did not record the muscles maximum potential of muscle fibres recruitment. The results of rectus femoris in OLP was particularly high and the test should have been different. The MVIC test were conducted with a knee flexion, but all exercises were conducted with a straight leg. Another test with straight leg should have been performed instead, as rectus femoris probably contributes with knee flexion as well during the exercises. The performed MVIC test for adductor longus were a standardized test for adduction/abduction force with other purposes beyond this project. It was conducted this way to enable future studies to use these force measurements. The maximum force values were used to determine which of the three contractions to use in finding the reference value. For ten of eighteen subjects the maximum force value was found in the second repetition. Six subjects performed the highest value in repetition number three, and only two in the first repetition. Since most subjects did not have the highest force value in the first repetition, it could have been beneficial to conduct several repetitions in the MVIC of rectus femoris as well, and/or ensured that the athletes were familiar with the motion beforehand.

For EMG measurements in general, several factors can affect the signal being detected. According to Konrad [43] such factors can be tissue characteristics, physiological cross talk, changes in the geometry between muscle belly and electrode site and external noise. Even though the human body is a good electrical conductor, the type, thickness and temperature of tissue between the muscles and skin surface influence the signal [43]. The moisture of the skin and the presence of superficial skin oil may affect skin impedance, and also influence the recorded signal [50]. Energy from neighboring muscles can spread into the recording field and add to the signal of the muscle being examined. This is called cross talk, and if this is present it usually does not exceed 10-15% of the overall signal. All dynamic movements involve the risk of changes in the geometric relationship between the detection site and the muscle [43]. These are all things that may have influenced the results in this thesis. During several recordings, electrodes fell off, and they had to be reattached. It is possible that they were not positioned in the exact same location as the first time, which will possibly affect the signal. Another thing that may have a large impact on the detected signals, is the lack of proper skin preparation, which is claimed to be important for the quality of EMG signals. This could have been done with hair removal and cleaning of the electrode site [43, 50]. Anyway, the detected signal was processed according to recommendations by Konrad [43]. The signal was smoothed using root mean square with a window length of 100 ms. This was within the numbers stated to work well in most conditions (between 50 and 100 ms). For faster movements the best time window can be as little as 20 ms, while for static activities 500 ms can be selected. Additional filter is not needed in regular kinesiological EMG studies, according to Konrad, and was therefore not practiced.

The load cell that was used, had a maximum capacity of 500 kg, which is far above the mass of every subject, and the signal showed quite a lot of noise. The data was processed by a moving average technique. This was not based on any recommendations, but several methods were tested to find a good solution. Figure 3-15 is an example of the processing for one recording. It seems like the averaged signal represents the original signal well. For the purpose of this project, exact values of torque were not that important, but rather the behavior during exercise performance and the ratio of magnitudes between exercises. To find the force direction of which the load cell detected, motion capture of markers attached to the device were used. One on top of it and two pairs bilaterally further down on the load cell. A line through the top marker and through the center points of the paired markers provides the direction of force. Initially, the idea was to interpolate between all five markers. This proved to be difficult, as some of the paired markers blinked quite a lot. Meaning they disappeared for some time in the recordings. A possible cause could be that the squat rack occluded the line of sight for some of the cameras. However, for every exercise and subject, one repetition was extracted with the visibility of the top marker and at least one of the pairs. It was decided to determine the line of force to pass through the top marker and the midpoint between the lowest pair of markers, when possible. This to reduce any errors when placing markers, as a misplacement of the higher markers has a greater potential to angle the line more as they are closer to the top marker.

Calculated torque was normalized to the subjects' weight. Both weight and hight influences the magnitude of the torque, through force and moment arm. The normalization intends to reduce these effects. Other possible normalization methods are height and body weight times height [98]. Typically, men are taller and heavier than women and successful normalization will reduce the gender differences. No gender differences in normalized torque were found for this project, and there is no reason to claim it was a wrong choice of normalization method. But several factors play a role, and there is no basis for claiming that it’s the best choice either.

6. Conclusion

This thesis has addressed the topic of prevention of groin injuries in soccer. One traditionally performed strength exercise in prevention work, CA1, was investigated, and the same measurements were also made for three other exercises, CA2, OLP and OPHA, which was designed and proposed with the hypothesis that they gave a higher load on groin structures. The torque exerted on the hip joint and muscle activation of adductor longus and rectus femoris, two commonly injured muscles in the groin, has been examined.

The result of torque measurements showed none significantly differences between any of the exercises. The muscle activations varied some, note surprisingly based on the great difference in nature of the exercises. For rectus femoris, OLP had a significantly higher activation than CA1, but OLP had significantly lower activation for the adductor longus muscle. OLP would be the preferred exercise to choose when the objective is to strengthen the rectus femoris. But because of the low adductor longus activation, and the fact that adductor longus is the most frequent injured muscle, it cannot be concluded that this exercise is overall better. None significantly differences in activation of adductor longus were found between CA1, CA2 and OPHFA. Further, the activation of rectus femoris was similar for CA1, CA2 and OPHFA in mean activation but a significantly difference ($p = 0.027$) in peak was seen between OPHFA and CA1. OPHFA had thus one out of five variables indicating a higher load on groin structures than CA1. The effect of this one difference is unknown, but with all other variable similar, OPHFA is probably equally good or better compared to CA1 for the purpose of groin injury prevention. This exercise should be further investigated, as this is far more soccer specific than CA1 because it resamples a soccer pass, which is one common mechanism for groin injuries. No significant differences were seen between CA1 and CA2, and thus no basis for claiming CA2 to have higher load than CA1.

Compared to CA1, which has shown an effect in preventing groin injuries, both CA2 and OPHFA seems to be exercises with a similar prevention potential, although

OPHFA possible have greater potential of prevention rectus femoris related injuries. However, the lack of studies on activation and prevention of rectus femoris related groin injuries makes it difficult to draw any general conclusion. And the significantly higher activation during OLP indicates an even greater prevention potential. Based on the results, CA1, CA2 or OPHFA should be performed in combination with OLP to ensure high activation of both adductor longus and rectus femoris.

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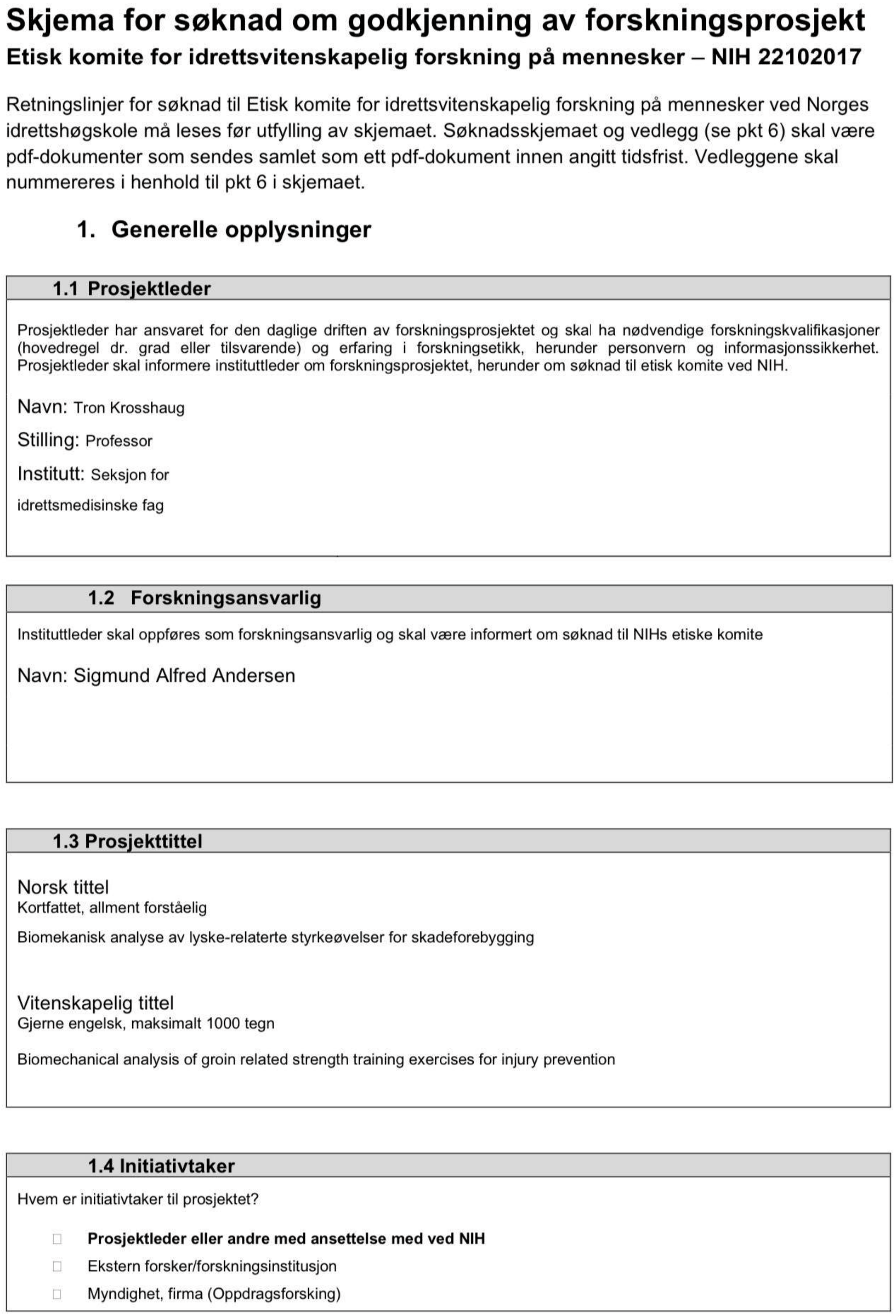
Appendix A – Application to the ethical committee of the Norwegian School of Sport Science



Skjema for søknad om godkjenning av forskningsprosjekt

Etisk komite for idrettsvitenskapelig forskning på mennesker – NIH 22102017

Retningslinjer for søknad til Etisk komite for idrettsvitenskapelig forskning på mennesker ved Norges idrettshøgskole må leses før utfylling av skjemaet. Søknadsskjemaet og vedlegg (se pkt 6) skal være pdf-dokumenter som sendes samlet som ett pdf-dokument innen angitt tidsfrist. Vedleggene skal nummereres i henhold til pkt 6 i skjemaet.

1. Generelle opplysninger

1.1 Prosjektleder

Prosjektleder har ansvaret for den daglige driften av forskningsprosjektet og skal ha nødvendige forskningskvalifikasjoner (hovedregel dr. grad eller tilsvarende) og erfaring i forskningsetikk, herunder personvern og informasjonssikkerhet. Prosjektleder skal informere instituttleder om forskningsprosjektet, herunder om søknad til etisk komite ved NIH.

Navn: Tron Krosshaug

Stilling: Professor

Institutt: Seksjon for idrettsmedisinske fag

1.2 Forskningsansvarlig

Instituttleder skal oppføres som forskningsansvarlig og skal være informert om søknad til NIHs etiske komite

Navn: Sigmund Alfred Andersen

1.3 Prosjekttittel

Norsk tittel
Kortfattet, allment forståelig

Biomekanisk analyse av lyske-relaterte styrkeøvelser for skadeforebygging

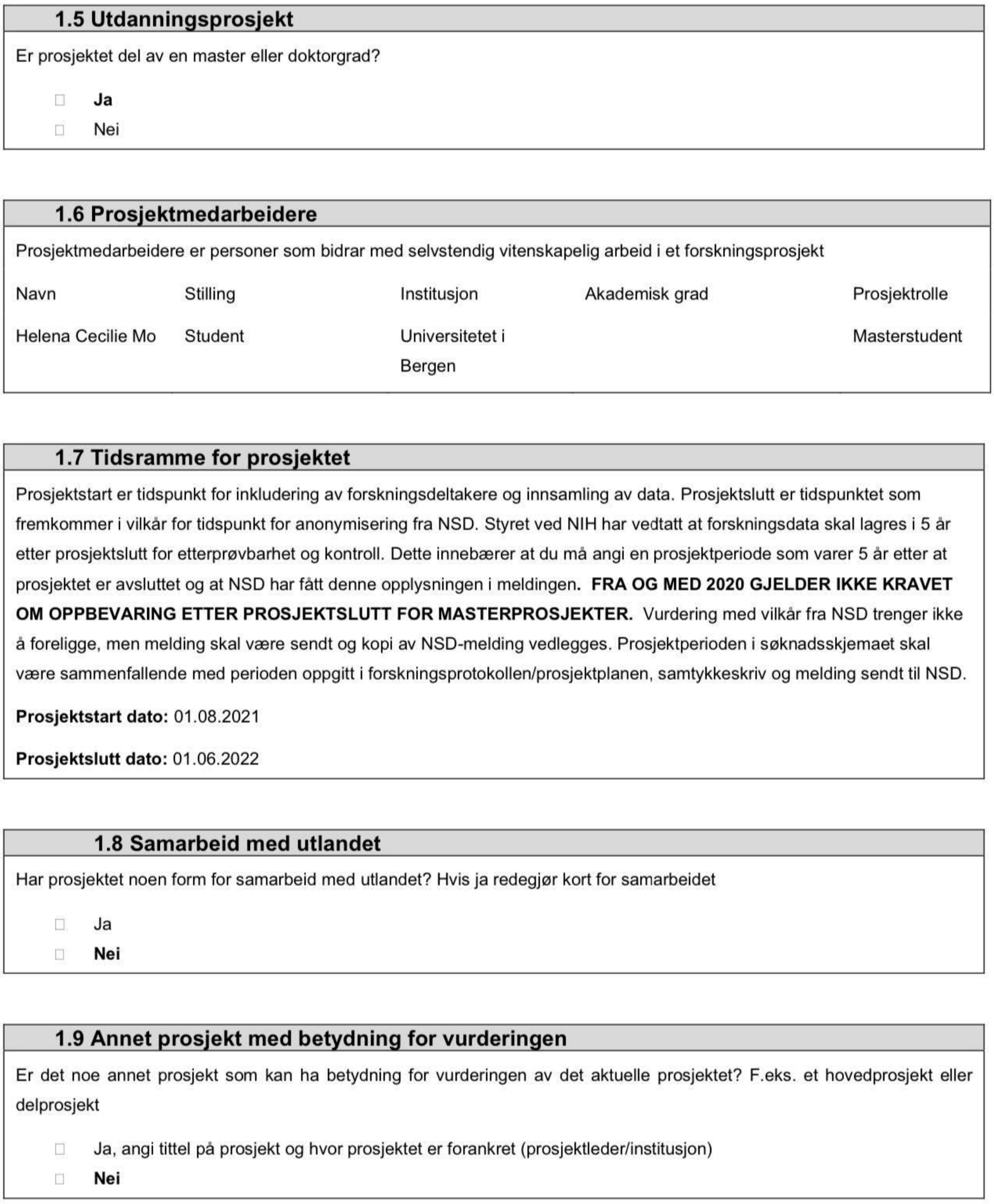
Vitenskapelig tittel
Gjerne engelsk, maksimalt 1000 tegn

Biomechanical analysis of groin related strength training exercises for injury prevention

1.4 Initiativtaker

Hvem er initiativtaker til prosjektet?

- ☐ **Prosjektleder eller andre med ansettelse med ved NIH**
- ☐ Ekstern forsker/forskningsinstitusjon
- ☐ Myndighet, firma (Oppdragsforsking)



1.5 Utdanningsprosjekt

Er prosjektet del av en master eller doktorgrad?

☐ **Ja**
☐ Nei

1.6 Prosjektmedarbeidere

Prosjektmedarbeidere er personer som bidrar med selvstendig vitenskapelig arbeid i et forskningsprosjekt

Navn	Stilling	Institusjon	Akademisk grad	Prosjektrolle
Helena Cecilie Mo	Student	Universitetet i Bergen		Masterstudent

1.7 Tidsramme for prosjektet

Prosjektstart er tidspunkt for inkludering av forskningsdeltakere og innsamling av data. Prosjektslutt er tidspunktet som fremkommer i vilkår for tidspunkt for anonymisering fra NSD. Styret ved NIH har vedtatt at forskningsdata skal lagres i 5 år etter prosjektslutt for etterprøvbarhet og kontroll. Dette innebærer at du må angi en prosjektperiode som varer 5 år etter at prosjektet er avsluttet og at NSD har fått denne opplysningen i meldingen**. FRA OG MED 2020 GJELDER IKKE KRAVET OM OPPBEVARING ETTER PROSJEKTSLUTT FOR MASTERPROSJEKTER.** Vurdering med vilkår fra NSD trenger ikke å foreligge, men melding skal være sendt og kopi av NSD-melding vedlegges. Prosjektperioden i søknadsskjemaet skal være sammenfallende med perioden oppgitt i forskningsprotokollen/prosjektplanen, samtykkeskriv og melding sendt til NSD.

Prosjektstart dato: 01.08.2021

Prosjektslutt dato: 01.06.2022

1.8 Samarbeid med utlandet

Har prosjektet noen form for samarbeid med utlandet? Hvis ja redegjør kort for samarbeidet

☐ Ja
☐ **Nei**

1.9 Annet prosjekt med betydning for vurderingen

Er det noe annet prosjekt som kan ha betydning for vurderingen av det aktuelle prosjektet? F.eks. et hovedprosjekt eller delprosjekt

☐ Ja, angi tittel på prosjekt og hvor prosjektet er forankret (prosjektleder/institusjon)
☐ **Nei**

2. Prosjektopplysninger

2.1 Oppsummering av forskningsprosjektet

Kort prosjektbeskrivelse
Hvilken ny kunnskap skal forskningen gi? Hvilken forskningsdesign og –metode skal brukes? Gi en allment forståelig og kortfattet beskrivelse av hvilke forskningsspørsmål prosjektet skal besvare og hvordan de skal besvares. Formålet med prosjektet må komme klart frem.

Lyskeskader er et stort problem i flere idretter, blant annet i fotball. Særlig utsatte muskler er adductor longus, iliopsoas og proximal rectus femoris. I dette prosjektet skal vi se på tre ulike en-fots plankeøvelser i slynge og se hvordan de nevnte musklene belastes. Øvelsene er Copenhagen adductor, pike og skrå planke med hoftefleksjon og hofteadduksjon. Sistnevnte øvelse er ikke en kjent øvelse, og vi har heller ikke hørt at den har blitt brukt tidligere. Den er en mellomting av Copenhagen adductor og pike, og tanken er at det skal være en mer idrettsspesifikk øvelse ved lignende bevegelser som under en innsidepasning i fotball. Det vil bli brukt EMG til å måle muskelaktivering og et helkroppsmarkøroppsett i Qualisys Motion Capture system for å samle inn data om bevegelsene og deretter gjøre en biomekanisk analyse. De tre øvelsene skal sammenlignes og vurderes om de er hensiktsmessige å bruke i forebygging av lyskeskader. I dag er Copenhagen adductor en foretrukken øvelse for mange, men kanskje vil studien gi god evidens for å bytte den ut med en av eller en kombinasjon av de to andre øvelsene. Forskningsdesign er eksperimentell biomekanisk studie.

2.2 Forskningsdata

Sensitive personopplysninger? (Rasemessig eller etnisk bakgrunn, politisk,,filosofisk eller religiøs oppfatninger, person mistenkt, siktet, tiltalt eller dømt for en straffbar handling, helseforhold, seksuelle forhold eller medlemskap fagforeninger)

☐ Ja
☐ **Nei**

Tidligere registrerte personopplysninger?

☐ Ja
☐ **Nei**

Nye personopplysninger

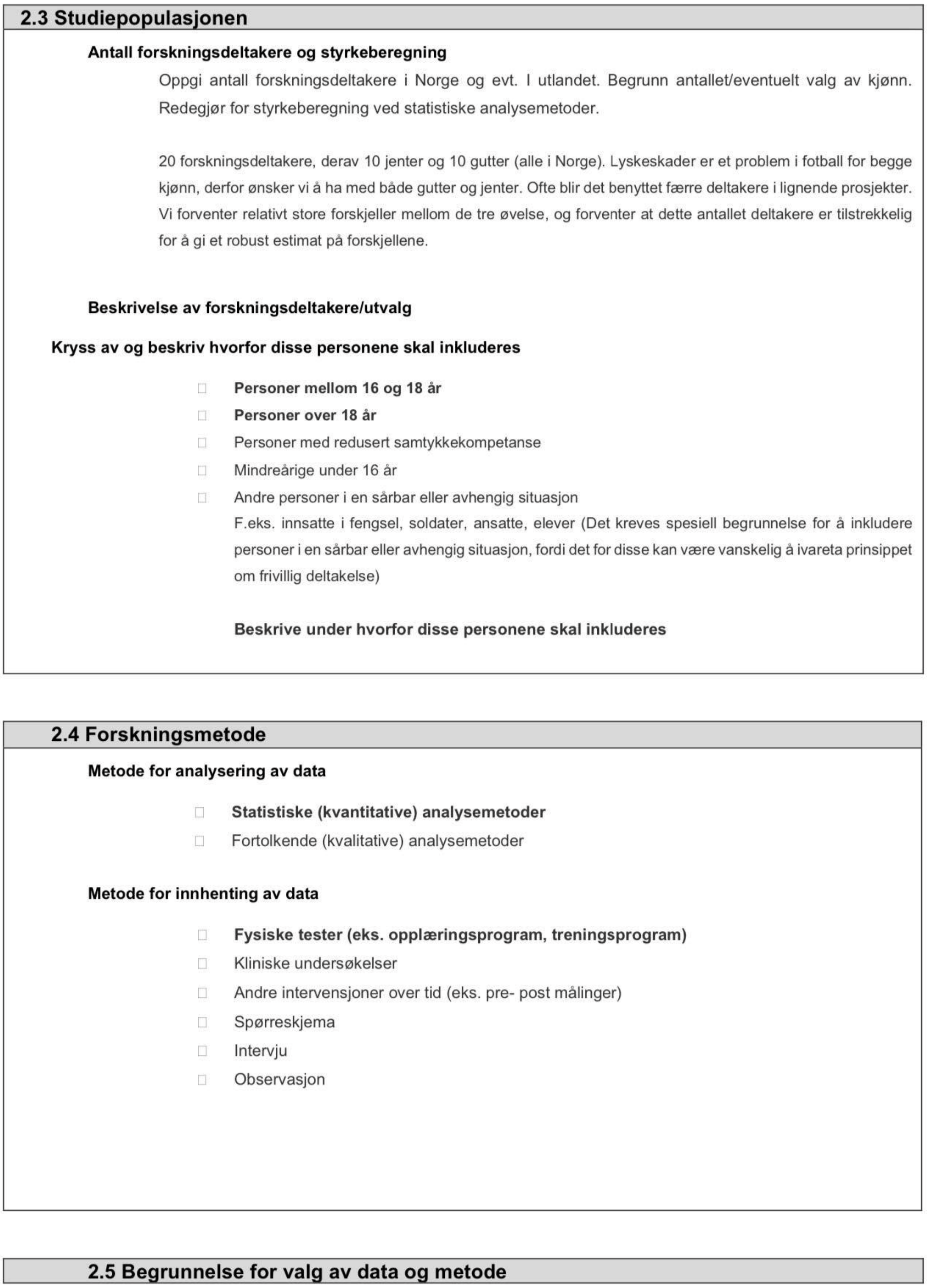
Personopplysninger som skal samles inn direkte fra studiepopulasjonen, ved f.eks. klinisk undersøkelse, intervensjon eller spørreskjema.

☐ **Ja**
☐ Nei

Humant biologisk materiale

Materiale som allerede er samlet inn eller som skal samles inn i prosjektet. Humant biologisk materiale er organer, deler av organer, celler og vev og bestanddeler av slikt materiale fra levende og døde mennesker.

☐ Ja
☐ **Nei**



2.3 Studiepopulasjonen

Antall forskningsdeltakere og styrkeberegning

Oppgi antall forskningsdeltakere i Norge og evt. I utlandet. Begrunn antallet/eventuelt valg av kjønn. Redegjør for styrkeberegning ved statistiske analysemetoder.

20 forskningsdeltakere, derav 10 jenter og 10 gutter (alle i Norge). Lyskeskader er et problem i fotball for begge kjønn, derfor ønsker vi å ha med både gutter og jenter. Ofte blir det benyttet færre deltakere i lignende prosjekter. Vi forventer relativt store forskjeller mellom de tre øvelse, og forventer at dette antallet deltakere er tilstrekkelig for å gi et robust estimat på forskjellene.

Beskrivelse av forskningsdeltakere/utvalg

Kryss av og beskriv hvorfor disse personene skal inkluderes

- ☐ **Personer mellom 16 og 18 år**
- ☐ **Personer over 18 år**
- ☐ Personer med redusert samtykkekompetanse
- ☐ Mindreårige under 16 år
- ☐ Andre personer i en sårbar eller avhengig situasjon
  F.eks. innsatte i fengsel, soldater, ansatte, elever (Det kreves spesiell begrunnelse for å inkludere personer i en sårbar eller avhengig situasjon, fordi det for disse kan være vanskelig å ivareta prinsippet om frivillig deltakelse)

Beskrive under hvorfor disse personene skal inkluderes

2.4 Forskningsmetode

Metode for analysering av data

- ☐ **Statistiske (kvantitative) analysemetoder**
- ☐ Fortolkende (kvalitative) analysemetoder

Metode for innhenting av data

- ☐ **Fysiske tester (eks. opplæringsprogram, treningsprogram)**
- ☐ Kliniske undersøkelser
- ☐ Andre intervensjoner over tid (eks. pre- post målinger)
- ☐ Spørreskjema
- ☐ Intervju
- ☐ Observasjon

2.5 Begrunnelse for valg av data og metode

Redegjør for den faglige og vitenskapelige begrunnelsen for valg av data og metode

EMG, markørbasert 3D analyse og kraftmålinger ansees som «gullstandard» for å måle muskelaktivering, kinetikk, kinematikk og leddmomenter.

3. Informasjon, samtykke og personvern

3.1 Samtykke vil bli innhentet

Hvis ja må Informasjonsskriv legges ved. Samtykket til deltakelse i forskning skal som hovedregel være informert, frivillig, uttrykkelig og dokumenterbart. Forespørsel om deltakelse og samtykkeerklæring skal utformes i samsvar med mal for informasjonsskriv. Lenker til maler for informasjonsskriv finner du på REK/NSDs sine hjemmesider. Det skal opplyses om at forskningsdata vil bli lagret i 5 år for etterprøvbarhet og kontroll. GJELDER IKKE FOR MASTERPROSJEKTER.

- ☐ **Ja**
- ☐ Nei

3.2 Samtykke er allerede innhentet

Hvis ja må tidligere godkjent informasjonsskriv legges ved.

- ☐ Ja
- ☐ **Nei**

3.3 Det søkes om fritak fra kravet om å innhente samtykke

- ☐ Ja
- ☐ **Nei**

4. Avveining av nytte og risiko ved prosjektet

4.1 Fordeler

Angi fysisk, psykisk, sosial og/eller praktisk fordel/nytte/gagn nå eller i fremtida for den enkelte pasient/deltaker, grupper av personer, samfunnet og/eller vitenskapen.

Deltakere vil få et innblikk i biomekaniske forskningsmetoder og kjennskap til en ny treningsøvelse for lysken. Videre kan de bidra med å skaffe ny kunnskap om skadeforebyggende øvelser, som senere kan være nyttig informasjon for mange idrettsutøvere og forhåpentligvis redusere antall lyskeskader.

4.2 Ulemper

Angi fysisk, psykisk, sosial og/eller praktisk risiko/skade/ubehag/belastning/uleilighet nå eller i fremtida for den enkelte pasient/deltaker, grupper av personer, samfunnet og/eller miljø

Deltakere kan bli sliten og/eller støl, noe som kan påvirke treningen de neste dagene.

4.3 Tiltak

Redegjør for tiltak for å ivareta og beskytte deltakerne i forskningsprosjektet og for å begrense mulig risiko/ulempe. Diskuter beredskap ved uventede hendelser og uventede funn der dette er aktuelt. Tiltak for å ivareta og beskytte deltakere i prosjektet kan for eksempel være, styrking av samtykkekompetanse, ekstra beskyttelse av deltakere i en sårbar eller avhengig situasjon, sikring av konfidensialitet ved kvalitative metoder og lite antall deltakere, eksklusjonskriterier, klinisk forundersøkelse, beredskap, interimsanalyser eller oppfølging av deltakere.

Risikoen for skade er liten, men det gjøres tiltak ved å redusere belastningen for den enkelte spilleren. Belastningen er størst når slyngen er ved ankel, men reduseres ved å flytte slyngen nærmere kneet.

4.4 Forsvarlighet

Hvorfor er det forsvarlig å gjennomføre prosjektet? Gi en begrunnet avveining av fordelene og ulempene ved forskningsprosjektet.

Det er liten risiko for å pådra seg en skade ved deltakelse i prosjektet, men det kan derimot hjelpe til med å redusere antall skader senere – noe som vil være positivt for enkeltspillere og deres lag.

5. Vurdering av andre instanser og interesser

5.1 Vurdering av andre instanser

Det skal som hovedregel ikke sendes søknad til REK og NIHs etiske komite samtidig. I de tilfeller søknad er sendt til REK, vil etisk komite avvente behandling av søknaden inntil det foreligger et REK vedtak. Er det tvil om prosjektet skal behandles av REK i henhold til Helseforskningsloven, skal skjemaet for fremleggelsesvurdering sendes inn til REK. REK sitt svar på fremleggelsesvurderingen/vedtak fra REK skal vedlegges søknaden

Er det sendt søknad til REK?

- ☐ Ja
- ☐ **Nei**

Vurdering av andre instanser skal vedlegges hvis det anses relevant for søknaden.

Prosjektet har blitt vurdert/skal vurderes av: Norsk senter for forskningsdata (NSD)

5.2 Interesser

Finansieringskilder

Hvem finansierer prosjektet? Ved oppdragsforskning skal økonomisk avtale vedlegges eller ettersendes

De eneste utgiftene til prosjektet er små utgifter for utstyr på labben. Dette er det NIH som finansierer.

Kompensasjon til forskningsdeltakere

Eventuell kompensasjon for utgifter, tapt arbeidsfortjeneste, tidsbruk, ulempe eller annet

Nei

Eventuelle interessekonflikter for prosjektleder/-medarbeidere

Det skal redegjøres for eventuelle bindinger til oppdragsgiver, eierinteresser, styreverv, aksjeinteresser

Ingen bindinger

6. Vedlegg

Hvert vedlegg skal være et pdf-dokument som nummereres som følger:

Vedlegg 1 Forskningsprotokoll/Prosjektplan

Vedlegg 2 Samtykkeskriv

Vedlegg 3 Melding til NSD, Ev vurdering med vilkår fra NSD hvis denne foreligger

Vedlegg 4 Spørreskjema hvis aktuelt

Vedlegg 5 CV for prosjektleder hvis ikke ansatt ved NIH

Vedlegg 6 Ev korrespondanse med REK (svar på fremleggelsesskjema/vedtak om at prosjektet falt utenfor Helseforskningsloven) Kun aktuelt dersom prosjektleder har vært i tvill om/ment at prosjektet faller innenfor Helseforskningsloven.

Vedlegg X Annen dokumentasjon og opplysninger som er nødvendig for å få en full forståelse for søknaden

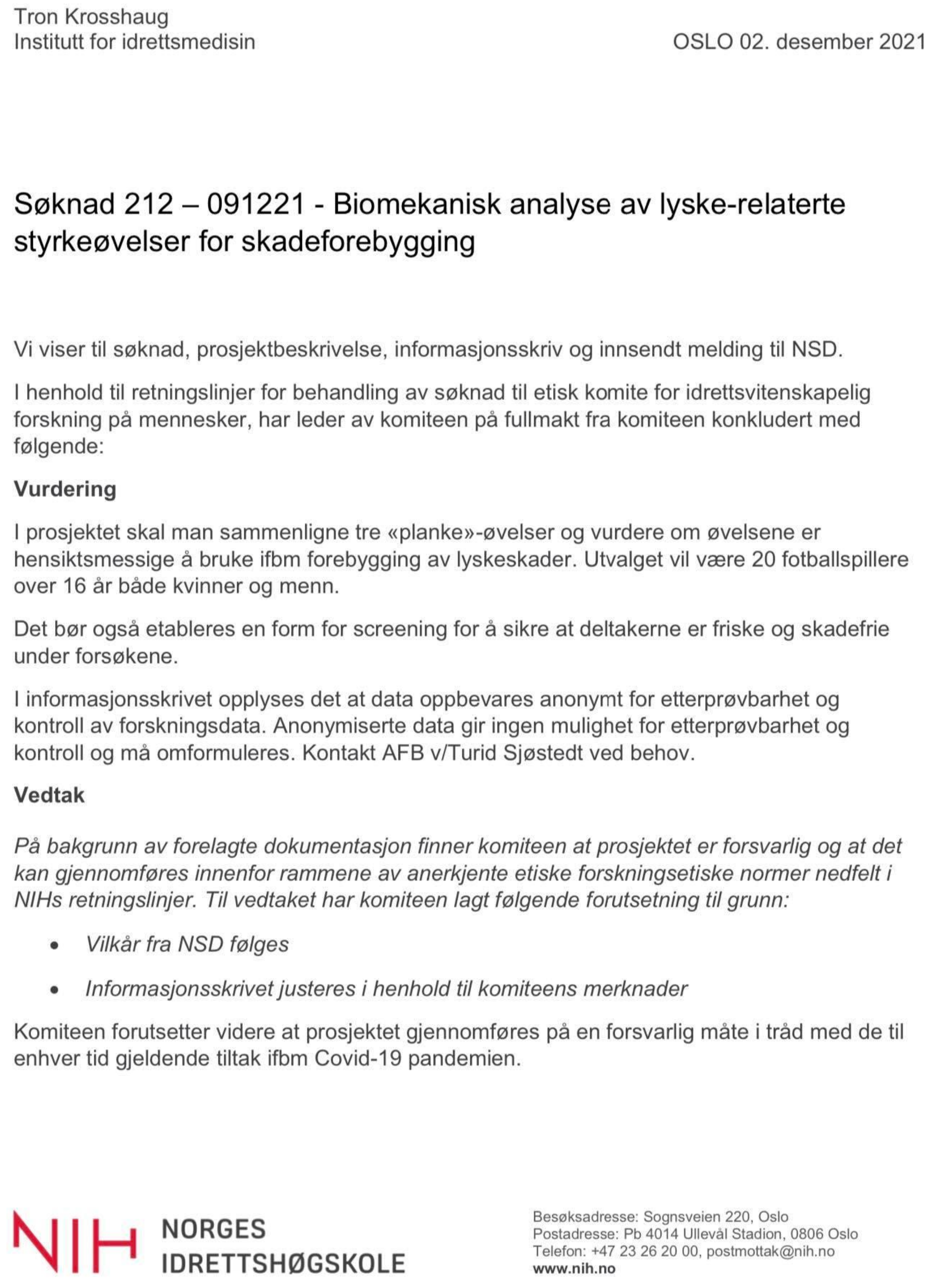
Søknadsskjema og vedlegg (i pdf-format) skal samles i ett pdf-dokument for innsendelse

7. Ansvarserklæring

Jeg erklærer at prosjektet vil bli gjennomført

- ☐ **I henhold til gjeldende lover, forskrifter og retningslinjer**
- ☐ **I samsvar med opplysninger gitt i denne søknaden**
- ☐ **I samsvar med eventuelle vilkår for godkjenning gitt av NIHs etiske komite, NSD og ev andre godkjenningsinstanser**

Appendix B – Approval from the ethical committee of the Norwegian School of Sport Science



Tron Krosshaug
Institutt for idrettsmedisin

OSLO 02. desember 2021

Søknad 212 – 091221 - Biomekanisk analyse av lyske-relaterte styrkeøvelser for skadeforebygging

Vi viser til søknad, prosjektbeskrivelse, informasjonsskriv og innsendt melding til NSD.

I henhold til retningslinjer for behandling av søknad til etisk komite for idrettsvitenskapelig forskning på mennesker, har leder av komiteen på fullmakt fra komiteen konkludert med følgende:

Vurdering

I prosjektet skal man sammenligne tre «planke»-øvelser og vurdere om øvelsene er hensiktsmessige å bruke ifbm forebygging av lyskeskader. Utvalget vil være 20 fotballspillere over 16 år både kvinner og menn.

Det bør også etableres en form for screening for å sikre at deltakerne er friske og skadefrie under forsøkene.

I informasjonsskrivet opplyses det at data oppbevares anonymt for etterprøvbarhet og kontroll av forskningsdata. Anonymiserte data gir ingen mulighet for etterprøvbarhet og kontroll og må omformuleres. Kontakt AFB v/Turid Sjøstedt ved behov.

Vedtak

På bakgrunn av forelagte dokumentasjon finner komiteen at prosjektet er forsvarlig og at det kan gjennomføres innenfor rammene av anerkjente etiske forskningsetiske normer nedfelt i NIHs retningslinjer. Til vedtaket har komiteen lagt følgende forutsetning til grunn:

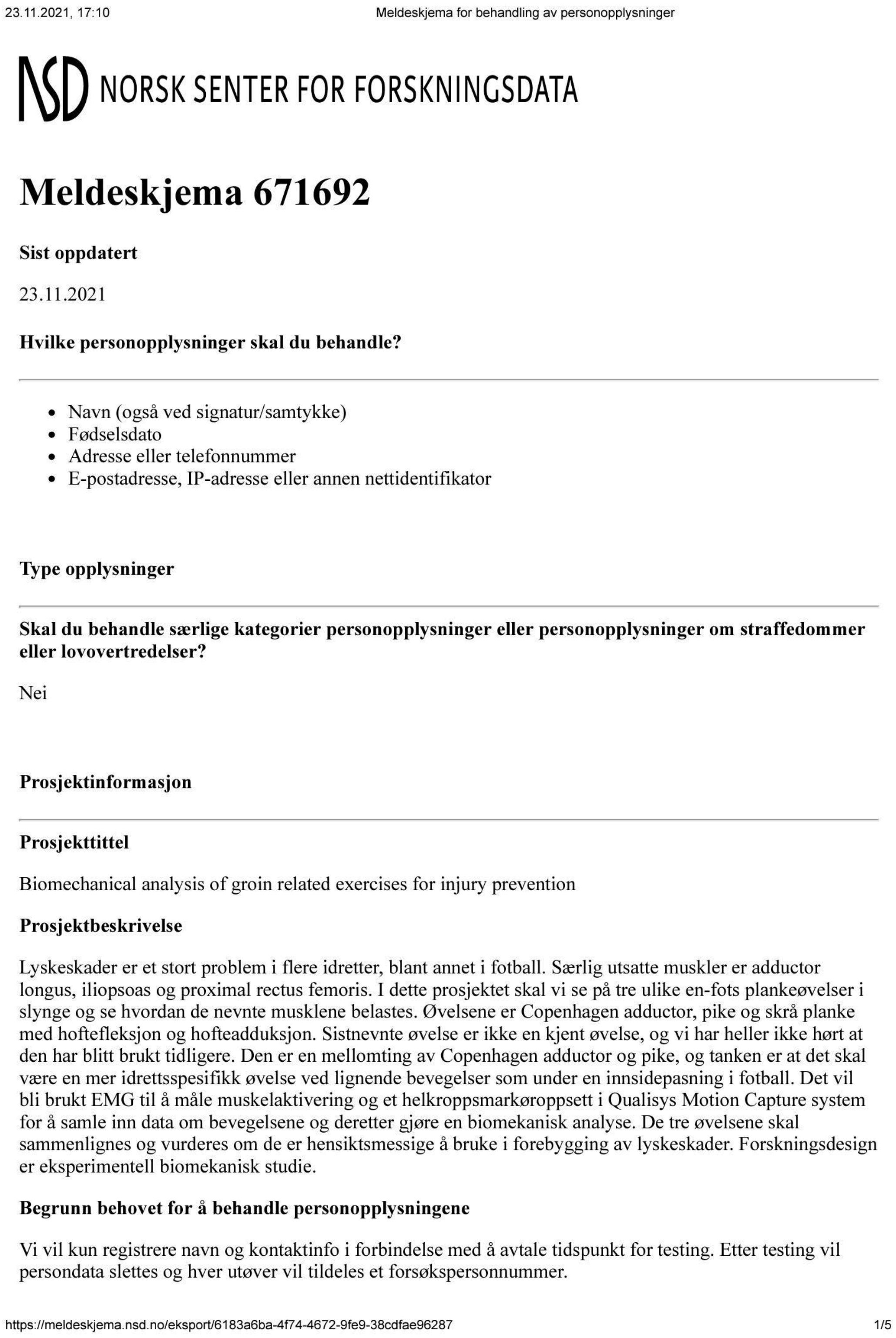
- *Vilkår fra NSD følges*
- *Informasjonsskrivet justeres i henhold til komiteens merknader*

Komiteen forutsetter videre at prosjektet gjennomføres på en forsvarlig måte i tråd med de til enhver tid gjeldende tiltak ifbm Covid-19 pandemien.

NIH NORGES IDRETTSHØGSKOLE

Besøksadresse: Sognsveien 220, Oslo
Postadresse: Pb 4014 Ullevål Stadion, 0806 Oslo
Telefon: +47 23 26 20 00, postmottak@nih.no
www.nih.no

Appendix C – Application to the Norwegian Centre for Research Data



NSD NORSK SENTER FOR FORSKNINGSDATA

Meldeskjema 671692

Sist oppdatert

23.11.2021

Hvilke personopplysninger skal du behandle?

- Navn (også ved signatur/samtykke)
- Fødselsdato
- Adresse eller telefonnummer
- E-postadresse, IP-adresse eller annen nettidentifikator

Type opplysninger

Skal du behandle særlige kategorier personopplysninger eller personopplysninger om straffedommer eller lovovertredelser?

Nei

Prosjektinformasjon

Prosjekttittel

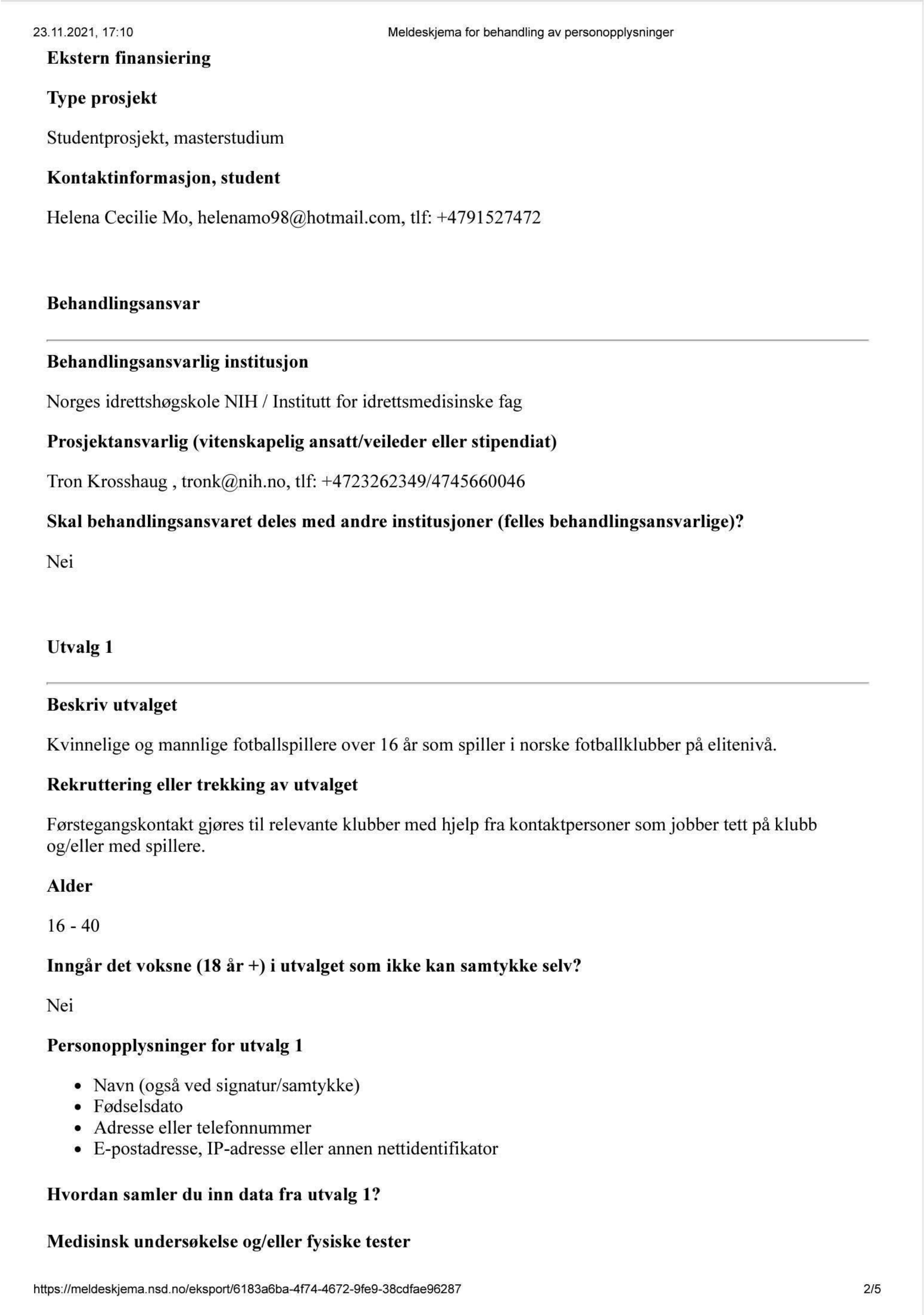
Biomechanical analysis of groin related exercises for injury prevention

Prosjektbeskrivelse

Lyskeskader er et stort problem i flere idretter, blant annet i fotball. Særlig utsatte muskler er adductor longus, iliopsoas og proximal rectus femoris. I dette prosjektet skal vi se på tre ulike en-fots plankeøvelser i slynge og se hvordan de nevnte musklene belastes. Øvelsene er Copenhagen adductor, pike og skrå planke med hoftefleksjon og hofteadduksjon. Sistnevnte øvelse er ikke en kjent øvelse, og vi har heller ikke hørt at den har blitt brukt tidligere. Den er en mellomting av Copenhagen adductor og pike, og tanken er at det skal være en mer idrettsspesifikk øvelse ved lignende bevegelser som under en innsidepasning i fotball. Det vil bli brukt EMG til å måle muskelaktivering og et helkroppsmarkøroppsett i Qualisys Motion Capture system for å samle inn data om bevegelsene og deretter gjøre en biomekanisk analyse. De tre øvelsene skal sammenlignes og vurderes om de er hensiktsmessige å bruke i forebygging av lyskeskader. Forskningsdesign er eksperimentell biomekanisk studie.

Begrunn behovet for å behandle personopplysningene

Vi vil kun registrere navn og kontaktinfo i forbindelse med å avtale tidspunkt for testing. Etter testing vil persondata slettes og hver utøver vil tildeles et forsøkspersonnummer.



Ekstern finansiering

Type prosjekt

Studentprosjekt, masterstudium

Kontaktinformasjon, student

Helena Cecilie Mo, helenamo98@hotmail.com, tlf: +4791527472

Behandlingsansvar

Behandlingsansvarlig institusjon

Norges idrettshøgskole NIH / Institutt for idrettsmedisinske fag

Prosjektansvarlig (vitenskapelig ansatt/veileder eller stipendiat)

Tron Krosshaug , tronk@nih.no, tlf: +4723262349/4745660046

Skal behandlingsansvaret deles med andre institusjoner (felles behandlingsansvarlige)?

Nei

Utvalg 1

Beskriv utvalget

Kvinnelige og mannlige fotballspillere over 16 år som spiller i norske fotballklubber på elitenivå.

Rekruttering eller trekking av utvalget

Førstegangskontakt gjøres til relevante klubber med hjelp fra kontaktpersoner som jobber tett på klubb og/eller med spillere.

Alder

16 - 40

Inngår det voksne (18 år +) i utvalget som ikke kan samtykke selv?

Nei

Personopplysninger for utvalg 1

- Navn (også ved signatur/samtykke)
- Fødselsdato
- Adresse eller telefonnummer
- E-postadresse, IP-adresse eller annen nettidentifikator

Hvordan samler du inn data fra utvalg 1?

Medisinsk undersøkelse og/eller fysiske tester

Grunnlag for å behandle alminnelige kategorier av personopplysninger

Samtykke (art. 6 nr. 1 bokstav a)

Hvem samtykker for ungdom 16 og 17 år?

Ungdom

Informasjon for utvalg 1

Informerer du utvalget om behandlingen av opplysningene?

Ja

Hvordan?

Skriftlig informasjon (papir eller elektronisk)

Tredjepersoner

Skal du behandle personopplysninger om tredjepersoner?

Nei

Dokumentasjon

Hvordan dokumenteres samtykkene?

- Manuelt (papir)

Hvordan kan samtykket trekkes tilbake?

Samtykket kan trekkes tilbake ved å kontakte prosjektleder, masterstudent eller Norges Idrettshøgskole, via e-post eller telefon. Det vil utvalget bli informert om.

Hvordan kan de registrerte få innsyn, rettet eller slettet opplysninger om seg selv?

De registrerte kan få innsyn, rettet eller slettet opplysninger om seg selv ved å ta kontakt med prosjektleder, masterstudent eller Norges Idrettshøgskole, via e-post eller telefon. Prosjektleder eller masterstudent vil så fort som mulig ta kontakt med vedkommende og gi personen innsyn i opplysningene, endre opplysninger og/eller bekrefte at opplysningene er rettet/slettet. De vil i et informasjonsskriv få vite om hvilke rettigheter de har, og hvordan de tar kontakt.

Totalt antall registrerte i prosjektet

1-99

Tillatelser

Skal du innhente følgende godkjenninger eller tillatelser for prosjektet?

- Annen godkjenning

Annen godkjenning

Godkjenning fra NIHs etiske komite

Behandling

Hvor behandles opplysningene?

- Maskinvare tilhørende behandlingsansvarlig institusjon
- Mobile enheter tilhørende behandlingsansvarlig institusjon

Hvem behandler/har tilgang til opplysningene?

- Prosjektansvarlig
- Student (studentprosjekt)
- Interne medarbeidere

Tilgjengeliggjøres opplysningene utenfor EU/EØS til en tredjestat eller internasjonal organisasjon?

Nei

Sikkerhet

Oppbevares personopplysningene atskilt fra øvrige data (koblingsnøkkel)?

Ja

Hvilke tekniske og fysiske tiltak sikrer personopplysningene?

- Adgangsbegrensning
- Opplysningene anonymiseres fortløpende

Varighet

Prosjektperiode

01.08.2021 - 01.06.2022

Skal data med personopplysninger oppbevares utover prosjektperioden?

Nei, data vil bli oppbevart uten personopplysninger (anonymisering)

Hvilke anonymiseringstiltak vil bli foretatt?

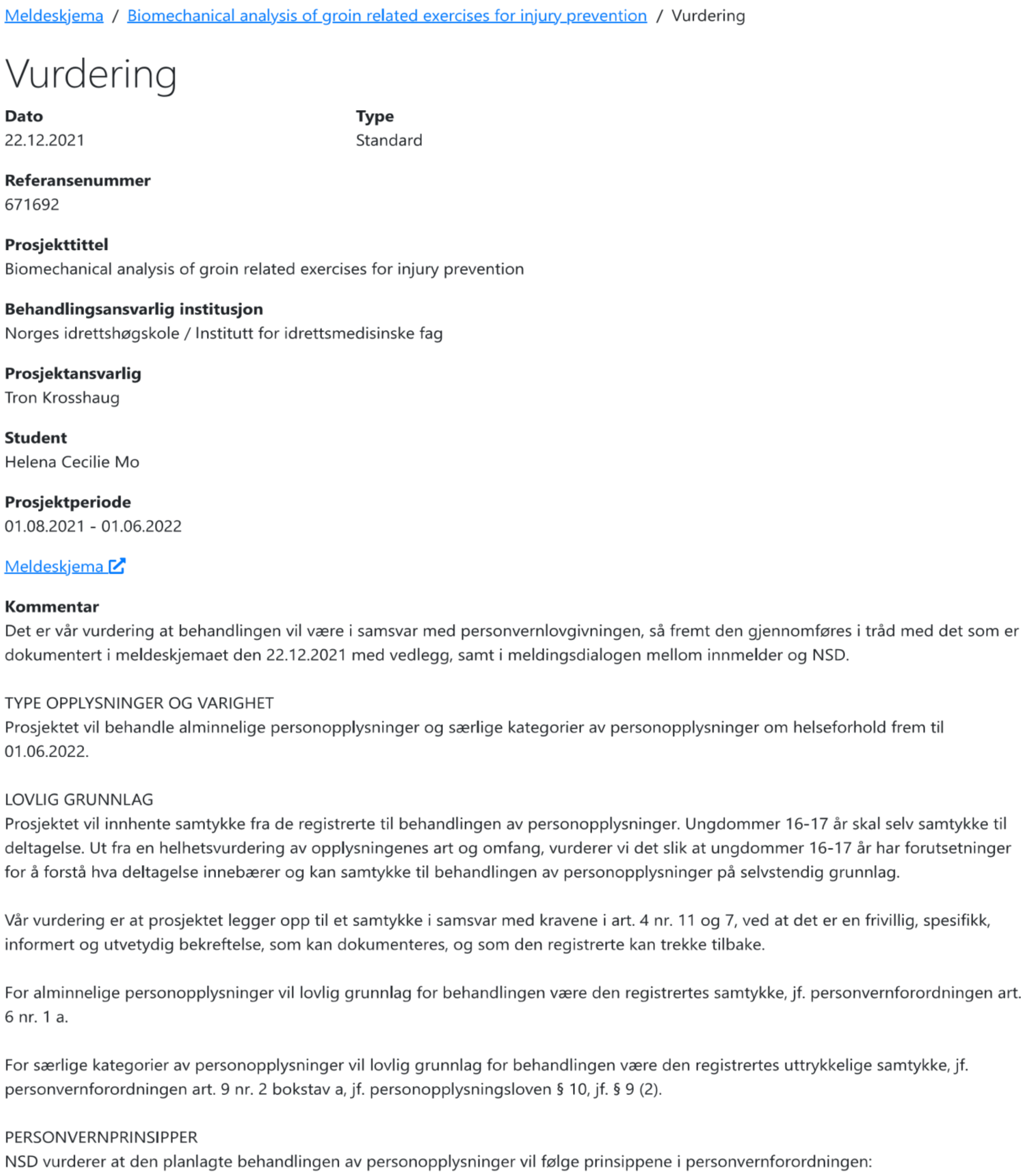
- Personidentifiserbare opplysninger fjernes, omskrives eller grovkategoriseres

Vil de registrerte kunne identifiseres (direkte eller indirekte) i oppgave/avhandling/øvrige publikasjoner fra prosjektet?

Nei

Tilleggsopplysninger

Appendix D – Approval from the Norwegian Centre for Research Data



Meldeskjema / Biomechanical analysis of groin related exercises for injury prevention / Vurdering

Vurdering

Dato 22.12.2021	**Type** Standard

Referansenummer
671692

Prosjekttittel
Biomechanical analysis of groin related exercises for injury prevention

Behandlingsansvarlig institusjon
Norges idrettshøgskole / Institutt for idrettsmedisinske fag

Prosjektansvarlig
Tron Krosshaug

Student
Helena Cecilie Mo

Prosjektperiode
01.08.2021 - 01.06.2022

Meldeskjema

Kommentar
Det er vår vurdering at behandlingen vil være i samsvar med personvernlovgivningen, så fremt den gjennomføres i tråd med det som er dokumentert i meldeskjemaet den 22.12.2021 med vedlegg, samt i meldingsdialogen mellom innmelder og NSD.

TYPE OPPLYSNINGER OG VARIGHET
Prosjektet vil behandle alminnelige personopplysninger og særlige kategorier av personopplysninger om helseforhold frem til 01.06.2022.

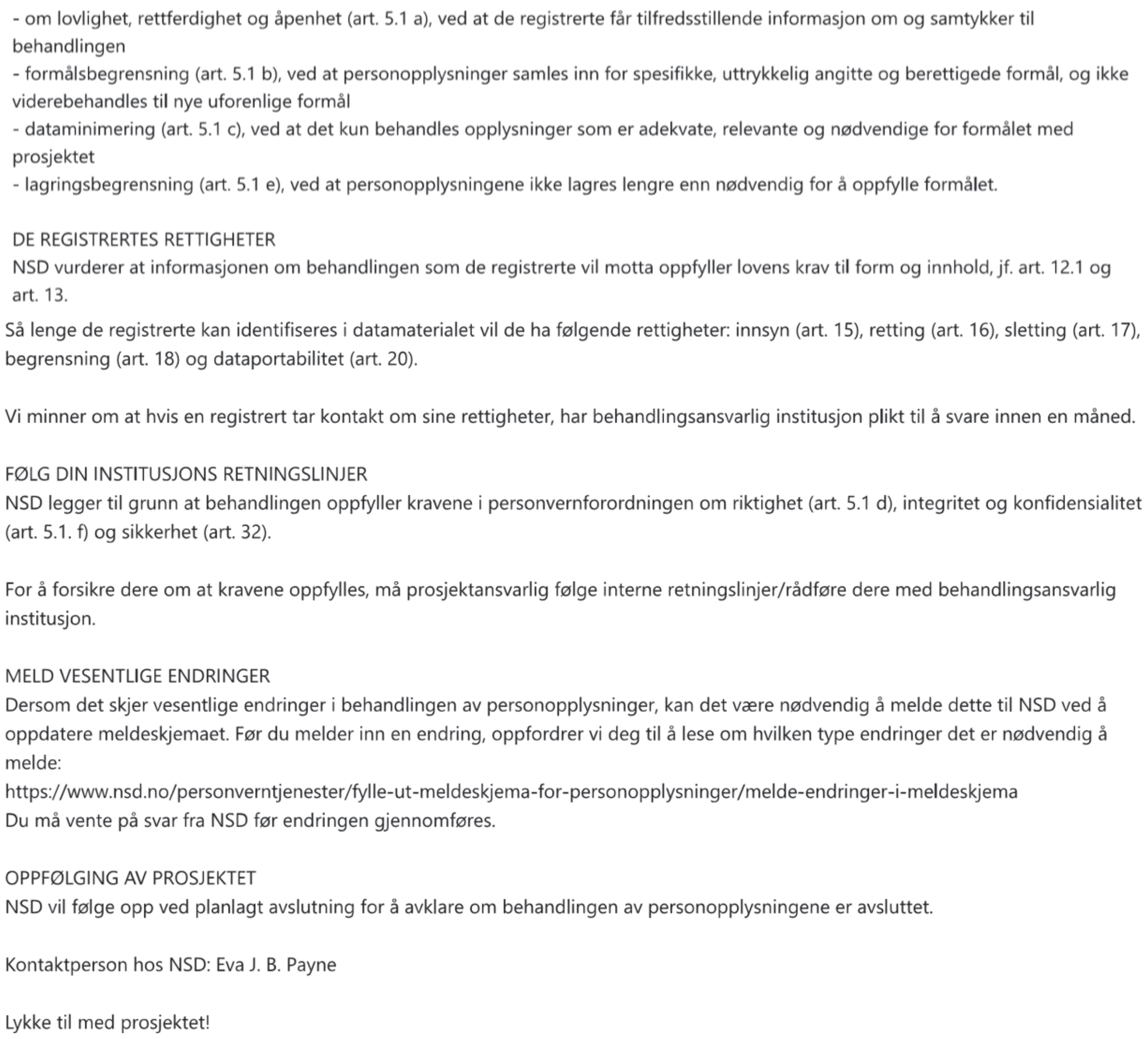
LOVLIG GRUNNLAG
Prosjektet vil innhente samtykke fra de registrerte til behandlingen av personopplysninger. Ungdommer 16-17 år skal selv samtykke til deltagelse. Ut fra en helhetsvurdering av opplysningenes art og omfang, vurderer vi det slik at ungdommer 16-17 år har forutsetninger for å forstå hva deltagelse innebærer og kan samtykke til behandlingen av personopplysninger på selvstendig grunnlag.

Vår vurdering er at prosjektet legger opp til et samtykke i samsvar med kravene i art. 4 nr. 11 og 7, ved at det er en frivillig, spesifikk, informert og utvetydig bekreftelse, som kan dokumenteres, og som den registrerte kan trekke tilbake.

For alminnelige personopplysninger vil lovlig grunnlag for behandlingen være den registrertes samtykke, jf. personvernforordningen art. 6 nr. 1 a.

For særlige kategorier av personopplysninger vil lovlig grunnlag for behandlingen være den registrertes uttrykkelige samtykke, jf. personvernforordningen art. 9 nr. 2 bokstav a, jf. personopplysningsloven § 10, jf. § 9 (2).

PERSONVERNPRINSIPPER
NSD vurderer at den planlagte behandlingen av personopplysninger vil følge prinsippene i personvernforordningen:



- om lovlighet, rettferdighet og åpenhet (art. 5.1 a), ved at de registrerte får tilfredsstillende informasjon om og samtykker til behandlingen
- formålsbegrensning (art. 5.1 b), ved at personopplysninger samles inn for spesifikke, uttrykkelig angitte og berettigede formål, og ikke viderebehandles til nye uforenlige formål
- dataminimering (art. 5.1 c), ved at det kun behandles opplysninger som er adekvate, relevante og nødvendige for formålet med prosjektet
- lagringsbegrensning (art. 5.1 e), ved at personopplysningene ikke lagres lengre enn nødvendig for å oppfylle formålet.

DE REGISTRERTES RETTIGHETER

NSD vurderer at informasjonen om behandlingen som de registrerte vil motta oppfyller lovens krav til form og innhold, jf. art. 12.1 og art. 13.

Så lenge de registrerte kan identifiseres i datamaterialet vil de ha følgende rettigheter: innsyn (art. 15), retting (art. 16), sletting (art. 17), begrensning (art. 18) og dataportabilitet (art. 20).

Vi minner om at hvis en registrert tar kontakt om sine rettigheter, har behandlingsansvarlig institusjon plikt til å svare innen en måned.

FØLG DIN INSTITUSJONS RETNINGSLINJER

NSD legger til grunn at behandlingen oppfyller kravene i personvernforordningen om riktighet (art. 5.1 d), integritet og konfidensialitet (art. 5.1. f) og sikkerhet (art. 32).

For å forsikre dere om at kravene oppfylles, må prosjektansvarlig følge interne retningslinjer/rådføre dere med behandlingsansvarlig institusjon.

MELD VESENTLIGE ENDRINGER

Dersom det skjer vesentlige endringer i behandlingen av personopplysninger, kan det være nødvendig å melde dette til NSD ved å oppdatere meldeskjemaet. Før du melder inn en endring, oppfordrer vi deg til å lese om hvilken type endringer det er nødvendig å melde:
https://www.nsd.no/personverntjenester/fylle-ut-meldeskjema-for-personopplysninger/melde-endringer-i-meldeskjema
Du må vente på svar fra NSD før endringen gjennomføres.

OPPFØLGING AV PROSJEKTET

NSD vil følge opp ved planlagt avslutning for å avklare om behandlingen av personopplysningene er avsluttet.

Kontaktperson hos NSD: Eva J. B. Payne

Lykke til med prosjektet!

Appendix E – Informed consent form

Vil du delta i forskningsprosjektet *«Biomekanisk analyse av lyske-relaterte styrkeøvelser for skadeforebygging»*?

Dette er et spørsmål til deg om å delta i et forskningsprosjekt hvor formålet er å kartlegge belastningen på lyskemuskulatur i tre ulike plankeøvelser. I dette skrivet gir vi deg informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Problemer i lysken bidrar med en stor andel av alle skader i fotball. I dag benyttes spesielt øvelsen «Copenhagen adductor exercise» (en sideliggende dynamisk planke) i skadeforebygging. Hensikten med denne studien er å måle leddbelastning og muskelaktivering i to andre plankeøvelser, dvs. en tradisjonell dynamisk planke/«pike» med ett bein, samt en skrå planke, som simulerer et innsidespark i fotball. Disse resultatene vil kunne avdekke hvilke av øvelsene som er mest hensiktsmessig å benytte i skadeforebyggende arbeid. Dataene i studien vil benyttes i et masterprosjekt.

Hvem er ansvarlig for forskningsprosjektet?
Institutt for idrettsmedisin ved Norges Idrettshøgskole er ansvarlig for prosjektet.

Hvorfor får du spørsmål om å delta?
Vi søker 20 fotballspillere. Lyskeskader er et problem i fotball for både kvinner og menn, og ønsker derfor å inkludere 10 av hvert kjønn. Du må ha fylt 16 år, være frisk og skadefri for å kunne delta.

Hva innebærer det for deg å delta?
Dette er et biomekanisk eksperiment. Vi vil feste elektroder på kroppen din for å måle muskelaktivering. I tillegg vil vi også feste refleksmarkører på kroppen din, disse blir filmet når du gjør de ulike øvelsene, slik at vi i ettertid kan analysere bevegelsesbanen. Du vil gjennomføre en kort oppvarming før du gjennomfører 5-6 repetisjoner av de tre øvelsene i tilfeldig rekkefølge. Antropometriske målinger av høyde og vekt vil bli gjort. Du må ha på deg en kort shorts og sports-BH (for jenter). Du vil bruke omtrent 2 timer i laboratoriet.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket.

- Det er kun masterstudent, veileder og prosjektmedarbeidere som vil ha tilgang til opplysningene om deg.
- I databehandlingen vil et forsøkspersonnummer erstatte navnet og kontaktopplysningene dine, men vi vil ha en egen navneliste adskilt fra øvrige data.
- Datamaskiner som benyttes i prosjektet er passordbeskyttet og lagret data vil ligge kryptert på NIHs forskningsserver.
- Ved publikasjon vil ingen individuelle deltakere kunne gjenkjennes.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?
Prosjektet skal etter planen avsluttes 01.06.2022, da vil all data anonymiseres.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke.

På oppdrag fra *Norges Idrettshøgskole* har NSD (Norsk senter for forskningsdata AS) vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til:

- innsyn i hvilke opplysninger vi behandler om deg, og å få utlevert en kopi av opplysningene
- å få rettet opplysninger om deg som er feil eller misvisende
- å få slettet personopplysninger om deg
- å sende klage til Datatilsynet om behandlingen av dine personopplysninger

Hvor kan du finne ut mer?
Hvis du har spørsmål til studien, eller ønsker å vite mer om eller benytte deg av dine rettigheter, ta kontakt med:

- *Norges Idrettshøgskole* ved masterstudent *Helena Cecilie Mo* (helenamo98@hotmail.com), eller veileder/prosjektleder *Tron Krosshaug* (tronk@nih.no, tlf: +47 456 60 046)
- Vårt personvernombud: Rolf Haavik (personvermombud@nih.no)

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 53 21 15 00.

Med vennlig hilsen

Tron Krosshaug *Helena Cecilie Mo*
(Forsker/veileder) (Masterstudent)

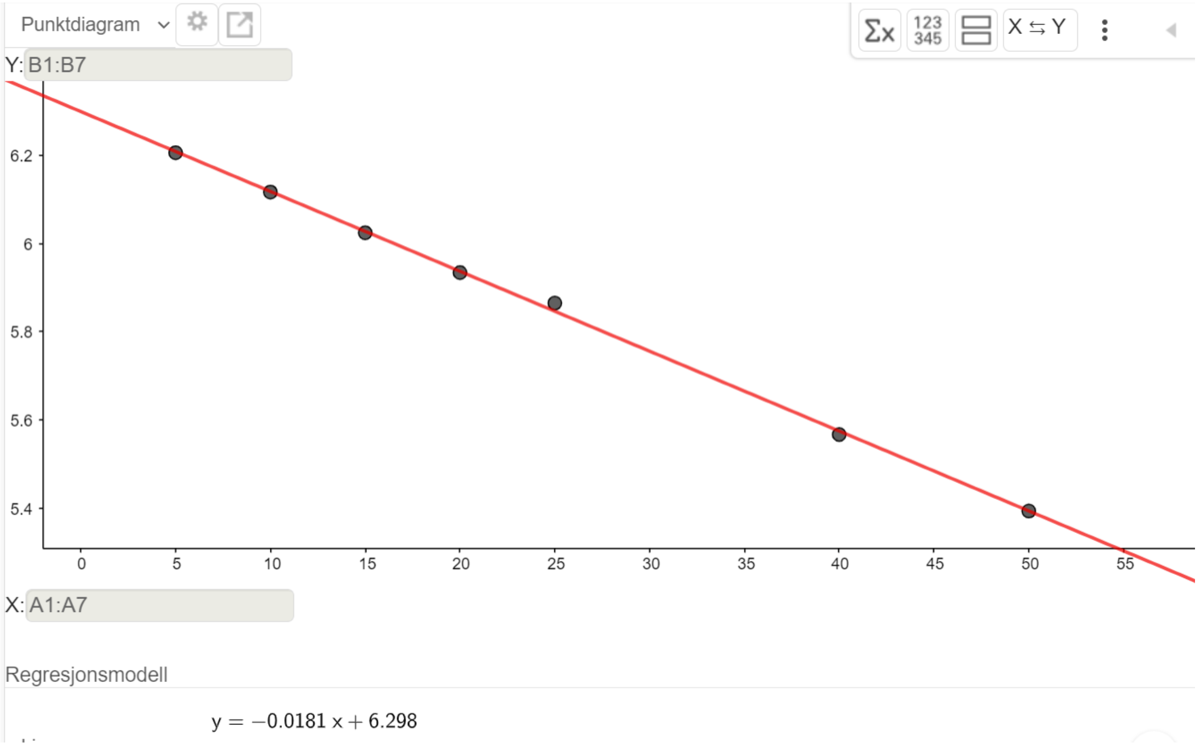
Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet «*Biomekanisk analyse av lyske-relaterte styrkeøvelser for skadeforebygging*», og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ å delta i prosjektet
- ☐ at mine opplysninger behandles frem til prosjektet er avsluttet

----
(Signert av prosjektdeltaker, dato)

Appendix F - Calibration of load cell



Punktdiagram

Y: B1:B7

X: A1:A7

Regresjonsmodell

$y = -0.0181\,x + 6.298$

Appendix G – masterthesis_collectdata.m

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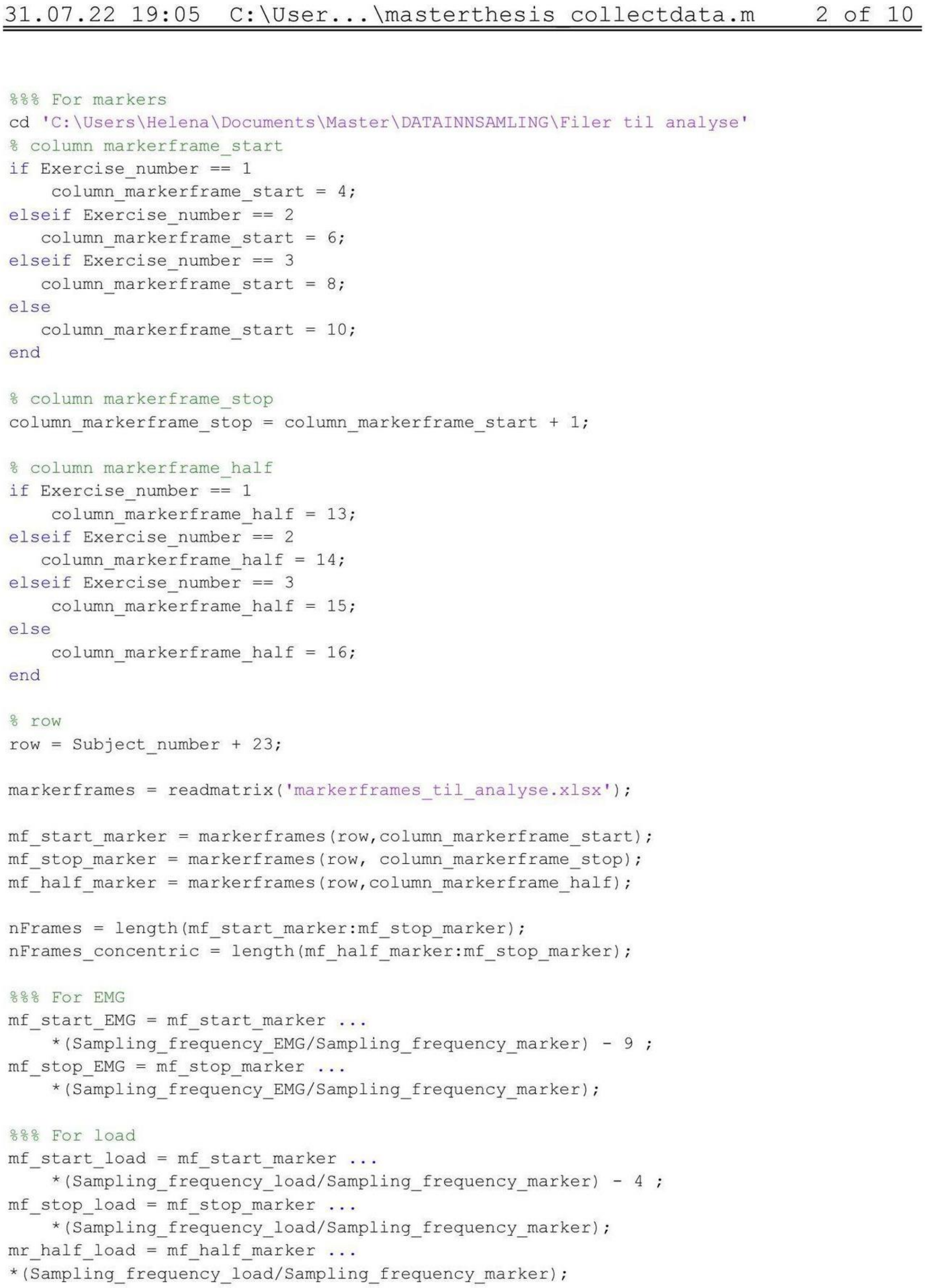
```
% Iterates through each subject and each exercise: retrives and processes
% data, collects it in four Excel files (one for each exercise)
% for further analyses.

% To select subject (two digits)
     % 01, 02, 03, 04, 05, 06, 07, 09, 10,
     % 12, 13, 14, 15, 16, 17, 18, 19, 20
        % data from 18 subjects are analyzed
first_digit = '000000001111111112';
second_digit = '123456790234567890';

% To select exercise
    % CA1 (Copengagen adduction variant 1), CA2 (Copenhagen variant 2),
    % OLP (One leg pike ), OPHFA (Oblique plank with hip flexion and
    % adduction)
        % Each subject condicted 4 exercises
first_letter = 'CCOO';
second_letter = 'AALP';
third_letter = '12PH';

for i = 1:length(first_digit)
    Subject = [first_digit(i) second_digit(i)];
    Subject_number = str2num(Subject);
    for k = 1:length(first_letter)
        E = [first_letter(k) second_letter(k) third_letter(k)];
        if E == 'OPH'
            Exercise = 'OPHFA'
        else % exercise CA1, CA2 or OLP
            Exercise = E
        end
        Exercise_number = k;


%% Filenames
% ==========================================================================
Filename_markers = ['FP-0' Subject '_' Exercise '.tsv'];
Filename_load = ['FP-0' Subject '_' Exercise '_a_1' '.tsv'];
Filename_EMG = ['FP-0' Subject '_' Exercise '_a_2' '.tsv'];
Filename_static = ['FP-0' Subject '_static' '.tsv'];
Filename_MVIC_add_long = ['FP-0' Subject '_MVIC_add_long_a_2.tsv'];
Filename_MVIC_ref_fem = ['FP-0' Subject '_MVIC_rec_fem_a_2.tsv'];
Filename_MVIC_ext_obl = ['FP-0' Subject '_MVIC_ext_obl_a_2.tsv'];

%% Constant
% ==========================================================================
Sampling_frequency_EMG = 2000; % Hz
Sampling_frequency_load = 1000; % Hz
Sampling_frequency_marker = 200; %Hz
Sampling_frequency_static = 200; %Hz
g = 9.81; %m/s^2
FREQ = 2000; % HZ %%

%% Find marekrframes
% ==========================================================================
```



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```
%%% For markers
cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\Filer til analyse'
% column markerframe_start
if Exercise_number == 1
    column_markerframe_start = 4;
elseif Exercise_number == 2
   column_markerframe_start = 6;
elseif Exercise_number == 3
   column_markerframe_start = 8;
else
   column_markerframe_start = 10;
end

% column markerframe_stop
column_markerframe_stop = column_markerframe_start + 1;

% column markerframe_half
if Exercise_number == 1
    column_markerframe_half = 13;
elseif Exercise_number == 2
   column_markerframe_half = 14;
elseif Exercise_number == 3
    column_markerframe_half = 15;
else
    column_markerframe_half = 16;
end

% row
row = Subject_number + 23;

markerframes = readmatrix('markerframes_til_analyse.xlsx');

mf_start_marker = markerframes(row,column_markerframe_start);
mf_stop_marker = markerframes(row, column_markerframe_stop);
mf_half_marker = markerframes(row,column_markerframe_half);

nFrames = length(mf_start_marker:mf_stop_marker);
nFrames_concentric = length(mf_half_marker:mf_stop_marker);

%%% For EMG
mf_start_EMG = mf_start_marker ...
    *(Sampling_frequency_EMG/Sampling_frequency_marker) - 9 ;
mf_stop_EMG = mf_stop_marker ...
    *(Sampling_frequency_EMG/Sampling_frequency_marker);

%%% For load
mf_start_load = mf_start_marker ...
    *(Sampling_frequency_load/Sampling_frequency_marker) - 4 ;
mf_stop_load = mf_stop_marker ...
    *(Sampling_frequency_load/Sampling_frequency_marker);
mr_half_load = mf_half_marker ...
*(Sampling_frequency_load/Sampling_frequency_marker);
```

```
%%% For static recording
cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\Filer til analyse'
markerframes_static = readmatrix('markerframes_til_analyse.xlsx');
row = Subject_number;
column_static_start = 2;
column_static_stop = 3;

static_start = markerframes_static(row,column_static_start);
static_stop = markerframes_static(row,column_static_stop);

%%% For MVIC
cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\Filer til analyse'
markerframes_MVIC = readmatrix('markerframes_til_analyse.xlsx');
mf_start_MVIC_add_long = markerframes(Subject_number,12);
mf_stop_MVIC_add_long = markerframes(Subject_number,13);
mf_start_MVIC_rec_fem = markerframes(Subject_number,14);
mf_stop_MVIC_rec_fem = markerframes(Subject_number,15);
mf_start_MVIC_ext_obl = markerframes(Subject_number,16);
mf_stop_MVIC_ext_obl = markerframes(Subject_number,17);

%% Import data
% ==========================================================================


%%% STATIC TRIAL %%%
    % average position of markers over 1 second
cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\Filer til analyse'
data_static = importdata(Filename_static,'  ',12);
matrix_static = data_static.data(:,:);
number_of_markerframes = 200;

s = struct;
s.r_tibia = matrix_static(:,13:15);
s.r_thigh_ant = matrix_static(:,16:18);
s.r_thigh_lat = matrix_static(:,19:21);
s.r_knee_lat = matrix_static(:,28:30);
s.r_shoulder = matrix_static(:,37:39);
s.r_asis = matrix_static(:,40:42);
s.l_asis = matrix_static(:,43:45);
s.r_psis = matrix_static(:,46:48);
s.l_psis = matrix_static(:,49:51);
s.c7 = matrix_static(:,52:54);
s.back_mid = matrix_static(:,55:57);
s.l_shoulder = matrix_static(:,64:66);
s.load_top = matrix_static(:,67:69);
s.load_high_1 = matrix_static(:,70:72);
s.load_high_2 = matrix_static(:,73:75);
s.load_low_1 = matrix_static(:,76:78);
s.load_low_2 = matrix_static(:,79:81);

s.r_tibia = sum(s.r_tibia(static_start:static_stop,:))/number_of_markerframes;
s.r_thigh_ant = sum(s.r_thigh_ant(static_start:static_stop,:))↙
/number_of_markerframes;
s.r_thigh_lat = sum(s.r_thigh_lat(static_start:static_stop,:))↙
```

```
/number_of_markerframes;
s.r_knee_lat = sum(s.r_knee_lat(static_start:static_stop,:))/number_of_markerframes;
s.r_shoulder = sum(s.r_shoulder(static_start:static_stop,:))/number_of_markerframes;
s.r_asis = sum(s.r_asis(static_start:static_stop,:))/number_of_markerframes;
s.l_asis = sum(s.l_asis(static_start:static_stop,:))/number_of_markerframes;
s.r_psis = sum(s.r_psis(static_start:static_stop,:))/number_of_markerframes;
s.l_psis = sum(s.l_psis(static_start:static_stop,:))/number_of_markerframes;
s.c7 = sum(s.c7(static_start:static_stop,:))/number_of_markerframes;
s.back_mid = sum(s.back_mid(static_start:static_stop,:))/number_of_markerframes;
s.l_shoulder = sum(s.l_shoulder(static_start:static_stop,:))/number_of_markerframes;
s.load_top = sum(s.load_top(static_start:static_stop,:))/number_of_markerframes;
s.load_high_1 = sum(s.load_high_1(static_start:static_stop,:))↙
/number_of_markerframes;
s.load_high_2 = sum(s.load_high_2(static_start:static_stop,:))↙
/number_of_markerframes;
s.load_low_1 = sum(s.load_low_1(static_start:static_stop,:))/number_of_markerframes;
s.load_low_2 = sum(s.load_low_2(static_start:static_stop,:))/number_of_markerframes;


%%% MARKERS %%%
cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\Filer til analyse'
data_markers = importdata(Filename_markers,'    ',12);
matrix_markers = data_markers.data(:,:);
m = struct;
m.r_toe_med = matrix_markers(mf_start_marker:mf_stop_marker,1:3);
m.r_toe_lat = matrix_markers(mf_start_marker:mf_stop_marker,4:6);
m.r_ankle_med = matrix_markers(mf_start_marker:mf_stop_marker,7:9);
m.r_ankle_lat = matrix_markers(mf_start_marker:mf_stop_marker,10:12);
m.r_tibia = matrix_markers(mf_start_marker:mf_stop_marker,13:15);
m.r_thigh_ant = matrix_markers(mf_start_marker:mf_stop_marker,16:18);
m.r_thigh_lat = matrix_markers(mf_start_marker:mf_stop_marker,19:21);
m.r_troch = matrix_markers(mf_start_marker:mf_stop_marker,22:24);
m.r_knee_med = matrix_markers(mf_start_marker:mf_stop_marker,25:27);
m.r_knee_lat = matrix_markers(mf_start_marker:mf_stop_marker,28:30);
m.r_elbow_med = matrix_markers(mf_start_marker:mf_stop_marker,31:33);
m.r_elbow_lat = matrix_markers(mf_start_marker:mf_stop_marker,34:36);
m.r_shoulder = matrix_markers(mf_start_marker:mf_stop_marker,37:39);
m.r_asis = matrix_markers(mf_start_marker:mf_stop_marker,40:42);
m.l_asis = matrix_markers(mf_start_marker:mf_stop_marker,43:45);
m.r_psis = matrix_markers(mf_start_marker:mf_stop_marker,46:48);
m.l_psis = matrix_markers(mf_start_marker:mf_stop_marker,49:51);
m.c7 = matrix_markers(mf_start_marker:mf_stop_marker,52:54);
m.back_mid = matrix_markers(mf_start_marker:mf_stop_marker,55:57);
m.back_lower = matrix_markers(mf_start_marker:mf_stop_marker,58:60);
m.jugular = matrix_markers(mf_start_marker:mf_stop_marker,61:63);
m.l_shoulder = matrix_markers(mf_start_marker:mf_stop_marker,64:66);
m.load_top = matrix_markers(mf_start_marker:mf_stop_marker,67:69);
m.load_high_1 = matrix_markers(mf_start_marker:mf_stop_marker,70:72);
m.load_high_2 = matrix_markers(mf_start_marker:mf_stop_marker,73:75);
m.load_low_1 = matrix_markers(mf_start_marker:mf_stop_marker,76:78);
m.load_low_2 = matrix_markers(mf_start_marker:mf_stop_marker,79:81);


%%% EMG %%%
```

```
cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\Filer til analyse'
data_EMG = importdata(Filename_EMG,'    ',14);
matrix_EMG = data_EMG.data(:,:);

 % All subjects had the same numbers on the electrodes except on of them
    % (FP-013)
if Subject_number == 13
    EMG_add_long = matrix_EMG(:,1);
    EMG_rec_fem = matrix_EMG(:,3);
    EMG_ext_obl = matrix_EMG(:,2);
else
    EMG_add_long = matrix_EMG(:,1);
    EMG_rec_fem = matrix_EMG(:,2);
    EMG_ext_obl = matrix_EMG(:,3);
end


%%% MVIC %%%
cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\Filer til analyse'
data_MVIC_add_long = importdata(Filename_MVIC_add_long,'    ',14);
data_MVIC_rec_fem = importdata(Filename_MVIC_rec_fem,'  ',14);
data_MVIC_ext_obl = importdata(Filename_MVIC_ext_obl,'  ',14);

 % All subjects had the same numbers on the electrodes except on of them
    % (FP-013)
if Subject_number == 13
    MVIC_add_long = data_MVIC_add_long.data(:,1);
    MVIC_rec_fem = data_MVIC_rec_fem.data(:,3);
    MVIC_ext_obl = data_MVIC_ext_obl.data(:,2);
else
    MVIC_add_long = data_MVIC_add_long.data(:,1);
    MVIC_rec_fem = data_MVIC_rec_fem.data(:,2);
    MVIC_ext_obl = data_MVIC_ext_obl.data(:,3);
end

MVIC_add_long = MVIC_add_long(mf_start_MVIC_add_long:mf_stop_MVIC_add_long,:);
MVIC_rec_fem = MVIC_rec_fem(mf_start_MVIC_rec_fem:mf_stop_MVIC_rec_fem,:);
MVIC_ext_obl = MVIC_ext_obl(mf_start_MVIC_ext_obl:mf_stop_MVIC_ext_obl,:);


%%% LOAD %%%
cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\Filer til analyse'\
data_load = importdata(Filename_load,'  ',14);
matrix_load = data_load.data(:,19);
load = matrix_load;


%% MVIC tests
% ==========================================================================

% One test for each muscle, the tests were performed in order to normalize
% the EMG signals from each exercise

% Change all NaN to 0
```

```
MVIC_add_long(isnan(MVIC_add_long)) = 0;
MVIC_rec_fem(isnan(MVIC_rec_fem)) = 0;
MVIC_ext_obl(isnan(MVIC_ext_obl)) = 0;

% One second of signal from the the tests processed using root-mean-square
max_add_long = rms(abs(MVIC_add_long));
max_rec_fem = rms(abs(MVIC_rec_fem));
max_ext_obl = rms(abs(MVIC_ext_obl));

%% EMG signal
% ========================================================================

% Change all NaN to 0
EMG_add_long(isnan(EMG_add_long)) = 0;
EMG_rec_fem(isnan(EMG_rec_fem)) = 0;
EMG_ext_obl(isnan(EMG_ext_obl)) = 0;

% Signal processing - smoothing
%   Use dsp.MovingRMS to compute the moving root mean square (RMS) of the
%   input signals (the EMG signals of each muscle for selected subject and
%   exercise)
movRMS = dsp.MovingRMS(200); % 200--> 100ms

s_EMG_add_long = movRMS(abs(EMG_add_long));
s_EMG_rec_fem = movRMS(abs(EMG_rec_fem));
s_EMG_ext_obl = movRMS(abs(EMG_ext_obl));

smooth_EMG_add_long = s_EMG_add_long(mf_start_EMG:mf_stop_EMG,:);
smooth_EMG_rec_fem = s_EMG_rec_fem(mf_start_EMG:mf_stop_EMG,:);
smooth_EMG_ext_obl = s_EMG_ext_obl(mf_start_EMG:mf_stop_EMG,:);

% Normalize EMG
norm_add_long = smooth_EMG_add_long/max_add_long;
norm_rec_fem = smooth_EMG_rec_fem/max_rec_fem;
norm_ext_obl = smooth_EMG_ext_obl/max_ext_obl;

% Normalized peak values
normPeak_add_long = max(norm_add_long);
normPeak_rec_fem = max(norm_rec_fem);
normPeak_ext_obl = max(norm_ext_obl);

% Normalized mean values
normMean_add_long = mean(norm_add_long);
normMean_rec_fem = mean(norm_rec_fem);
normMean_ext_obl = mean(norm_ext_obl);
    % with standard deviations
std_normMean_add_long = std(norm_add_long);
std_normMean_rec_fem = std(norm_rec_fem);
std_normMean_ext_obl = std(norm_ext_obl);

% Downsample (2000 Hz --> 200 Hz)
ds_EMG_add_long = resample(s_EMG_add_long,1,10);
ds_EMG_rec_fem = resample(s_EMG_rec_fem,1,10);
ds_normEMG_add_long = ds_EMG_add_long(mf_start_marker:mf_stop_marker,:)↙
```

```
/max_add_long;
ds_normEMG_rec_fem = ds_EMG_rec_fem(mf_start_marker:mf_stop_marker,:)/max_rec_fem;


%% Marker trajectories
% ==========================================================================

cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\'
% Determine coordinate system for the pelvis
[epx,epy,epz,epx_static,epy_static,epz_static,rHC,rHC_static] ...
    = pelvis_axicross(m.r_asis,m.l_asis,m.r_psis,m.l_psis,s.r_asis,s.l_asis,s.↙
r_psis,s.l_psis,...
    nFrames,1,FREQ);
            % function calculate and return the local coordinate sytem of
            % pelvis and right hip center, both during static trial and
            % performance of the four exercises

% global coordinatsystem
gx = [ones(nFrames,1), zeros(nFrames,2)];
gy = [zeros(nFrames,1), ones(nFrames,1), zeros(nFrames,1)];
gz = [zeros(nFrames,2), ones(nFrames,1)];

% find angle of pelvis in relation to the floor
degrees = zeros(nFrames,1);
for h = 1:nFrames
    rad = acos(dot(-epy(h,:),gx(h,:)));
    degrees(h) = rad2deg(rad);
end


%% Force
% ==========================================================================

% Calibration of the loadcell:
% Output data (in Volt) from the loadcell was tested at different loads
% (using weight plates). A linear regression analysis was made from the
% results: y = -0.0181*x + 6.298. y is the output data from the loadcell
% with the unit Volt. x is the mass of the weight plates in kilograms.

s_load = movmean(load,50);

% downsample load data to match markers (1000 Hz --> 200 Hz)
ds_load = resample(s_load,1,5);
smooth_load = ds_load(mf_start_marker:mf_stop_marker);

mass = (6.298 - smooth_load)/-0.0181;
force = abs(mass) * g;

% Find the subject's mass
cd 'C:\Users\Helena\Documents\Master'
profile = readmatrix('DataCollection_master.xlsx');
Subject_mass = profile(Subject_number,5);

% Normalize the force with respect to the subjects' weight
```

```
normForce = force / (Subject_mass * g);

% Find distance from right hip center to line of force
high_or_low = ...
    [1 0 0 1 1 0 0 NaN 0 0 NaN 0 0 0 0 0 1 1 1 0; ...
    1 0 0 1 1 0 0 NaN 0 0 NaN 0 0 0 0 0 1 1 1 0; ...
    1 0 0 1 1 0 0 NaN 0 0 NaN 1 0 0 0 0 1 1 1 0; ...
    1 0 0 1 1 0 0 NaN 0 1 NaN 0 0 0 0 0 1 1 1 1]; % 1 = high, 0 = low

load_marker = high_or_low(Exercise_number,Subject_number);

if load_marker == 1        % use the high markers
    load_1 = m.load_high_1;
    load_2 = m.load_high_2;
else                        % use the low markers
    load_1 = m.load_low_1;
    load_2 = m.load_low_2;
end

load_top = m.load_top;
load_lower = (load_1 + load_2)/2;

cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING\'
[distance, intersection_point] = distancePointToLine(load_top,load_lower,rHC);
        %%% function finds the shortest distance between right hip center
        %%% (rHC) and the line of force (a line through load_top and
        %%% load_lower)

% Torque
torque = force .* distance;
% Torque normalized
normTorque = normForce .* distance;


%% Write data to Excel spreadsheet

Filename_data_to_Excel = ['data_' Exercise '.xlsx'];

headers = {'max_add_long', 'max_rec_fem', 'max_ext_obl', ...
    'norm_add_long', 'norm_rec_fem', 'norm_ext_obl', ...
    'normPeak_add_long', 'normPeak_rec_fem', 'normPeak_ext_obl', ...
    'normMean_add_long', 'normMean_rec_fem', 'normMean_ext_obl', ...
    'rHC (x)', 'rHC (y)', 'rHC (z)', ...
    'force', 'normForce', 'torque', 'normTorque', 'distance', ...
    'intersection_point (x)', 'intersection_point (y)',...
    'intersection_point↙
(z)','ds_normEMG_add_long','ds_normEMG_rec_fem','m_degrees'};

cd 'C:\Users\Helena\Documents\Master\'
% writematrix(headers,Filename_data_to_Excel,'Sheet',Subject_number)
xlswrite(Filename_data_to_Excel,headers,Subject_number,'A1')

writematrix(max_add_long,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'A2')
```

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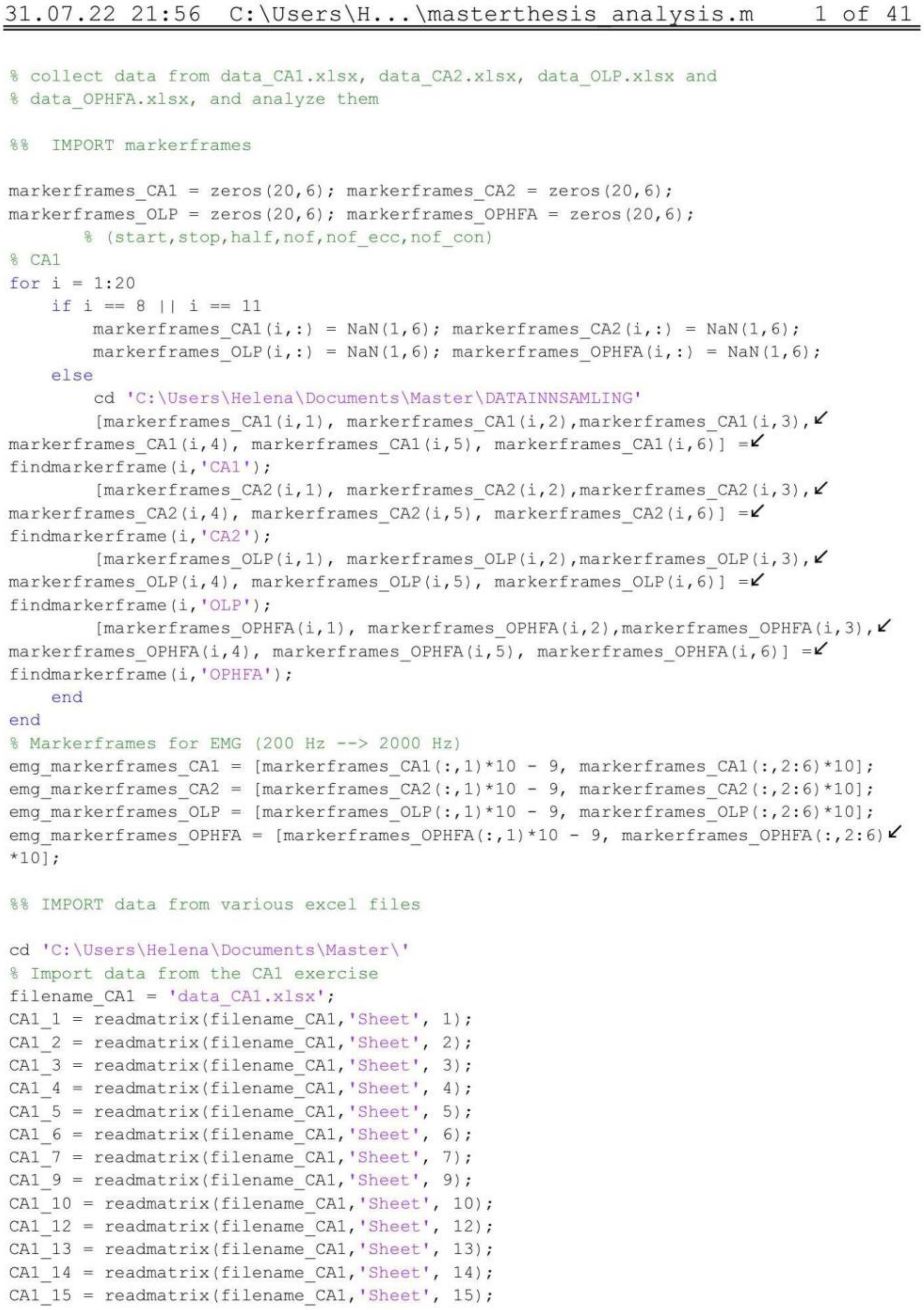
```
writematrix(max_rec_fem,Filename_data_to_Excel,'Sheet',Subject_number,'Range', 'B2')
writematrix(max_ext_obl,Filename_data_to_Excel,'Sheet',Subject_number,'Range', 'C2')
writematrix(norm_add_long,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'D2')
writematrix(norm_rec_fem,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'E2')
writematrix(norm_ext_obl,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'F2')
writematrix(normPeak_add_long,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'G2')
writematrix(normPeak_rec_fem,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'H2')
writematrix(normPeak_ext_obl,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'I2')
writematrix(normMean_add_long,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'J2')
writematrix(normMean_rec_fem,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'K2')
writematrix(normMean_ext_obl,Filename_data_to_Excel,'Sheet',Subject_number,'Range',↙
'L2')
writematrix(std_normMean_add_long,Filename_data_to_Excel,'Sheet',↙
Subject_number,'Range', 'J3')
writematrix(std_normMean_rec_fem,Filename_data_to_Excel,'Sheet',↙
Subject_number,'Range', 'K3')
writematrix(std_normMean_ext_obl,Filename_data_to_Excel,'Sheet',↙
Subject_number,'Range', 'L3')
writematrix(rHC,Filename_data_to_Excel,'Sheet',Subject_number,'Range', 'M2')
writematrix(force,Filename_data_to_Excel,'Sheet',Subject_number,'Range', 'P2')
writematrix(normForce,Filename_data_to_Excel,'Sheet',Subject_number,'Range', 'Q2')
writematrix(torque,Filename_data_to_Excel,'Sheet',Subject_number,'Range', 'R2')
writematrix(normTorque,Filename_data_to_Excel,'Sheet',Subject_number,'Range', 'S2')
writematrix(distance,Filename_data_to_Excel,'Sheet',Subject_number,'Range','T2')
writematrix(intersection_point,Filename_data_to_Excel,'Sheet',↙
Subject_number,'Range','U2')
writematrix(ds_normEMG_add_long,Filename_data_to_Excel,'Sheet',↙
Subject_number,'Range','X2')
writematrix(ds_normEMG_rec_fem,Filename_data_to_Excel,'Sheet',↙
Subject_number,'Range','Y2')
```

Appendix H – masterthesis_analysis.m



```
31.07.22 21:56  C:\Users\H...\masterthesis_analysis.m     1 of 41

% collect data from data_CA1.xlsx, data_CA2.xlsx, data_OLP.xlsx and
% data_OPHFA.xlsx, and analyze them

%%  IMPORT markerframes

markerframes_CA1 = zeros(20,6); markerframes_CA2 = zeros(20,6);
markerframes_OLP = zeros(20,6); markerframes_OPHFA = zeros(20,6);
       % (start,stop,half,nof,nof_ecc,nof_con)
% CA1
for i = 1:20
    if i == 8 || i == 11
        markerframes_CA1(i,:) = NaN(1,6); markerframes_CA2(i,:) = NaN(1,6);
        markerframes_OLP(i,:) = NaN(1,6); markerframes_OPHFA(i,:) = NaN(1,6);
    else
        cd 'C:\Users\Helena\Documents\Master\DATAINNSAMLING'
        [markerframes_CA1(i,1), markerframes_CA1(i,2),markerframes_CA1(i,3),↙
markerframes_CA1(i,4), markerframes_CA1(i,5), markerframes_CA1(i,6)] =↙
findmarkerframe(i,'CA1');
        [markerframes_CA2(i,1), markerframes_CA2(i,2),markerframes_CA2(i,3),↙
markerframes_CA2(i,4), markerframes_CA2(i,5), markerframes_CA2(i,6)] =↙
findmarkerframe(i,'CA2');
        [markerframes_OLP(i,1), markerframes_OLP(i,2),markerframes_OLP(i,3),↙
markerframes_OLP(i,4), markerframes_OLP(i,5), markerframes_OLP(i,6)] =↙
findmarkerframe(i,'OLP');
        [markerframes_OPHFA(i,1), markerframes_OPHFA(i,2),markerframes_OPHFA(i,3),↙
markerframes_OPHFA(i,4), markerframes_OPHFA(i,5), markerframes_OPHFA(i,6)] =↙
findmarkerframe(i,'OPHFA');
    end
end
% Markerframes for EMG (200 Hz --> 2000 Hz)
emg_markerframes_CA1 = [markerframes_CA1(:,1)*10 - 9, markerframes_CA1(:,2:6)*10];
emg_markerframes_CA2 = [markerframes_CA2(:,1)*10 - 9, markerframes_CA2(:,2:6)*10];
emg_markerframes_OLP = [markerframes_OLP(:,1)*10 - 9, markerframes_OLP(:,2:6)*10];
emg_markerframes_OPHFA = [markerframes_OPHFA(:,1)*10 - 9, markerframes_OPHFA(:,2:6)↙
*10];

%% IMPORT data from various excel files

cd 'C:\Users\Helena\Documents\Master\'
% Import data from the CA1 exercise
filename_CA1 = 'data_CA1.xlsx';
CA1_1 = readmatrix(filename_CA1,'Sheet', 1);
CA1_2 = readmatrix(filename_CA1,'Sheet', 2);
CA1_3 = readmatrix(filename_CA1,'Sheet', 3);
CA1_4 = readmatrix(filename_CA1,'Sheet', 4);
CA1_5 = readmatrix(filename_CA1,'Sheet', 5);
CA1_6 = readmatrix(filename_CA1,'Sheet', 6);
CA1_7 = readmatrix(filename_CA1,'Sheet', 7);
CA1_9 = readmatrix(filename_CA1,'Sheet', 9);
CA1_10 = readmatrix(filename_CA1,'Sheet', 10);
CA1_12 = readmatrix(filename_CA1,'Sheet', 12);
CA1_13 = readmatrix(filename_CA1,'Sheet', 13);
CA1_14 = readmatrix(filename_CA1,'Sheet', 14);
CA1_15 = readmatrix(filename_CA1,'Sheet', 15);
```

```
CA1_16 = readmatrix(filename_CA1,'Sheet', 16);
CA1_17 = readmatrix(filename_CA1,'Sheet', 17);
CA1_18 = readmatrix(filename_CA1,'Sheet', 18);
CA1_19 = readmatrix(filename_CA1,'Sheet', 19);
CA1_20 = readmatrix(filename_CA1,'Sheet', 20);
% Import data from the CA2 exercise
filename_CA2 = 'data_CA2.xlsx';
CA2_1 = readmatrix(filename_CA2,'Sheet', 1);
CA2_2 = readmatrix(filename_CA2,'Sheet', 2);
CA2_3 = readmatrix(filename_CA2,'Sheet', 3);
CA2_4 = readmatrix(filename_CA2,'Sheet', 4);
CA2_5 = readmatrix(filename_CA2,'Sheet', 5);
CA2_6 = readmatrix(filename_CA2,'Sheet', 6);
CA2_7 = readmatrix(filename_CA2,'Sheet', 7);
CA2_9 = readmatrix(filename_CA2,'Sheet', 9);
CA2_10 = readmatrix(filename_CA2,'Sheet', 10);
CA2_12 = readmatrix(filename_CA2,'Sheet', 12);
CA2_13 = readmatrix(filename_CA2,'Sheet', 13);
CA2_14 = readmatrix(filename_CA2,'Sheet', 14);
CA2_15 = readmatrix(filename_CA2,'Sheet', 15);
CA2_16 = readmatrix(filename_CA2,'Sheet', 16);
CA2_17 = readmatrix(filename_CA2,'Sheet', 17);
CA2_18 = readmatrix(filename_CA2,'Sheet', 18);
CA2_19 = readmatrix(filename_CA2,'Sheet', 19);
CA2_20 = readmatrix(filename_CA2,'Sheet', 20);
% Import data from the OLP exercise
filename_OLP = 'data_OLP.xlsx';
OLP_1 = readmatrix(filename_OLP,'Sheet', 1);
OLP_2 = readmatrix(filename_OLP,'Sheet', 2);
OLP_3 = readmatrix(filename_OLP,'Sheet', 3);
OLP_4 = readmatrix(filename_OLP,'Sheet', 4);
OLP_5 = readmatrix(filename_OLP,'Sheet', 5);
OLP_6 = readmatrix(filename_OLP,'Sheet', 6);
OLP_7 = readmatrix(filename_OLP,'Sheet', 7);
OLP_9 = readmatrix(filename_OLP,'Sheet', 9);
OLP_10 = readmatrix(filename_OLP,'Sheet', 10);
OLP_12 = readmatrix(filename_OLP,'Sheet', 12);
OLP_13 = readmatrix(filename_OLP,'Sheet', 13);
OLP_14 = readmatrix(filename_OLP,'Sheet', 14);
OLP_15 = readmatrix(filename_OLP,'Sheet', 15);
OLP_16 = readmatrix(filename_OLP,'Sheet', 16);
OLP_17 = readmatrix(filename_OLP,'Sheet', 17);
OLP_18 = readmatrix(filename_OLP,'Sheet', 18);
OLP_19 = readmatrix(filename_OLP,'Sheet', 19);
OLP_20 = readmatrix(filename_OLP,'Sheet', 20);
% Import data from the OPHFA exercise
filename_OPHFA = 'data_OPHFA.xlsx';
OPHFA_1 = readmatrix(filename_OPHFA,'Sheet', 1);
OPHFA_2 = readmatrix(filename_OPHFA,'Sheet', 2);
OPHFA_3 = readmatrix(filename_OPHFA,'Sheet', 3);
OPHFA_4 = readmatrix(filename_OPHFA,'Sheet', 4);
OPHFA_5 = readmatrix(filename_OPHFA,'Sheet', 5);
OPHFA_6 = readmatrix(filename_OPHFA,'Sheet', 6);
OPHFA_7 = readmatrix(filename_OPHFA,'Sheet', 7);
```

```
OPHFA_9 = readmatrix(filename_OPHFA,'Sheet', 9);
OPHFA_10 = readmatrix(filename_OPHFA,'Sheet', 10);
OPHFA_12 = readmatrix(filename_OPHFA,'Sheet', 12);
OPHFA_13 = readmatrix(filename_OPHFA,'Sheet', 13);
OPHFA_14 = readmatrix(filename_OPHFA,'Sheet', 14);
OPHFA_15 = readmatrix(filename_OPHFA,'Sheet', 15);
OPHFA_16 = readmatrix(filename_OPHFA,'Sheet', 16);
OPHFA_17 = readmatrix(filename_OPHFA,'Sheet', 17);
OPHFA_18 = readmatrix(filename_OPHFA,'Sheet', 18);
OPHFA_19 = readmatrix(filename_OPHFA,'Sheet', 19);
OPHFA_20 = readmatrix(filename_OPHFA,'Sheet', 20);

%% Find results of the three MVIC-tests for each subject

max_EMG = [CA1_1(1,1:3);CA1_2(1,1:3);CA1_3(1,1:3);CA1_4(1,1:3);...
    CA1_5(1,1:3);CA1_6(1,1:3);CA1_7(1,1:3);zeros(1,3);CA1_9(1,1:3);...
    CA1_10(1,1:3);zeros(1,3);CA1_12(1,1:3);CA1_13(1,1:3);CA1_14(1,1:3);...
    CA1_15(1,1:3);CA1_16(1,1:3);CA1_17(1,1:3);CA1_18(1,1:3);...
    CA1_19(1,1:3);CA1_20(1,1:3)];

%% Find normalized EMG of each muscle for each subject

% In the CA1 exercise
normEMG_CA1_1 = CA1_1(1:emg_markerframes_CA1(1,4),4:6);
normEMG_CA1_2 = CA1_2(1:emg_markerframes_CA1(2,4),4:6);
normEMG_CA1_3 = CA1_3(1:emg_markerframes_CA1(3,4),4:6);
normEMG_CA1_4 = CA1_4(1:emg_markerframes_CA1(4,4),4:6);
normEMG_CA1_5 = CA1_5(1:emg_markerframes_CA1(5,4),4:6);
normEMG_CA1_6 = CA1_6(1:emg_markerframes_CA1(6,4),4:6);
normEMG_CA1_7 = CA1_7(1:emg_markerframes_CA1(7,4),4:6);
normEMG_CA1_8 = zeros(1,3);
normEMG_CA1_9 = CA1_9(1:emg_markerframes_CA1(9,4),4:6);
normEMG_CA1_10 = CA1_10(1:emg_markerframes_CA1(10,4),4:6);
normEMG_CA1_11 = zeros(1,3);
normEMG_CA1_12 = CA1_12(1:emg_markerframes_CA1(12,4),4:6);
normEMG_CA1_13 = CA1_13(1:emg_markerframes_CA1(13,4),4:6);
normEMG_CA1_14 = CA1_14(1:emg_markerframes_CA1(14,4),4:6);
normEMG_CA1_15 = CA1_15(1:emg_markerframes_CA1(15,4),4:6);
normEMG_CA1_16 = CA1_16(1:emg_markerframes_CA1(16,4),4:6);
normEMG_CA1_17 = CA1_17(1:emg_markerframes_CA1(17,4),4:6);
normEMG_CA1_18 = CA1_18(1:emg_markerframes_CA1(18,4),4:6);
normEMG_CA1_19 = CA1_19(1:emg_markerframes_CA1(19,4),4:6);
normEMG_CA1_20 = CA1_20(1:emg_markerframes_CA1(20,4),4:6);
% In the CA2 exercise
normEMG_CA2_1 = CA2_1(1:emg_markerframes_CA2(1,4),4:6);
normEMG_CA2_2 = CA2_2(1:emg_markerframes_CA2(2,4),4:6);
normEMG_CA2_3 = CA2_3(1:emg_markerframes_CA2(3,4),4:6);
normEMG_CA2_4 = CA2_4(1:emg_markerframes_CA2(4,4),4:6);
normEMG_CA2_5 = CA2_5(1:emg_markerframes_CA2(5,4),4:6);
normEMG_CA2_6 = CA2_6(1:emg_markerframes_CA2(6,4),4:6);
normEMG_CA2_7 = CA2_7(1:emg_markerframes_CA2(7,4),4:6);
normEMG_CA2_8 = zeros(1,3);
normEMG_CA2_9 = CA2_9(1:emg_markerframes_CA2(9,4),4:6);
normEMG_CA2_10 = CA2_10(1:emg_markerframes_CA2(10,4),4:6);
```

```
normEMG_CA2_11 = zeros(1,3);
normEMG_CA2_12 = CA2_12(1:emg_markerframes_CA2(12,4),4:6);
normEMG_CA2_13 = CA2_13(1:emg_markerframes_CA2(13,4),4:6);
normEMG_CA2_14 = CA2_14(1:emg_markerframes_CA2(14,4),4:6);
normEMG_CA2_15 = CA2_15(1:emg_markerframes_CA2(15,4),4:6);
normEMG_CA2_16 = CA2_16(1:emg_markerframes_CA2(16,4),4:6);
normEMG_CA2_17 = CA2_17(1:emg_markerframes_CA2(17,4),4:6);
normEMG_CA2_18 = CA2_18(1:emg_markerframes_CA2(18,4),4:6);
normEMG_CA2_19 = CA2_19(1:emg_markerframes_CA2(19,4),4:6);
normEMG_CA2_20 = CA2_20(1:emg_markerframes_CA2(20,4),4:6);
% In the OLP exercise
normEMG_OLP_1 = OLP_1(1:emg_markerframes_OLP(1,4),4:6);
normEMG_OLP_2 = OLP_2(1:emg_markerframes_OLP(2,4),4:6);
normEMG_OLP_3 = OLP_3(1:emg_markerframes_OLP(3,4),4:6);
normEMG_OLP_4 = OLP_4(1:emg_markerframes_OLP(4,4),4:6);
normEMG_OLP_5 = OLP_5(1:emg_markerframes_OLP(5,4),4:6);
normEMG_OLP_6 = OLP_6(1:emg_markerframes_OLP(6,4),4:6);
normEMG_OLP_7 = OLP_7(1:emg_markerframes_OLP(7,4),4:6);
normEMG_OLP_8 = zeros(1,3);
normEMG_OLP_9 = OLP_9(1:emg_markerframes_OLP(9,4),4:6);
normEMG_OLP_10 = OLP_10(1:emg_markerframes_OLP(10,4),4:6);
normEMG_OLP_11 = zeros(1,3);
normEMG_OLP_12 = OLP_12(1:emg_markerframes_OLP(12,4),4:6);
normEMG_OLP_13 = OLP_13(1:emg_markerframes_OLP(13,4),4:6);
normEMG_OLP_14 = OLP_14(1:emg_markerframes_OLP(14,4),4:6);
normEMG_OLP_15 = OLP_15(1:emg_markerframes_OLP(15,4),4:6);
normEMG_OLP_16 = OLP_16(1:emg_markerframes_OLP(16,4),4:6);
normEMG_OLP_17 = OLP_17(1:emg_markerframes_OLP(17,4),4:6);
normEMG_OLP_18 = OLP_18(1:emg_markerframes_OLP(18,4),4:6);
normEMG_OLP_19 = OLP_19(1:emg_markerframes_OLP(19,4),4:6);
normEMG_OLP_20 = OLP_20(1:emg_markerframes_OLP(20,4),4:6);
% In the OPHFA exercise
normEMG_OPHFA_1 = OPHFA_1(1:emg_markerframes_OPHFA(1,4),4:6);
normEMG_OPHFA_2 = OPHFA_2(1:emg_markerframes_OPHFA(2,4),4:6);
normEMG_OPHFA_3 = OPHFA_3(1:emg_markerframes_OPHFA(3,4),4:6);
normEMG_OPHFA_4 = OPHFA_4(1:emg_markerframes_OPHFA(4,4),4:6);
normEMG_OPHFA_5 = OPHFA_5(1:emg_markerframes_OPHFA(5,4),4:6);
normEMG_OPHFA_6 = OPHFA_6(1:emg_markerframes_OPHFA(6,4),4:6);
normEMG_OPHFA_7 = OPHFA_7(1:emg_markerframes_OPHFA(7,4),4:6);
normEMG_OPHFA_8 = zeros(1,3);
normEMG_OPHFA_9 = OPHFA_9(1:emg_markerframes_OPHFA(9,4),4:6);
normEMG_OPHFA_10 = OPHFA_10(1:emg_markerframes_OPHFA(10,4),4:6);
normEMG_OPHFA_11 = zeros(1,3);
normEMG_OPHFA_12 = OPHFA_12(1:emg_markerframes_OPHFA(12,4),4:6);
normEMG_OPHFA_13 = OPHFA_13(1:emg_markerframes_OPHFA(13,4),4:6);
normEMG_OPHFA_14 = OPHFA_14(1:emg_markerframes_OPHFA(14,4),4:6);
normEMG_OPHFA_15 = OPHFA_15(1:emg_markerframes_OPHFA(15,4),4:6);
normEMG_OPHFA_16 = OPHFA_16(1:emg_markerframes_OPHFA(16,4),4:6);
normEMG_OPHFA_17 = OPHFA_17(1:emg_markerframes_OPHFA(17,4),4:6);
normEMG_OPHFA_18 = OPHFA_18(1:emg_markerframes_OPHFA(18,4),4:6);
normEMG_OPHFA_19 = OPHFA_19(1:emg_markerframes_OPHFA(19,4),4:6);
normEMG_OPHFA_20 = OPHFA_20(1:emg_markerframes_OPHFA(20,4),4:6);

%% Find downsampled normalized EMG of each muscle for each subject
```

```
%%%%% In the eccentric phase of the exercises %%%%%
% For the CA1 exercise
normEMG_CA1_1_ecc = ds_normEMG_CA1_1(1:markerframes_CA1(1,5),:);
normEMG_CA1_2_ecc = ds_normEMG_CA1_2(1:markerframes_CA1(2,5),:);
normEMG_CA1_3_ecc = ds_normEMG_CA1_3(1:markerframes_CA1(3,5),:);
normEMG_CA1_4_ecc = ds_normEMG_CA1_4(1:markerframes_CA1(4,5),:);
normEMG_CA1_5_ecc = ds_normEMG_CA1_5(1:markerframes_CA1(5,5),:);
normEMG_CA1_6_ecc = ds_normEMG_CA1_6(1:markerframes_CA1(6,5),:);
normEMG_CA1_7_ecc = ds_normEMG_CA1_7(1:markerframes_CA1(7,5),:);
normEMG_CA1_8_ecc = zeros(1,3);
normEMG_CA1_9_ecc = ds_normEMG_CA1_9(1:markerframes_CA1(9,5),:);
normEMG_CA1_10_ecc = ds_normEMG_CA1_10(1:markerframes_CA1(10,5),:);
normEMG_CA1_11_ecc = zeros(1,3);
normEMG_CA1_12_ecc = ds_normEMG_CA1_12(1:markerframes_CA1(12,5),:);
normEMG_CA1_13_ecc = ds_normEMG_CA1_13(1:markerframes_CA1(13,5),:);
normEMG_CA1_14_ecc = ds_normEMG_CA1_14(1:markerframes_CA1(14,5),:);
normEMG_CA1_15_ecc = ds_normEMG_CA1_15(1:markerframes_CA1(15,5),:);
normEMG_CA1_16_ecc = ds_normEMG_CA1_16(1:markerframes_CA1(16,5),:);
normEMG_CA1_17_ecc = ds_normEMG_CA1_17(1:markerframes_CA1(17,5),:);
normEMG_CA1_18_ecc = ds_normEMG_CA1_18(1:markerframes_CA1(18,5),:);
normEMG_CA1_19_ecc = ds_normEMG_CA1_19(1:markerframes_CA1(19,5),:);
normEMG_CA1_20_ecc = ds_normEMG_CA1_20(1:markerframes_CA1(20,5),:);
% For the CA2 exercise
normEMG_CA2_1_ecc = ds_normEMG_CA2_1(1:markerframes_CA2(1,5),:);
normEMG_CA2_2_ecc = ds_normEMG_CA2_2(1:markerframes_CA2(2,5),:);
normEMG_CA2_3_ecc = ds_normEMG_CA2_3(1:markerframes_CA2(3,5),:);
normEMG_CA2_4_ecc = ds_normEMG_CA2_4(1:markerframes_CA2(4,5),:);
normEMG_CA2_5_ecc = ds_normEMG_CA2_5(1:markerframes_CA2(5,5),:);
normEMG_CA2_6_ecc = ds_normEMG_CA2_6(1:markerframes_CA2(6,5),:);
normEMG_CA2_7_ecc = ds_normEMG_CA2_7(1:markerframes_CA2(7,5),:);
normEMG_CA2_8_ecc = zeros(1,3);
normEMG_CA2_9_ecc = ds_normEMG_CA2_9(1:markerframes_CA2(9,5),:);
normEMG_CA2_10_ecc = ds_normEMG_CA2_10(1:markerframes_CA2(10,5),:);
normEMG_CA2_11_ecc = zeros(1,3);
normEMG_CA2_12_ecc = ds_normEMG_CA2_12(1:markerframes_CA2(12,5),:);
normEMG_CA2_13_ecc = ds_normEMG_CA2_13(1:markerframes_CA2(13,5),:);
normEMG_CA2_14_ecc = ds_normEMG_CA2_14(1:markerframes_CA2(14,5),:);
normEMG_CA2_15_ecc = ds_normEMG_CA2_15(1:markerframes_CA2(15,5),:);
normEMG_CA2_16_ecc = ds_normEMG_CA2_16(1:markerframes_CA2(16,5),:);
normEMG_CA2_17_ecc = ds_normEMG_CA2_17(1:markerframes_CA2(17,5),:);
normEMG_CA2_18_ecc = ds_normEMG_CA2_18(1:markerframes_CA2(18,5),:);
normEMG_CA2_19_ecc = ds_normEMG_CA2_19(1:markerframes_CA2(19,5),:);
normEMG_CA2_20_ecc = ds_normEMG_CA2_20(1:markerframes_CA2(20,5),:);
% For the OLP exercise
normEMG_OLP_1_ecc = ds_normEMG_OLP_1(1:markerframes_OLP(1,5),:);
normEMG_OLP_2_ecc = ds_normEMG_OLP_2(1:markerframes_OLP(2,5),:);
normEMG_OLP_3_ecc = ds_normEMG_OLP_3(1:markerframes_OLP(3,5),:);
normEMG_OLP_4_ecc = ds_normEMG_OLP_4(1:markerframes_OLP(4,5),:);
normEMG_OLP_5_ecc = ds_normEMG_OLP_5(1:markerframes_OLP(5,5),:);
normEMG_OLP_6_ecc = ds_normEMG_OLP_6(1:markerframes_OLP(6,5),:);
normEMG_OLP_7_ecc = ds_normEMG_OLP_7(1:markerframes_OLP(7,5),:);
normEMG_OLP_8_ecc = zeros(1,3);
normEMG_OLP_9_ecc = ds_normEMG_OLP_9(1:markerframes_OLP(9,5),:);
```

```
normEMG_OLP_10_ecc = ds_normEMG_OLP_10(1:markerframes_OLP(10,5),:);
normEMG_OLP_11_ecc = zeros(1,3);
normEMG_OLP_12_ecc = ds_normEMG_OLP_12(1:markerframes_OLP(12,5),:);
normEMG_OLP_13_ecc = ds_normEMG_OLP_13(1:markerframes_OLP(13,5),:);
normEMG_OLP_14_ecc = ds_normEMG_OLP_14(1:markerframes_OLP(14,5),:);
normEMG_OLP_15_ecc = ds_normEMG_OLP_15(1:markerframes_OLP(15,5),:);
normEMG_OLP_16_ecc = ds_normEMG_OLP_16(1:markerframes_OLP(16,5),:);
normEMG_OLP_17_ecc = ds_normEMG_OLP_17(1:markerframes_OLP(17,5),:);
normEMG_OLP_18_ecc = ds_normEMG_OLP_18(1:markerframes_OLP(18,5),:);
normEMG_OLP_19_ecc = ds_normEMG_OLP_19(1:markerframes_OLP(19,5),:);
normEMG_OLP_20_ecc = ds_normEMG_OLP_20(1:markerframes_OLP(20,5),:);
% For the OPHFA exercise
normEMG_OPHFA_1_ecc = ds_normEMG_OPHFA_1(1:markerframes_OPHFA(1,5),:);
normEMG_OPHFA_2_ecc = ds_normEMG_OPHFA_2(1:markerframes_OPHFA(2,5),:);
normEMG_OPHFA_3_ecc = ds_normEMG_OPHFA_3(1:markerframes_OPHFA(3,5),:);
normEMG_OPHFA_4_ecc = ds_normEMG_OPHFA_4(1:markerframes_OPHFA(4,5),:);
normEMG_OPHFA_5_ecc = ds_normEMG_OPHFA_5(1:markerframes_OPHFA(5,5),:);
normEMG_OPHFA_6_ecc = ds_normEMG_OPHFA_6(1:markerframes_OPHFA(6,5),:);
normEMG_OPHFA_7_ecc = ds_normEMG_OPHFA_7(1:markerframes_OPHFA(7,5),:);
normEMG_OPHFA_8_ecc = zeros(1,3);
normEMG_OPHFA_9_ecc = ds_normEMG_OPHFA_9(1:markerframes_OPHFA(9,5),:);
normEMG_OPHFA_10_ecc = ds_normEMG_OPHFA_10(1:markerframes_OPHFA(10,5),:);
normEMG_OPHFA_11_ecc = zeros(1,3);
normEMG_OPHFA_12_ecc = ds_normEMG_OPHFA_12(1:markerframes_OPHFA(12,5),:);
normEMG_OPHFA_13_ecc = ds_normEMG_OPHFA_13(1:markerframes_OPHFA(13,5),:);
normEMG_OPHFA_14_ecc = ds_normEMG_OPHFA_14(1:markerframes_OPHFA(14,5),:);
normEMG_OPHFA_15_ecc = ds_normEMG_OPHFA_15(1:markerframes_OPHFA(15,5),:);
normEMG_OPHFA_16_ecc = ds_normEMG_OPHFA_16(1:markerframes_OPHFA(16,5),:);
normEMG_OPHFA_17_ecc = ds_normEMG_OPHFA_17(1:markerframes_OPHFA(17,5),:);
normEMG_OPHFA_18_ecc = ds_normEMG_OPHFA_18(1:markerframes_OPHFA(18,5),:);
normEMG_OPHFA_19_ecc = ds_normEMG_OPHFA_19(1:markerframes_OPHFA(19,5),:);
normEMG_OPHFA_20_ecc = ds_normEMG_OPHFA_20(1:markerframes_OPHFA(20,5),:);

%%%%% In the concentric phase of the exercises %%%%%
% For the CA1 exercise
normEMG_CA1_1_con = ds_normEMG_CA1_1(markerframes_CA1(1,5):markerframes_CA1(1,4),:);
normEMG_CA1_2_con = ds_normEMG_CA1_2(markerframes_CA1(2,5):markerframes_CA1(2,4),:);
normEMG_CA1_3_con = ds_normEMG_CA1_3(markerframes_CA1(3,5):markerframes_CA1(3,4),:);
normEMG_CA1_4_con = ds_normEMG_CA1_4(markerframes_CA1(4,5):markerframes_CA1(4,4),:);
normEMG_CA1_5_con = ds_normEMG_CA1_5(markerframes_CA1(5,5):markerframes_CA1(5,4),:);
normEMG_CA1_6_con = ds_normEMG_CA1_6(markerframes_CA1(6,5):markerframes_CA1(6,4),:);
normEMG_CA1_7_con = ds_normEMG_CA1_7(markerframes_CA1(7,5):markerframes_CA1(7,4),:);
normEMG_CA1_8_con = zeros(1,3);
normEMG_CA1_9_con = ds_normEMG_CA1_9(markerframes_CA1(9,5):markerframes_CA1(9,4),:);
normEMG_CA1_10_con = ds_normEMG_CA1_10(markerframes_CA1(10,5):markerframes_CA1↙
(10,4),:);
normEMG_CA1_11_con = zeros(1,3);
normEMG_CA1_12_con = ds_normEMG_CA1_12(markerframes_CA1(12,5):markerframes_CA1↙
(12,4),:);
normEMG_CA1_13_con = ds_normEMG_CA1_13(markerframes_CA1(13,5):markerframes_CA1↙
(13,4),:);
normEMG_CA1_14_con = ds_normEMG_CA1_14(markerframes_CA1(14,5):markerframes_CA1↙
(14,4),:);
normEMG_CA1_15_con = ds_normEMG_CA1_15(markerframes_CA1(15,5):markerframes_CA1↙
```

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(15,4),:);
normEMG_CA1_16_con = ds_normEMG_CA1_16(markerframes_CA1(16,5):markerframes_CA1↙
(16,4),:);
normEMG_CA1_17_con = ds_normEMG_CA1_17(markerframes_CA1(17,5):markerframes_CA1↙
(17,4),:);
normEMG_CA1_18_con = ds_normEMG_CA1_18(markerframes_CA1(18,5):markerframes_CA1↙
(18,4),:);
normEMG_CA1_19_con = ds_normEMG_CA1_19(markerframes_CA1(19,5):markerframes_CA1↙
(19,4),:);
normEMG_CA1_20_con = ds_normEMG_CA1_20(markerframes_CA1(20,5):markerframes_CA1↙
(20,4),:);
% For the CA2 exercise
normEMG_CA2_1_con = ds_normEMG_CA2_1(markerframes_CA2(1,5):markerframes_CA2(1,4),:);
normEMG_CA2_2_con = ds_normEMG_CA2_2(markerframes_CA2(2,5):markerframes_CA2(2,4),:);
normEMG_CA2_3_con = ds_normEMG_CA2_3(markerframes_CA2(3,5):markerframes_CA2(3,4),:);
normEMG_CA2_4_con = ds_normEMG_CA2_4(markerframes_CA2(4,5):markerframes_CA2(4,4),:);
normEMG_CA2_5_con = ds_normEMG_CA2_5(markerframes_CA2(5,5):markerframes_CA2(5,4),:);
normEMG_CA2_6_con = ds_normEMG_CA2_6(markerframes_CA2(6,5):markerframes_CA2(6,4),:);
normEMG_CA2_7_con = ds_normEMG_CA2_7(markerframes_CA2(7,5):markerframes_CA2(7,4),:);
normEMG_CA2_8_con = zeros(1,3);
normEMG_CA2_9_con = ds_normEMG_CA2_9(markerframes_CA2(9,5):markerframes_CA2(9,4),:);
normEMG_CA2_10_con = ds_normEMG_CA2_10(markerframes_CA2(10,5):markerframes_CA2↙
(10,4),:);
normEMG_CA2_11_con = zeros(1,3);
normEMG_CA2_12_con = ds_normEMG_CA2_12(markerframes_CA2(12,5):markerframes_CA2↙
(12,4),:);
normEMG_CA2_13_con = ds_normEMG_CA2_13(markerframes_CA2(13,5):markerframes_CA2↙
(13,4),:);
normEMG_CA2_14_con = ds_normEMG_CA2_14(markerframes_CA2(14,5):markerframes_CA2↙
(14,4),:);
normEMG_CA2_15_con = ds_normEMG_CA2_15(markerframes_CA2(15,5):markerframes_CA2↙
(15,4),:);
normEMG_CA2_16_con = ds_normEMG_CA2_16(markerframes_CA2(16,5):markerframes_CA2↙
(16,4),:);
normEMG_CA2_17_con = ds_normEMG_CA2_17(markerframes_CA2(17,5):markerframes_CA2↙
(17,4),:);
normEMG_CA2_18_con = ds_normEMG_CA2_18(markerframes_CA2(18,5):markerframes_CA2↙
(18,4),:);
normEMG_CA2_19_con = ds_normEMG_CA2_19(markerframes_CA2(19,5):markerframes_CA2↙
(19,4),:);
normEMG_CA2_20_con = ds_normEMG_CA2_20(markerframes_CA2(20,5):markerframes_CA2↙
(20,4),:);
% For the OLP exercise
normEMG_OLP_1_con = ds_normEMG_OLP_1(markerframes_OLP(1,5):markerframes_OLP(1,4),:);
normEMG_OLP_2_con = ds_normEMG_OLP_2(markerframes_OLP(2,5):markerframes_OLP(2,4),:);
normEMG_OLP_3_con = ds_normEMG_OLP_3(markerframes_OLP(3,5):markerframes_OLP(3,4),:);
normEMG_OLP_4_con = ds_normEMG_OLP_4(markerframes_OLP(4,5):markerframes_OLP(4,4),:);
normEMG_OLP_5_con = ds_normEMG_OLP_5(markerframes_OLP(5,5):markerframes_OLP(5,4),:);
normEMG_OLP_6_con = ds_normEMG_OLP_6(markerframes_OLP(6,5):markerframes_OLP(6,4),:);
normEMG_OLP_7_con = ds_normEMG_OLP_7(markerframes_OLP(7,5):markerframes_OLP(7,4),:);
normEMG_OLP_8_con = zeros(1,3);
normEMG_OLP_9_con = ds_normEMG_OLP_9(markerframes_OLP(9,5):markerframes_OLP(9,4),:);
normEMG_OLP_10_con = ds_normEMG_OLP_10(markerframes_OLP(10,5):markerframes_OLP↙
(10,4),:);
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normEMG_OLP_11_con = zeros(1,3);
normEMG_OLP_12_con = ds_normEMG_OLP_12(markerframes_OLP(12,5):markerframes_OLP↙
(12,4),:);
normEMG_OLP_13_con = ds_normEMG_OLP_13(markerframes_OLP(13,5):markerframes_OLP↙
(13,4),:);
normEMG_OLP_14_con = ds_normEMG_OLP_14(markerframes_OLP(14,5):markerframes_OLP↙
(14,4),:);
normEMG_OLP_15_con = ds_normEMG_OLP_15(markerframes_OLP(15,5):markerframes_OLP↙
(15,4),:);
normEMG_OLP_16_con = ds_normEMG_OLP_16(markerframes_OLP(16,5):markerframes_OLP↙
(16,4),:);
normEMG_OLP_17_con = ds_normEMG_OLP_17(markerframes_OLP(17,5):markerframes_OLP↙
(17,4),:);
normEMG_OLP_18_con = ds_normEMG_OLP_18(markerframes_OLP(18,5):markerframes_OLP↙
(18,4),:);
normEMG_OLP_19_con = ds_normEMG_OLP_19(markerframes_OLP(19,5):markerframes_OLP↙
(19,4),:);
normEMG_OLP_20_con = ds_normEMG_OLP_20(markerframes_OLP(20,5):markerframes_OLP↙
(20,4),:);
% For the OPHFA exercise
normEMG_OPHFA_1_con = ds_normEMG_OPHFA_1(markerframes_OPHFA(1,5):markerframes_OPHFA↙
(1,4),:);
normEMG_OPHFA_2_con = ds_normEMG_OPHFA_2(markerframes_OPHFA(2,5):markerframes_OPHFA↙
(2,4),:);
normEMG_OPHFA_3_con = ds_normEMG_OPHFA_3(markerframes_OPHFA(3,5):markerframes_OPHFA↙
(3,4),:);
normEMG_OPHFA_4_con = ds_normEMG_OPHFA_4(markerframes_OPHFA(4,5):markerframes_OPHFA↙
(4,4),:);
normEMG_OPHFA_5_con = ds_normEMG_OPHFA_5(markerframes_OPHFA(5,5):markerframes_OPHFA↙
(5,4),:);
normEMG_OPHFA_6_con = ds_normEMG_OPHFA_6(markerframes_OPHFA(6,5):markerframes_OPHFA↙
(6,4),:);
normEMG_OPHFA_7_con = ds_normEMG_OPHFA_7(markerframes_OPHFA(7,5):markerframes_OPHFA↙
(7,4),:);
normEMG_OPHFA_8_con = zeros(1,3);
normEMG_OPHFA_9_con = ds_normEMG_OPHFA_9(markerframes_OPHFA(9,5):markerframes_OPHFA↙
(9,4),:);
normEMG_OPHFA_10_con = ds_normEMG_OPHFA_10(markerframes_OPHFA(10,5):↙
markerframes_OPHFA(10,4),:);
normEMG_OPHFA_11_con = zeros(1,3);
normEMG_OPHFA_12_con = ds_normEMG_OPHFA_12(markerframes_OPHFA(12,5):↙
markerframes_OPHFA(12,4),:);
normEMG_OPHFA_13_con = ds_normEMG_OPHFA_13(markerframes_OPHFA(13,5):↙
markerframes_OPHFA(13,4),:);
normEMG_OPHFA_14_con = ds_normEMG_OPHFA_14(markerframes_OPHFA(14,5):↙
markerframes_OPHFA(14,4),:);
normEMG_OPHFA_15_con = ds_normEMG_OPHFA_15(markerframes_OPHFA(15,5):↙
markerframes_OPHFA(15,4),:);
normEMG_OPHFA_16_con = ds_normEMG_OPHFA_16(markerframes_OPHFA(16,5):↙
markerframes_OPHFA(16,4),:);
normEMG_OPHFA_17_con = ds_normEMG_OPHFA_17(markerframes_OPHFA(17,5):↙
markerframes_OPHFA(17,4),:);
normEMG_OPHFA_18_con = ds_normEMG_OPHFA_18(markerframes_OPHFA(18,5):↙
markerframes_OPHFA(18,4),:);
```

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normEMG_OPHFA_19_con = ds_normEMG_OPHFA_19(markerframes_OPHFA(19,5):↙
markerframes_OPHFA(19,4),:);
normEMG_OPHFA_20_con = ds_normEMG_OPHFA_20(markerframes_OPHFA(20,5):↙
markerframes_OPHFA(20,4),:);


%% Find peak value EMG

% the maximum value of each muscle during recordings of the exercises

normPeak_1 = [max(normEMG_CA1_1); max(normEMG_CA2_1); max(normEMG_OLP_1); max↙
(normEMG_OPHFA_1)];
normPeak_2 = [max(normEMG_CA1_2); max(normEMG_CA2_2); max(normEMG_OLP_2); max↙
(normEMG_OPHFA_2)];
normPeak_3 = [max(normEMG_CA1_3); max(normEMG_CA2_3); max(normEMG_OLP_3); max↙
(normEMG_OPHFA_3)];
normPeak_4 = [max(normEMG_CA1_4); max(normEMG_CA2_4); max(normEMG_OLP_4); max↙
(normEMG_OPHFA_4)];
normPeak_5 = [max(normEMG_CA1_5); max(normEMG_CA2_5); max(normEMG_OLP_5); max↙
(normEMG_OPHFA_5)];
normPeak_6 = [max(normEMG_CA1_6); max(normEMG_CA2_6); max(normEMG_OLP_6); max↙
(normEMG_OPHFA_6)];
normPeak_7 = [max(normEMG_CA1_7); max(normEMG_CA2_7); max(normEMG_OLP_7); max↙
(normEMG_OPHFA_7)];
normPeak_8 = [zeros(1,3) ; zeros(1,3) ; zeros(1,3) ; zeros(1,3)];
normPeak_9 = [max(normEMG_CA1_9); max(normEMG_CA2_9); max(normEMG_OLP_9); max↙
(normEMG_OPHFA_9)];
normPeak_10 = [max(normEMG_CA1_10); max(normEMG_CA2_10); max(normEMG_OLP_10); max↙
(normEMG_OPHFA_10)];
normPeak_11 = [zeros(1,3) ; zeros(1,3) ; zeros(1,3) ; zeros(1,3)];
normPeak_12 = [max(normEMG_CA1_12); max(normEMG_CA2_12); max(normEMG_OLP_12); max↙
(normEMG_OPHFA_12)];
normPeak_13 = [max(normEMG_CA1_13); max(normEMG_CA2_13); max(normEMG_OLP_13); max↙
(normEMG_OPHFA_13)];
normPeak_14 = [max(normEMG_CA1_14); max(normEMG_CA2_14); max(normEMG_OLP_14); max↙
(normEMG_OPHFA_14)];
normPeak_15 = [max(normEMG_CA1_15); max(normEMG_CA2_15); max(normEMG_OLP_15); max↙
(normEMG_OPHFA_15)];
normPeak_16 = [max(normEMG_CA1_16); max(normEMG_CA2_16); max(normEMG_OLP_16); max↙
(normEMG_OPHFA_16)];
normPeak_17 = [max(normEMG_CA1_17); max(normEMG_CA2_17); max(normEMG_OLP_17); max↙
(normEMG_OPHFA_17)];
normPeak_18 = [max(normEMG_CA1_18); max(normEMG_CA2_18); max(normEMG_OLP_18); max↙
(normEMG_OPHFA_18)];
normPeak_19 = [max(normEMG_CA1_19); max(normEMG_CA2_19); max(normEMG_OLP_19); max↙
(normEMG_OPHFA_19)];
normPeak_20 = [max(normEMG_CA1_20); max(normEMG_CA2_20); max(normEMG_OLP_20); max↙
(normEMG_OPHFA_20)];

% Collect all peak values in a table
table_peak = table(normPeak_1,normPeak_2,normPeak_3,normPeak_4,normPeak_5, ...
    normPeak_6,normPeak_7,normPeak_8,normPeak_9,normPeak_10,normPeak_11, ...
    normPeak_12,normPeak_13,normPeak_14,normPeak_15,normPeak_16,normPeak_17, ...
    normPeak_18,normPeak_19,normPeak_20);
```

```
% Collect all peak values in a matrix
peak_EMG = [normPeak_1,normPeak_2,normPeak_3,normPeak_4,normPeak_5, ...
    normPeak_6,normPeak_7,normPeak_8,normPeak_9,normPeak_10,normPeak_11, ...
    normPeak_12,normPeak_13,normPeak_14,normPeak_15,normPeak_16,normPeak_17, ...
    normPeak_18,normPeak_19,normPeak_20];


%% Find mean value EMG

% the mean value of each muscle during recordings of the exercises
normMean_1 = [mean(normEMG_CA1_1); mean(normEMG_CA2_1); mean(normEMG_OLP_1); mean↙
(normEMG_OPHFA_1)];
normMean_2 = [mean(normEMG_CA1_2); mean(normEMG_CA2_2); mean(normEMG_OLP_2); mean↙
(normEMG_OPHFA_2)];
normMean_3 = [mean(normEMG_CA1_3); mean(normEMG_CA2_3); mean(normEMG_OLP_3); mean↙
(normEMG_OPHFA_3)];
normMean_4 = [mean(normEMG_CA1_4); mean(normEMG_CA2_4); mean(normEMG_OLP_4); mean↙
(normEMG_OPHFA_4)];
normMean_5 = [mean(normEMG_CA1_5); mean(normEMG_CA2_5); mean(normEMG_OLP_5); mean↙
(normEMG_OPHFA_5)];
normMean_6 = [mean(normEMG_CA1_6); mean(normEMG_CA2_6); mean(normEMG_OLP_6); mean↙
(normEMG_OPHFA_6)];
normMean_7 = [mean(normEMG_CA1_7); mean(normEMG_CA2_7); mean(normEMG_OLP_7); mean↙
(normEMG_OPHFA_7)];
normMean_8 = [zeros(1,3) ; zeros(1,3) ; zeros(1,3) ; zeros(1,3)];
normMean_9 = [mean(normEMG_CA1_9); mean(normEMG_CA2_9); mean(normEMG_OLP_9); mean↙
(normEMG_OPHFA_9)];
normMean_10 = [mean(normEMG_CA1_10); mean(normEMG_CA2_10); mean(normEMG_OLP_10);↙
mean(normEMG_OPHFA_10)];
normMean_11 = [zeros(1,3) ; zeros(1,3) ; zeros(1,3) ; zeros(1,3)];
normMean_12 = [mean(normEMG_CA1_12); mean(normEMG_CA2_12); mean(normEMG_OLP_12);↙
mean(normEMG_OPHFA_12)];
normMean_13 = [mean(normEMG_CA1_13); mean(normEMG_CA2_13); mean(normEMG_OLP_13);↙
mean(normEMG_OPHFA_13)];
normMean_14 = [mean(normEMG_CA1_14); mean(normEMG_CA2_14); mean(normEMG_OLP_14);↙
mean(normEMG_OPHFA_14)];
normMean_15 = [mean(normEMG_CA1_15); mean(normEMG_CA2_15); mean(normEMG_OLP_15);↙
mean(normEMG_OPHFA_15)];
normMean_16 = [mean(normEMG_CA1_16); mean(normEMG_CA2_16); mean(normEMG_OLP_16);↙
mean(normEMG_OPHFA_16)];
normMean_17 = [mean(normEMG_CA1_17); mean(normEMG_CA2_17); mean(normEMG_OLP_17);↙
mean(normEMG_OPHFA_17)];
normMean_18 = [mean(normEMG_CA1_18); mean(normEMG_CA2_18); mean(normEMG_OLP_18);↙
mean(normEMG_OPHFA_18)];
normMean_19 = [mean(normEMG_CA1_19); mean(normEMG_CA2_19); mean(normEMG_OLP_19);↙
mean(normEMG_OPHFA_19)];
normMean_20 = [mean(normEMG_CA1_20); mean(normEMG_CA2_20); mean(normEMG_OLP_20);↙
mean(normEMG_OPHFA_20)];

% stadard deviation
std_normMean_1 = [std(normEMG_CA1_1,1); std(normEMG_CA2_1,1); std(normEMG_OLP_1,1);↙
std(normEMG_OPHFA_1,1)];
std_normMean_2 = [std(normEMG_CA1_2,1); std(normEMG_CA2_2,1); std(normEMG_OLP_2,1);↙
std(normEMG_OPHFA_2,1)];
```

```
std_normMean_3 = [std(normEMG_CA1_3,1); std(normEMG_CA2_3,1); std(normEMG_OLP_3,1);↙
std(normEMG_OPHFA_3,1)];
std_normMean_4 = [std(normEMG_CA1_4,1); std(normEMG_CA2_4,1); std(normEMG_OLP_4,1);↙
std(normEMG_OPHFA_4,1)];
std_normMean_5 = [std(normEMG_CA1_5,1); std(normEMG_CA2_5,1); std(normEMG_OLP_5,1);↙
std(normEMG_OPHFA_5,1)];
std_normMean_6 = [std(normEMG_CA1_6,1); std(normEMG_CA2_6,1); std(normEMG_OLP_6,1);↙
std(normEMG_OPHFA_6,1)]; %%% add long CA1 er feil
std_normMean_7 = [std(normEMG_CA1_7,1); std(normEMG_CA2_7,1); std(normEMG_OLP_7,1);↙
std(normEMG_OPHFA_7,1)];
std_normMean_8 = [zeros(1,3) ; zeros(1,3) ; zeros(1,3) ; zeros(1,3)];
std_normMean_9 = [std(normEMG_CA1_9,1); std(normEMG_CA2_9,1); std(normEMG_OLP_9,1);↙
std(normEMG_OPHFA_9,1)];
std_normMean_10 = [std(normEMG_CA1_10,1); std(normEMG_CA2_10,1); std(normEMG_OLP_10,↙
1); std(normEMG_OPHFA_10,1)];
std_normMean_11 = [zeros(1,3) ; zeros(1,3) ; zeros(1,3) ; zeros(1,3)];
std_normMean_12 = [std(normEMG_CA1_12,1); std(normEMG_CA2_12,1); std(normEMG_OLP_12,↙
1); std(normEMG_OPHFA_12,1)];
std_normMean_13 = [std(normEMG_CA1_13,1); std(normEMG_CA2_13,1); std(normEMG_OLP_13,↙
1); std(normEMG_OPHFA_13,1)];
std_normMean_14 = [std(normEMG_CA1_14,1); std(normEMG_CA2_14,1); std(normEMG_OLP_14,↙
1); std(normEMG_OPHFA_14,1)];
std_normMean_15 = [std(normEMG_CA1_15,1); std(normEMG_CA2_15,1); std(normEMG_OLP_15,↙
1); std(normEMG_OPHFA_15,1)];
std_normMean_16 = [std(normEMG_CA1_16,1); std(normEMG_CA2_16,1); std(normEMG_OLP_16,↙
1); std(normEMG_OPHFA_16,1)]; %%% add long CA1 helt feil
std_normMean_17 = [std(normEMG_CA1_17,1); std(normEMG_CA2_17,1); std(normEMG_OLP_17,↙
1); std(normEMG_OPHFA_17,1)];
std_normMean_18 = [std(normEMG_CA1_18,1); std(normEMG_CA2_18,1); std(normEMG_OLP_18,↙
1); std(normEMG_OPHFA_18,1)];
std_normMean_19 = [std(normEMG_CA1_19,1); std(normEMG_CA2_19,1); std(normEMG_OLP_19,↙
1); std(normEMG_OPHFA_19,1)];
std_normMean_20 = [std(normEMG_CA1_20,1); std(normEMG_CA2_20,1); std(normEMG_OLP_20,↙
1); std(normEMG_OPHFA_20,1)];

%% Sort EMG data by muscle and exercise

%%% Adductor longus CA1 %%%
    % mean add long, std add long, peak add long
% CA1
add_long_CA1 = zeros(20,3);
k = 1;
i = 1;
while k < 21
    add_long_CA1(k,:) = [mean_EMG(1,i), std_EMG(1,i), peak_EMG(1,i)];
    k = k + 1;
    i = i + 3;
end
% CA2
add_long_CA2 = zeros(20,3);
k = 1;
i = 1;
while k < 21
    add_long_CA2(k,:) = [mean_EMG(2,i), std_EMG(2,i), peak_EMG(2,i)];
```

```
    k = k + 1;
    i = i + 3;
end
% OLP
add_long_OLP = zeros(20,3);
k = 1;
i = 1;
while k < 21
    add_long_OLP(k,:) = [mean_EMG(3,i), std_EMG(3,i), peak_EMG(3,i)];
    k = k + 1;
    i = i + 3;
end
% OPHFA
add_long_OPHFA = zeros(20,3);
k = 1;
i = 1;
while k < 21
    add_long_OPHFA(k,:) = [mean_EMG(4,i), std_EMG(4,i), peak_EMG(4,i)];
    k = k + 1;
    i = i + 3;
end

%%% Rectus femoris %%%
    % mean add long, std add long, peak add long
% CA1
rec_fem_CA1 = zeros(20,3);
k = 1;
i = 2;
while k < 21
    rec_fem_CA1(k,:) = [mean_EMG(1,i), std_EMG(1,i), peak_EMG(1,i)];
    k = k + 1;
    i = i + 3;
end
% CA2
rec_fem_CA2 = zeros(20,3);
k = 1;
i = 2;
while k < 21
    rec_fem_CA2(k,:) = [mean_EMG(2,i), std_EMG(2,i), peak_EMG(2,i)];
    k = k + 1;
    i = i + 3;
end
% OLP
rec_fem_OLP = zeros(20,3);
k = 1;
i = 2;
while k < 21
    rec_fem_OLP(k,:) = [mean_EMG(3,i), std_EMG(3,i), peak_EMG(3,i)];
    k = k + 1;
    i = i + 3;
end
% OPHFA
rec_fem_OPHFA = zeros(20,3);
k = 1;
```

```
i = 2;
while k < 21
    rec_fem_OPHFA(k,:) = [mean_EMG(4,i), std_EMG(4,i), peak_EMG(4,i)];
    k = k + 1;
    i = i + 3;
end


%% Results EMG

%%% Average of mean values %%%
mean_add_long_CA1 = mean(nonzeros(add_long_CA1(:,1)));
mean_add_long_CA2 = mean(nonzeros(add_long_CA2(:,1)));
mean_add_long_OLP = mean(nonzeros(add_long_OLP(:,1)));
mean_add_long_OPHFA = mean(nonzeros(add_long_OPHFA(:,1)));

mean_rec_fem_CA1 = mean(nonzeros(rec_fem_CA1(:,1)));
mean_rec_fem_CA2 = mean(nonzeros(rec_fem_CA2(:,1)));
mean_rec_fem_OLP = mean(nonzeros(rec_fem_OLP(:,1)));
mean_rec_fem_OPHFA = mean(nonzeros(rec_fem_OPHFA(:,1)));


% Standard deviation
al_CA1 = (markerframes_CA1(:,4)*10-1) .* (add_long_CA1(:,2).^2);
al_CA2 = (markerframes_CA2(:,4)*10-1) .* (add_long_CA2(:,2).^2);
al_OLP = (markerframes_OLP(:,4)*10-1) .* (add_long_OLP(:,2).^2);
al_OPHFA = (markerframes_OPHFA(:,4)*10-1) .* (add_long_OPHFA(:,2).^2);
rf_CA1 = (markerframes_CA1(:,4)*10-1) .* (rec_fem_CA1(:,2).^2);
rf_CA2 = (markerframes_CA2(:,4)*10-1) .* (rec_fem_CA1(:,2).^2);
rf_OLP = (markerframes_OLP(:,4)*10-1) .* (rec_fem_OLP(:,2).^2);
rf_OPHFA = (markerframes_OPHFA(:,4)*10-1) .* (rec_fem_OPHFA(:,2).^2);

std_mean_add_long_CA1 = sqrt(sum(al_CA1,'omitnan')/sum(markerframes_CA1(:,4)*10-↙
1,'omitnan'));
std_mean_add_long_CA2 = sqrt(sum(al_CA2,'omitnan')/sum(markerframes_CA2(:,4)*10-↙
1,'omitnan'));
std_mean_add_long_OLP = sqrt(sum(al_OLP,'omitnan')/sum(markerframes_OLP(:,4)*10-↙
1,'omitnan'));
std_mean_add_long_OPHFA = sqrt(sum(al_OPHFA,'omitnan')/sum(markerframes_OPHFA(:,4)↙
*10-1,'omitnan'));

std_mean_rec_fem_CA1 = sqrt(sum(rf_CA1,'omitnan')/sum(markerframes_CA1(:,4)*10-↙
1,'omitnan'));
std_mean_rec_fem_CA2 = sqrt(sum(rf_CA2,'omitnan')/sum(markerframes_CA2(:,4)*10-↙
1,'omitnan'));
std_mean_rec_fem_OLP = sqrt(sum(rf_OLP,'omitnan')/sum(markerframes_OLP(:,4)*10-↙
1,'omitnan'));
std_mean_rec_fem_OPHFA = sqrt(sum(rf_OPHFA,'omitnan')/sum(markerframes_OPHFA(:,4)↙
*10-1,'omitnan'));


%%% Average of peak values %%%
peak_add_long_CA1 = mean(nonzeros(add_long_CA1(:,3)));
peak_add_long_CA2 = mean(nonzeros(add_long_CA2(:,3)));
```

```
peak_add_long_OLP = mean(nonzeros(add_long_OLP(:,3)));
peak_add_long_OPHFA = mean(nonzeros(add_long_OPHFA(:,3)));

peak_rec_fem_CA1 = mean(nonzeros(rec_fem_CA1(:,3)));
peak_rec_fem_CA2 = mean(nonzeros(rec_fem_CA2(:,3)));
peak_rec_fem_OLP = mean(nonzeros(rec_fem_OLP(:,3)));
peak_rec_fem_OPHFA = mean(nonzeros(rec_fem_OPHFA(:,3)));


% Standard deviation
std_peak_add_long_CA1 = std(nonzeros(add_long_CA1(:,3)));
std_peak_add_long_CA2 = std(nonzeros(add_long_CA2(:,3)));
std_peak_add_long_OLP = std(nonzeros(add_long_OLP(:,3)));
std_peak_add_long_OPHFA = std(nonzeros(add_long_OPHFA(:,3)));

std_peak_rec_fem_CA1 = std(nonzeros(rec_fem_CA1(:,3)));
std_peak_rec_fem_CA2 = std(nonzeros(rec_fem_CA2(:,3)));
std_peak_rec_fem_OLP = std(nonzeros(rec_fem_OLP(:,3)));
std_peak_rec_fem_OPHFA = std(nonzeros(rec_fem_OPHFA(:,3)));


% Collect the results in tables
exercises = ["CA1";"CA2";"OLP";"OPHFA"];

peak_add_long = [peak_add_long_CA1;peak_add_long_CA2;peak_add_long_OLP;↙
peak_add_long_OPHFA];
std_peak_add_long = [std_peak_add_long_CA1;std_peak_add_long_CA2;↙
std_peak_add_long_OLP;std_peak_add_long_OPHFA];
mean_add_long = [mean_add_long_CA1;mean_add_long_CA2;mean_add_long_OLP;↙
mean_add_long_OPHFA];
std_mean_add_long = [std_mean_add_long_CA1;std_mean_add_long_CA2;↙
std_mean_add_long_OLP;std_mean_add_long_OPHFA];
peak_rec_fem = [peak_rec_fem_CA1;peak_rec_fem_CA2;peak_rec_fem_OLP;↙
peak_rec_fem_OPHFA];
std_peak_rec_fem = [std_peak_rec_fem_CA1;std_peak_rec_fem_CA2;std_peak_rec_fem_OLP;↙
std_peak_rec_fem_OPHFA];
mean_rec_fem = [mean_rec_fem_CA1;mean_rec_fem_CA2;mean_rec_fem_OLP;↙
mean_rec_fem_OPHFA];
std_mean_rec_fem = [std_mean_rec_fem_CA1;std_mean_rec_fem_CA2;std_mean_rec_fem_OLP;↙
std_mean_rec_fem_OPHFA];

table_EMG_total = table(exercises,peak_add_long,std_peak_add_long,mean_add_long,↙
std_mean_add_long,peak_rec_fem,std_peak_rec_fem,mean_rec_fem,std_mean_rec_fem);

cd 'C:\Users\Helena\Documents\Master\'
writetable(table_EMG_total,'result_EMGtotal.xlsx');

%% Interpolate EMG

int_nof = 50001;

%%%%% Interpolation of eccentric phase %%%%%
% For the CA1 exercise
int_EMG_CA1_1_ecc = interp1(1:markerframes_CA1(1,5),normEMG_CA1_1_ecc,linspace(1,↙
```

```
markerframes_CA1(1,5),int_nof));
int_EMG_CA1_2_ecc = interp1(1:markerframes_CA1(2,5),normEMG_CA1_2_ecc,linspace(1,↙
markerframes_CA1(2,5),int_nof));
int_EMG_CA1_3_ecc = interp1(1:markerframes_CA1(3,5),normEMG_CA1_3_ecc,linspace(1,↙
markerframes_CA1(3,5),int_nof));
int_EMG_CA1_4_ecc = interp1(1:markerframes_CA1(4,5),normEMG_CA1_4_ecc,linspace(1,↙
markerframes_CA1(4,5),int_nof));
int_EMG_CA1_5_ecc = interp1(1:markerframes_CA1(5,5),normEMG_CA1_5_ecc,linspace(1,↙
markerframes_CA1(5,5),int_nof));
int_EMG_CA1_6_ecc = interp1(1:markerframes_CA1(6,5),normEMG_CA1_6_ecc,linspace(1,↙
markerframes_CA1(6,5),int_nof));
int_EMG_CA1_7_ecc = interp1(1:markerframes_CA1(7,5),normEMG_CA1_7_ecc,linspace(1,↙
markerframes_CA1(7,5),int_nof));
int_EMG_CA1_8_ecc = zeros(int_nof,3);
int_EMG_CA1_9_ecc = interp1(1:markerframes_CA1(9,5),normEMG_CA1_9_ecc,linspace(1,↙
markerframes_CA1(9,5),int_nof));
int_EMG_CA1_10_ecc = interp1(1:markerframes_CA1(10,5),normEMG_CA1_10_ecc,linspace(1,↙
markerframes_CA1(10,5),int_nof));
int_EMG_CA1_11_ecc = zeros(int_nof,3);
int_EMG_CA1_12_ecc = interp1(1:markerframes_CA1(12,5),normEMG_CA1_12_ecc,linspace(1,↙
markerframes_CA1(12,5),int_nof));
int_EMG_CA1_13_ecc = interp1(1:markerframes_CA1(13,5),normEMG_CA1_13_ecc,linspace(1,↙
markerframes_CA1(13,5),int_nof));
int_EMG_CA1_14_ecc = interp1(1:markerframes_CA1(14,5),normEMG_CA1_14_ecc,linspace(1,↙
markerframes_CA1(14,5),int_nof));
int_EMG_CA1_15_ecc = interp1(1:markerframes_CA1(15,5),normEMG_CA1_15_ecc,linspace(1,↙
markerframes_CA1(15,5),int_nof));
int_EMG_CA1_16_ecc = interp1(1:markerframes_CA1(16,5),normEMG_CA1_16_ecc,linspace(1,↙
markerframes_CA1(16,5),int_nof));
int_EMG_CA1_17_ecc = interp1(1:markerframes_CA1(17,5),normEMG_CA1_17_ecc,linspace(1,↙
markerframes_CA1(17,5),int_nof));
int_EMG_CA1_18_ecc = interp1(1:markerframes_CA1(18,5),normEMG_CA1_18_ecc,linspace(1,↙
markerframes_CA1(18,5),int_nof));
int_EMG_CA1_19_ecc = interp1(1:markerframes_CA1(19,5),normEMG_CA1_19_ecc,linspace(1,↙
markerframes_CA1(19,5),int_nof));
int_EMG_CA1_20_ecc = interp1(1:markerframes_CA1(20,5),normEMG_CA1_20_ecc,linspace(1,↙
markerframes_CA1(20,5),int_nof));
% For the CA2 exercise
int_EMG_CA2_1_ecc = interp1(1:markerframes_CA2(1,5),normEMG_CA2_1_ecc,linspace(1,↙
markerframes_CA2(1,5),int_nof));
int_EMG_CA2_2_ecc = interp1(1:markerframes_CA2(2,5),normEMG_CA2_2_ecc,linspace(1,↙
markerframes_CA2(2,5),int_nof));
int_EMG_CA2_3_ecc = interp1(1:markerframes_CA2(3,5),normEMG_CA2_3_ecc,linspace(1,↙
markerframes_CA2(3,5),int_nof));
int_EMG_CA2_4_ecc = interp1(1:markerframes_CA2(4,5),normEMG_CA2_4_ecc,linspace(1,↙
markerframes_CA2(4,5),int_nof));
int_EMG_CA2_5_ecc = interp1(1:markerframes_CA2(5,5),normEMG_CA2_5_ecc,linspace(1,↙
markerframes_CA2(5,5),int_nof));
int_EMG_CA2_6_ecc = interp1(1:markerframes_CA2(6,5),normEMG_CA2_6_ecc,linspace(1,↙
markerframes_CA2(6,5),int_nof));
int_EMG_CA2_7_ecc = interp1(1:markerframes_CA2(7,5),normEMG_CA2_7_ecc,linspace(1,↙
markerframes_CA2(7,5),int_nof));
int_EMG_CA2_8_ecc = zeros(int_nof,3);
int_EMG_CA2_9_ecc = interp1(1:markerframes_CA2(9,5),normEMG_CA2_9_ecc,linspace(1,↙
```

```
markerframes_CA2(9,5),int_nof));
int_EMG_CA2_10_ecc = interp1(1:markerframes_CA2(10,5),normEMG_CA2_10_ecc,linspace(1,↙
markerframes_CA2(10,5),int_nof));
int_EMG_CA2_11_ecc = zeros(int_nof,3);
int_EMG_CA2_12_ecc = interp1(1:markerframes_CA2(12,5),normEMG_CA2_12_ecc,linspace(1,↙
markerframes_CA2(12,5),int_nof));
int_EMG_CA2_13_ecc = interp1(1:markerframes_CA2(13,5),normEMG_CA2_13_ecc,linspace(1,↙
markerframes_CA2(13,5),int_nof));
int_EMG_CA2_14_ecc = interp1(1:markerframes_CA2(14,5),normEMG_CA2_14_ecc,linspace(1,↙
markerframes_CA2(14,5),int_nof));
int_EMG_CA2_15_ecc = interp1(1:markerframes_CA2(15,5),normEMG_CA2_15_ecc,linspace(1,↙
markerframes_CA2(15,5),int_nof));
int_EMG_CA2_16_ecc = interp1(1:markerframes_CA2(16,5),normEMG_CA2_16_ecc,linspace(1,↙
markerframes_CA2(16,5),int_nof));
int_EMG_CA2_17_ecc = interp1(1:markerframes_CA2(17,5),normEMG_CA2_17_ecc,linspace(1,↙
markerframes_CA2(17,5),int_nof));
int_EMG_CA2_18_ecc = interp1(1:markerframes_CA2(18,5),normEMG_CA2_18_ecc,linspace(1,↙
markerframes_CA2(18,5),int_nof));
int_EMG_CA2_19_ecc = interp1(1:markerframes_CA2(19,5),normEMG_CA2_19_ecc,linspace(1,↙
markerframes_CA2(19,5),int_nof));
int_EMG_CA2_20_ecc = interp1(1:markerframes_CA2(20,5),normEMG_CA2_20_ecc,linspace(1,↙
markerframes_CA2(20,5),int_nof));
% For the OLP exercise
int_EMG_OLP_1_ecc = interp1(1:markerframes_OLP(1,5),normEMG_OLP_1_ecc,linspace(1,↙
markerframes_OLP(1,5),int_nof));
int_EMG_OLP_2_ecc = interp1(1:markerframes_OLP(2,5),normEMG_OLP_2_ecc,linspace(1,↙
markerframes_OLP(2,5),int_nof));
int_EMG_OLP_3_ecc = interp1(1:markerframes_OLP(3,5),normEMG_OLP_3_ecc,linspace(1,↙
markerframes_OLP(3,5),int_nof));
int_EMG_OLP_4_ecc = interp1(1:markerframes_OLP(4,5),normEMG_OLP_4_ecc,linspace(1,↙
markerframes_OLP(4,5),int_nof));
int_EMG_OLP_5_ecc = interp1(1:markerframes_OLP(5,5),normEMG_OLP_5_ecc,linspace(1,↙
markerframes_OLP(5,5),int_nof));
int_EMG_OLP_6_ecc = interp1(1:markerframes_OLP(6,5),normEMG_OLP_6_ecc,linspace(1,↙
markerframes_OLP(6,5),int_nof));
int_EMG_OLP_7_ecc = interp1(1:markerframes_OLP(7,5),normEMG_OLP_7_ecc,linspace(1,↙
markerframes_OLP(7,5),int_nof));
int_EMG_OLP_8_ecc = zeros(int_nof,3);
int_EMG_OLP_9_ecc = interp1(1:markerframes_OLP(9,5),normEMG_OLP_9_ecc,linspace(1,↙
markerframes_OLP(9,5),int_nof));
int_EMG_OLP_10_ecc = interp1(1:markerframes_OLP(10,5),normEMG_OLP_10_ecc,linspace(1,↙
markerframes_OLP(10,5),int_nof));
int_EMG_OLP_11_ecc = zeros(int_nof,3);
int_EMG_OLP_12_ecc = interp1(1:markerframes_OLP(12,5),normEMG_OLP_12_ecc,linspace(1,↙
markerframes_OLP(12,5),int_nof));
int_EMG_OLP_13_ecc = interp1(1:markerframes_OLP(13,5),normEMG_OLP_13_ecc,linspace(1,↙
markerframes_OLP(13,5),int_nof));
int_EMG_OLP_14_ecc = interp1(1:markerframes_OLP(14,5),normEMG_OLP_14_ecc,linspace(1,↙
markerframes_OLP(14,5),int_nof));
int_EMG_OLP_15_ecc = interp1(1:markerframes_OLP(15,5),normEMG_OLP_15_ecc,linspace(1,↙
markerframes_OLP(15,5),int_nof));
int_EMG_OLP_16_ecc = interp1(1:markerframes_OLP(16,5),normEMG_OLP_16_ecc,linspace(1,↙
markerframes_OLP(16,5),int_nof));
int_EMG_OLP_17_ecc = interp1(1:markerframes_OLP(17,5),normEMG_OLP_17_ecc,linspace(1,↙
```

```
markerframes_OLP(17,5),int_nof));
int_EMG_OLP_18_ecc = interp1(1:markerframes_OLP(18,5),normEMG_OLP_18_ecc,linspace(1,↙
markerframes_OLP(18,5),int_nof));
int_EMG_OLP_19_ecc = interp1(1:markerframes_OLP(19,5),normEMG_OLP_19_ecc,linspace(1,↙
markerframes_OLP(19,5),int_nof));
int_EMG_OLP_20_ecc = interp1(1:markerframes_OLP(20,5),normEMG_OLP_20_ecc,linspace(1,↙
markerframes_OLP(20,5),int_nof));
% For the OPHFA exercise
int_EMG_OPHFA_1_ecc = interp1(1:markerframes_OPHFA(1,5),normEMG_OPHFA_1_ecc,linspace↙
(1,markerframes_OPHFA(1,5),int_nof));
int_EMG_OPHFA_2_ecc = interp1(1:markerframes_OPHFA(2,5),normEMG_OPHFA_2_ecc,linspace↙
(1,markerframes_OPHFA(2,5),int_nof));
int_EMG_OPHFA_3_ecc = interp1(1:markerframes_OPHFA(3,5),normEMG_OPHFA_3_ecc,linspace↙
(1,markerframes_OPHFA(3,5),int_nof));
int_EMG_OPHFA_4_ecc = interp1(1:markerframes_OPHFA(4,5),normEMG_OPHFA_4_ecc,linspace↙
(1,markerframes_OPHFA(4,5),int_nof));
int_EMG_OPHFA_5_ecc = interp1(1:markerframes_OPHFA(5,5),normEMG_OPHFA_5_ecc,linspace↙
(1,markerframes_OPHFA(5,5),int_nof));
int_EMG_OPHFA_6_ecc = interp1(1:markerframes_OPHFA(6,5),normEMG_OPHFA_6_ecc,linspace↙
(1,markerframes_OPHFA(6,5),int_nof));
int_EMG_OPHFA_7_ecc = interp1(1:markerframes_OPHFA(7,5),normEMG_OPHFA_7_ecc,linspace↙
(1,markerframes_OPHFA(7,5),int_nof));
int_EMG_OPHFA_8_ecc = zeros(int_nof,3);
int_EMG_OPHFA_9_ecc = interp1(1:markerframes_OPHFA(9,5),normEMG_OPHFA_9_ecc,linspace↙
(1,markerframes_OPHFA(9,5),int_nof));
int_EMG_OPHFA_10_ecc = interp1(1:markerframes_OPHFA(10,5),normEMG_OPHFA_10_ecc,↙
linspace(1,markerframes_OPHFA(10,5),int_nof));
int_EMG_OPHFA_11_ecc = zeros(int_nof,3);
int_EMG_OPHFA_12_ecc = interp1(1:markerframes_OPHFA(12,5),normEMG_OPHFA_12_ecc,↙
linspace(1,markerframes_OPHFA(12,5),int_nof));
int_EMG_OPHFA_13_ecc = interp1(1:markerframes_OPHFA(13,5),normEMG_OPHFA_13_ecc,↙
linspace(1,markerframes_OPHFA(13,5),int_nof));
int_EMG_OPHFA_14_ecc = interp1(1:markerframes_OPHFA(14,5),normEMG_OPHFA_14_ecc,↙
linspace(1,markerframes_OPHFA(14,5),int_nof));
int_EMG_OPHFA_15_ecc = interp1(1:markerframes_OPHFA(15,5),normEMG_OPHFA_15_ecc,↙
linspace(1,markerframes_OPHFA(15,5),int_nof));
int_EMG_OPHFA_16_ecc = interp1(1:markerframes_OPHFA(16,5),normEMG_OPHFA_16_ecc,↙
linspace(1,markerframes_OPHFA(16,5),int_nof));
int_EMG_OPHFA_17_ecc = interp1(1:markerframes_OPHFA(17,5),normEMG_OPHFA_17_ecc,↙
linspace(1,markerframes_OPHFA(17,5),int_nof));
int_EMG_OPHFA_18_ecc = interp1(1:markerframes_OPHFA(18,5),normEMG_OPHFA_18_ecc,↙
linspace(1,markerframes_OPHFA(18,5),int_nof));
int_EMG_OPHFA_19_ecc = interp1(1:markerframes_OPHFA(19,5),normEMG_OPHFA_19_ecc,↙
linspace(1,markerframes_OPHFA(19,5),int_nof));
int_EMG_OPHFA_20_ecc = interp1(1:markerframes_OPHFA(20,5),normEMG_OPHFA_20_ecc,↙
linspace(1,markerframes_OPHFA(20,5),int_nof));

%%%%% Interpolation of concentric phase %%%%%
% For the CA1 exercise
int_EMG_CA1_1_con = interp1(1:markerframes_CA1(1,6),normEMG_CA1_1_con,linspace(1,↙
markerframes_CA1(1,6),int_nof));
int_EMG_CA1_2_con = interp1(1:markerframes_CA1(2,6),normEMG_CA1_2_con,linspace(1,↙
markerframes_CA1(2,6),int_nof));
int_EMG_CA1_3_con = interp1(1:markerframes_CA1(3,6),normEMG_CA1_3_con,linspace(1,↙
```

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markerframes_CA1(3,6),int_nof));
int_EMG_CA1_4_con = interp1(1:markerframes_CA1(4,6),normEMG_CA1_4_con,linspace(1,↙
markerframes_CA1(4,6),int_nof));
int_EMG_CA1_5_con = interp1(1:markerframes_CA1(5,6),normEMG_CA1_5_con,linspace(1,↙
markerframes_CA1(5,6),int_nof));
int_EMG_CA1_6_con = interp1(1:markerframes_CA1(6,6),normEMG_CA1_6_con,linspace(1,↙
markerframes_CA1(6,6),int_nof));
int_EMG_CA1_7_con = interp1(1:markerframes_CA1(7,6),normEMG_CA1_7_con,linspace(1,↙
markerframes_CA1(7,6),int_nof));
int_EMG_CA1_8_con = zeros(int_nof,3);
int_EMG_CA1_9_con = interp1(1:markerframes_CA1(9,6),normEMG_CA1_9_con,linspace(1,↙
markerframes_CA1(9,6),int_nof));
int_EMG_CA1_10_con = interp1(1:markerframes_CA1(10,6),normEMG_CA1_10_con,linspace(1,↙
markerframes_CA1(10,6),int_nof));
int_EMG_CA1_11_con = zeros(int_nof,3);
int_EMG_CA1_12_con = interp1(1:markerframes_CA1(12,6),normEMG_CA1_12_con,linspace(1,↙
markerframes_CA1(12,6),int_nof));
int_EMG_CA1_13_con = interp1(1:markerframes_CA1(13,6),normEMG_CA1_13_con,linspace(1,↙
markerframes_CA1(13,6),int_nof));
int_EMG_CA1_14_con = interp1(1:markerframes_CA1(14,6),normEMG_CA1_14_con,linspace(1,↙
markerframes_CA1(14,6),int_nof));
int_EMG_CA1_15_con = interp1(1:markerframes_CA1(15,6),normEMG_CA1_15_con,linspace(1,↙
markerframes_CA1(15,6),int_nof));
int_EMG_CA1_16_con = interp1(1:markerframes_CA1(16,6),normEMG_CA1_16_con,linspace(1,↙
markerframes_CA1(16,6),int_nof));
int_EMG_CA1_17_con = interp1(1:markerframes_CA1(17,6),normEMG_CA1_17_con,linspace(1,↙
markerframes_CA1(17,6),int_nof));
int_EMG_CA1_18_con = interp1(1:markerframes_CA1(18,6),normEMG_CA1_18_con,linspace(1,↙
markerframes_CA1(18,6),int_nof));
int_EMG_CA1_19_con = interp1(1:markerframes_CA1(19,6),normEMG_CA1_19_con,linspace(1,↙
markerframes_CA1(19,6),int_nof));
int_EMG_CA1_20_con = interp1(1:markerframes_CA1(20,6),normEMG_CA1_20_con,linspace(1,↙
markerframes_CA1(20,6),int_nof));
% For the CA2 exercise
int_EMG_CA2_1_con = interp1(1:markerframes_CA2(1,6),normEMG_CA2_1_con,linspace(1,↙
markerframes_CA2(1,6),int_nof));
int_EMG_CA2_2_con = interp1(1:markerframes_CA2(2,6),normEMG_CA2_2_con,linspace(1,↙
markerframes_CA2(2,6),int_nof));
int_EMG_CA2_3_con = interp1(1:markerframes_CA2(3,6),normEMG_CA2_3_con,linspace(1,↙
markerframes_CA2(3,6),int_nof));
int_EMG_CA2_4_con = interp1(1:markerframes_CA2(4,6),normEMG_CA2_4_con,linspace(1,↙
markerframes_CA2(4,6),int_nof));
int_EMG_CA2_5_con = interp1(1:markerframes_CA2(5,6),normEMG_CA2_5_con,linspace(1,↙
markerframes_CA2(5,6),int_nof));
int_EMG_CA2_6_con = interp1(1:markerframes_CA2(6,6),normEMG_CA2_6_con,linspace(1,↙
markerframes_CA2(6,6),int_nof));
int_EMG_CA2_7_con = interp1(1:markerframes_CA2(7,6),normEMG_CA2_7_con,linspace(1,↙
markerframes_CA2(7,6),int_nof));
int_EMG_CA2_8_con = zeros(int_nof,3);
int_EMG_CA2_9_con = interp1(1:markerframes_CA2(9,6),normEMG_CA2_9_con,linspace(1,↙
markerframes_CA2(9,6),int_nof));
int_EMG_CA2_10_con = interp1(1:markerframes_CA2(10,6),normEMG_CA2_10_con,linspace(1,↙
markerframes_CA2(10,6),int_nof));
int_EMG_CA2_11_con = zeros(int_nof,3);
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int_EMG_CA2_12_con = interp1(1:markerframes_CA2(12,6),normEMG_CA2_12_con,linspace(1,↙
markerframes_CA2(12,6),int_nof));
int_EMG_CA2_13_con = interp1(1:markerframes_CA2(13,6),normEMG_CA2_13_con,linspace(1,↙
markerframes_CA2(13,6),int_nof));
int_EMG_CA2_14_con = interp1(1:markerframes_CA2(14,6),normEMG_CA2_14_con,linspace(1,↙
markerframes_CA2(14,6),int_nof));
int_EMG_CA2_15_con = interp1(1:markerframes_CA2(15,6),normEMG_CA2_15_con,linspace(1,↙
markerframes_CA2(15,6),int_nof));
int_EMG_CA2_16_con = interp1(1:markerframes_CA2(16,6),normEMG_CA2_16_con,linspace(1,↙
markerframes_CA2(16,6),int_nof));
int_EMG_CA2_17_con = interp1(1:markerframes_CA2(17,6),normEMG_CA2_17_con,linspace(1,↙
markerframes_CA2(17,6),int_nof));
int_EMG_CA2_18_con = interp1(1:markerframes_CA2(18,6),normEMG_CA2_18_con,linspace(1,↙
markerframes_CA2(18,6),int_nof));
int_EMG_CA2_19_con = interp1(1:markerframes_CA2(19,6),normEMG_CA2_19_con,linspace(1,↙
markerframes_CA2(19,6),int_nof));
int_EMG_CA2_20_con = interp1(1:markerframes_CA2(20,6),normEMG_CA2_20_con,linspace(1,↙
markerframes_CA2(20,6),int_nof));
% For the OLP exercise
int_EMG_OLP_1_con = interp1(1:markerframes_OLP(1,6),normEMG_OLP_1_con,linspace(1,↙
markerframes_OLP(1,6),int_nof));
int_EMG_OLP_2_con = interp1(1:markerframes_OLP(2,6),normEMG_OLP_2_con,linspace(1,↙
markerframes_OLP(2,6),int_nof));
int_EMG_OLP_3_con = interp1(1:markerframes_OLP(3,6),normEMG_OLP_3_con,linspace(1,↙
markerframes_OLP(3,6),int_nof));
int_EMG_OLP_4_con = interp1(1:markerframes_OLP(4,6),normEMG_OLP_4_con,linspace(1,↙
markerframes_OLP(4,6),int_nof));
int_EMG_OLP_5_con = interp1(1:markerframes_OLP(5,6),normEMG_OLP_5_con,linspace(1,↙
markerframes_OLP(5,6),int_nof));
int_EMG_OLP_6_con = interp1(1:markerframes_OLP(6,6),normEMG_OLP_6_con,linspace(1,↙
markerframes_OLP(6,6),int_nof));
int_EMG_OLP_7_con = interp1(1:markerframes_OLP(7,6),normEMG_OLP_7_con,linspace(1,↙
markerframes_OLP(7,6),int_nof));
int_EMG_OLP_8_con = zeros(int_nof,3);
int_EMG_OLP_9_con = interp1(1:markerframes_OLP(9,6),normEMG_OLP_9_con,linspace(1,↙
markerframes_OLP(9,6),int_nof));
int_EMG_OLP_10_con = interp1(1:markerframes_OLP(10,6),normEMG_OLP_10_con,linspace(1,↙
markerframes_OLP(10,6),int_nof));
int_EMG_OLP_11_con = zeros(int_nof,3);
int_EMG_OLP_12_con = interp1(1:markerframes_OLP(12,6),normEMG_OLP_12_con,linspace(1,↙
markerframes_OLP(12,6),int_nof));
int_EMG_OLP_13_con = interp1(1:markerframes_OLP(13,6),normEMG_OLP_13_con,linspace(1,↙
markerframes_OLP(13,6),int_nof));
int_EMG_OLP_14_con = interp1(1:markerframes_OLP(14,6),normEMG_OLP_14_con,linspace(1,↙
markerframes_OLP(14,6),int_nof));
int_EMG_OLP_15_con = interp1(1:markerframes_OLP(15,6),normEMG_OLP_15_con,linspace(1,↙
markerframes_OLP(15,6),int_nof));
int_EMG_OLP_16_con = interp1(1:markerframes_OLP(16,6),normEMG_OLP_16_con,linspace(1,↙
markerframes_OLP(16,6),int_nof));
int_EMG_OLP_17_con = interp1(1:markerframes_OLP(17,6),normEMG_OLP_17_con,linspace(1,↙
markerframes_OLP(17,6),int_nof));
int_EMG_OLP_18_con = interp1(1:markerframes_OLP(18,6),normEMG_OLP_18_con,linspace(1,↙
markerframes_OLP(18,6),int_nof));
int_EMG_OLP_19_con = interp1(1:markerframes_OLP(19,6),normEMG_OLP_19_con,linspace(1,↙
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markerframes_OLP(19,6),int_nof));
int_EMG_OLP_20_con = interp1(1:markerframes_OLP(20,6),normEMG_OLP_20_con,linspace(1,↙
markerframes_OLP(20,6),int_nof));
% For the OPHFA exercise
int_EMG_OPHFA_1_con = interp1(1:markerframes_OPHFA(1,6),normEMG_OPHFA_1_con,linspace↙
(1,markerframes_OPHFA(1,6),int_nof));
int_EMG_OPHFA_2_con = interp1(1:markerframes_OPHFA(2,6),normEMG_OPHFA_2_con,linspace↙
(1,markerframes_OPHFA(2,6),int_nof));
int_EMG_OPHFA_3_con = interp1(1:markerframes_OPHFA(3,6),normEMG_OPHFA_3_con,linspace↙
(1,markerframes_OPHFA(3,6),int_nof));
int_EMG_OPHFA_4_con = interp1(1:markerframes_OPHFA(4,6),normEMG_OPHFA_4_con,linspace↙
(1,markerframes_OPHFA(4,6),int_nof));
int_EMG_OPHFA_5_con = interp1(1:markerframes_OPHFA(5,6),normEMG_OPHFA_5_con,linspace↙
(1,markerframes_OPHFA(5,6),int_nof));
int_EMG_OPHFA_6_con = interp1(1:markerframes_OPHFA(6,6),normEMG_OPHFA_6_con,linspace↙
(1,markerframes_OPHFA(6,6),int_nof));
int_EMG_OPHFA_7_con = interp1(1:markerframes_OPHFA(7,6),normEMG_OPHFA_7_con,linspace↙
(1,markerframes_OPHFA(7,6),int_nof));
int_EMG_OPHFA_8_con = zeros(int_nof,3);
int_EMG_OPHFA_9_con = interp1(1:markerframes_OPHFA(9,6),normEMG_OPHFA_9_con,linspace↙
(1,markerframes_OPHFA(9,6),int_nof));
int_EMG_OPHFA_10_con = interp1(1:markerframes_OPHFA(10,6),normEMG_OPHFA_10_con,↙
linspace(1,markerframes_OPHFA(10,6),int_nof));
int_EMG_OPHFA_11_con = zeros(int_nof,3);
int_EMG_OPHFA_12_con = interp1(1:markerframes_OPHFA(12,6),normEMG_OPHFA_12_con,↙
linspace(1,markerframes_OPHFA(12,6),int_nof));
int_EMG_OPHFA_13_con = interp1(1:markerframes_OPHFA(13,6),normEMG_OPHFA_13_con,↙
linspace(1,markerframes_OPHFA(13,6),int_nof));
int_EMG_OPHFA_14_con = interp1(1:markerframes_OPHFA(14,6),normEMG_OPHFA_14_con,↙
linspace(1,markerframes_OPHFA(14,6),int_nof));
int_EMG_OPHFA_15_con = interp1(1:markerframes_OPHFA(15,6),normEMG_OPHFA_15_con,↙
linspace(1,markerframes_OPHFA(15,6),int_nof));
int_EMG_OPHFA_16_con = interp1(1:markerframes_OPHFA(16,6),normEMG_OPHFA_16_con,↙
linspace(1,markerframes_OPHFA(16,6),int_nof));
int_EMG_OPHFA_17_con = interp1(1:markerframes_OPHFA(17,6),normEMG_OPHFA_17_con,↙
linspace(1,markerframes_OPHFA(17,6),int_nof));
int_EMG_OPHFA_18_con = interp1(1:markerframes_OPHFA(18,6),normEMG_OPHFA_18_con,↙
linspace(1,markerframes_OPHFA(18,6),int_nof));
int_EMG_OPHFA_19_con = interp1(1:markerframes_OPHFA(19,6),normEMG_OPHFA_19_con,↙
linspace(1,markerframes_OPHFA(19,6),int_nof));
int_EMG_OPHFA_20_con = interp1(1:markerframes_OPHFA(20,6),normEMG_OPHFA_20_con,↙
linspace(1,markerframes_OPHFA(20,6),int_nof));


% Collect all interpolated arrays for each exercise and muscle

%%% CA1 %%%
add_long_EMG_CA1_ecc = [int_EMG_CA1_1_ecc(:,1), int_EMG_CA1_2_ecc(:,1),↙
int_EMG_CA1_3_ecc(:,1), int_EMG_CA1_4_ecc(:,1), int_EMG_CA1_5_ecc(:,1),...
                        int_EMG_CA1_6_ecc(:,1), int_EMG_CA1_7_ecc(:,1),↙
int_EMG_CA1_8_ecc(:,1), int_EMG_CA1_9_ecc(:,1), int_EMG_CA1_10_ecc(:,1),...
                        int_EMG_CA1_11_ecc(:,1), int_EMG_CA1_12_ecc(:,1),↙
int_EMG_CA1_13_ecc(:,1), int_EMG_CA1_14_ecc(:,1), int_EMG_CA1_15_ecc(:,1),...
                        int_EMG_CA1_16_ecc(:,1), int_EMG_CA1_17_ecc(:,1),↙
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int_EMG_CA1_18_ecc(:,1), int_EMG_CA1_19_ecc(:,1), int_EMG_CA1_20_ecc(:,1)];
add_long_EMG_CA1_con = [int_EMG_CA1_1_con(:,1), int_EMG_CA1_2_con(:,1),↙
int_EMG_CA1_3_con(:,1), int_EMG_CA1_4_con(:,1), int_EMG_CA1_5_con(:,1),...
                        int_EMG_CA1_6_con(:,1), int_EMG_CA1_7_con(:,1),↙
int_EMG_CA1_8_con(:,1), int_EMG_CA1_9_con(:,1), int_EMG_CA1_10_con(:,1),...
                        int_EMG_CA1_11_con(:,1), int_EMG_CA1_12_con(:,1),↙
int_EMG_CA1_13_con(:,1), int_EMG_CA1_14_con(:,1), int_EMG_CA1_15_con(:,1),...
                        int_EMG_CA1_16_con(:,1), int_EMG_CA1_17_con(:,1),↙
int_EMG_CA1_18_con(:,1), int_EMG_CA1_19_con(:,1), int_EMG_CA1_20_con(:,1)];
rec_fem_EMG_CA1_ecc = [int_EMG_CA1_1_ecc(:,2), int_EMG_CA1_2_ecc(:,2),↙
int_EMG_CA1_3_ecc(:,2), int_EMG_CA1_4_ecc(:,2), int_EMG_CA1_5_ecc(:,2),...
                        int_EMG_CA1_6_ecc(:,2), int_EMG_CA1_7_ecc(:,2),↙
int_EMG_CA1_8_ecc(:,2), int_EMG_CA1_9_ecc(:,2), int_EMG_CA1_10_ecc(:,2),...
                        int_EMG_CA1_11_ecc(:,2), int_EMG_CA1_12_ecc(:,2),↙
int_EMG_CA1_13_ecc(:,2), int_EMG_CA1_14_ecc(:,2), int_EMG_CA1_15_ecc(:,2),...
                        int_EMG_CA1_16_ecc(:,2), int_EMG_CA1_17_ecc(:,2),↙
int_EMG_CA1_18_ecc(:,2), int_EMG_CA1_19_ecc(:,2), int_EMG_CA1_20_ecc(:,2)];
rec_fem_EMG_CA1_con = [int_EMG_CA1_1_con(:,2), int_EMG_CA1_2_con(:,2),↙
int_EMG_CA1_3_con(:,2), int_EMG_CA1_4_con(:,2), int_EMG_CA1_5_con(:,2),...
                        int_EMG_CA1_6_con(:,2), int_EMG_CA1_7_con(:,2),↙
int_EMG_CA1_8_con(:,2), int_EMG_CA1_9_con(:,2), int_EMG_CA1_10_con(:,2),...
                        int_EMG_CA1_11_con(:,2), int_EMG_CA1_12_con(:,2),↙
int_EMG_CA1_13_con(:,2), int_EMG_CA1_14_con(:,2), int_EMG_CA1_15_con(:,2),...
                        int_EMG_CA1_16_con(:,2), int_EMG_CA1_17_con(:,2),↙
int_EMG_CA1_18_con(:,2), int_EMG_CA1_19_con(:,2), int_EMG_CA1_20_con(:,2)];
%%% CA2 %%%
add_long_EMG_CA2_ecc = [int_EMG_CA2_1_ecc(:,1), int_EMG_CA2_2_ecc(:,1),↙
int_EMG_CA2_3_ecc(:,1), int_EMG_CA2_4_ecc(:,1), int_EMG_CA2_5_ecc(:,1),...
                        int_EMG_CA2_6_ecc(:,1), int_EMG_CA2_7_ecc(:,1),↙
int_EMG_CA2_8_ecc(:,1), int_EMG_CA2_9_ecc(:,1), int_EMG_CA2_10_ecc(:,1),...
                        int_EMG_CA2_11_ecc(:,1), int_EMG_CA2_12_ecc(:,1),↙
int_EMG_CA2_13_ecc(:,1), int_EMG_CA2_14_ecc(:,1), int_EMG_CA2_15_ecc(:,1),...
                        int_EMG_CA2_16_ecc(:,1), int_EMG_CA2_17_ecc(:,1),↙
int_EMG_CA2_18_ecc(:,1), int_EMG_CA2_19_ecc(:,1), int_EMG_CA2_20_ecc(:,1)];
add_long_EMG_CA2_con = [int_EMG_CA2_1_con(:,1), int_EMG_CA2_2_con(:,1),↙
int_EMG_CA2_3_con(:,1), int_EMG_CA2_4_con(:,1), int_EMG_CA2_5_con(:,1),...
                        int_EMG_CA2_6_con(:,1), int_EMG_CA2_7_con(:,1),↙
int_EMG_CA2_8_con(:,1), int_EMG_CA2_9_con(:,1), int_EMG_CA2_10_con(:,1),...
                        int_EMG_CA2_11_con(:,1), int_EMG_CA2_12_con(:,1),↙
int_EMG_CA2_13_con(:,1), int_EMG_CA2_14_con(:,1), int_EMG_CA2_15_con(:,1),...
                        int_EMG_CA2_16_con(:,1), int_EMG_CA2_17_con(:,1),↙
int_EMG_CA2_18_con(:,1), int_EMG_CA2_19_con(:,1), int_EMG_CA2_20_con(:,1)];
rec_fem_EMG_CA2_ecc = [int_EMG_CA2_1_ecc(:,2), int_EMG_CA2_2_ecc(:,2),↙
int_EMG_CA2_3_ecc(:,2), int_EMG_CA2_4_ecc(:,2), int_EMG_CA2_5_ecc(:,2),...
                        int_EMG_CA2_6_ecc(:,2), int_EMG_CA2_7_ecc(:,2),↙
int_EMG_CA2_8_ecc(:,2), int_EMG_CA2_9_ecc(:,2), int_EMG_CA2_10_ecc(:,2),...
                        int_EMG_CA2_11_ecc(:,2), int_EMG_CA2_12_ecc(:,2),↙
int_EMG_CA2_13_ecc(:,2), int_EMG_CA2_14_ecc(:,2), int_EMG_CA2_15_ecc(:,2),...
                        int_EMG_CA2_16_ecc(:,2), int_EMG_CA2_17_ecc(:,2),↙
int_EMG_CA2_18_ecc(:,2), int_EMG_CA2_19_ecc(:,2), int_EMG_CA2_20_ecc(:,2)];
rec_fem_EMG_CA2_con = [int_EMG_CA2_1_con(:,2), int_EMG_CA2_2_con(:,2),↙
int_EMG_CA2_3_con(:,2), int_EMG_CA2_4_con(:,2), int_EMG_CA2_5_con(:,2),...
                        int_EMG_CA2_6_con(:,2), int_EMG_CA2_7_con(:,2),↙
int_EMG_CA2_8_con(:,2), int_EMG_CA2_9_con(:,2), int_EMG_CA2_10_con(:,2),...
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                        int_EMG_CA2_11_con(:,2), int_EMG_CA2_12_con(:,2),↙
int_EMG_CA2_13_con(:,2), int_EMG_CA2_14_con(:,2), int_EMG_CA2_15_con(:,2),...
                        int_EMG_CA2_16_con(:,2), int_EMG_CA2_17_con(:,2),↙
int_EMG_CA2_18_con(:,2), int_EMG_CA2_19_con(:,2), int_EMG_CA2_20_con(:,2)];
%%% OLP %%%
add_long_EMG_OLP_ecc = [int_EMG_OLP_1_ecc(:,1), int_EMG_OLP_2_ecc(:,1),↙
int_EMG_OLP_3_ecc(:,1), int_EMG_OLP_4_ecc(:,1), int_EMG_OLP_5_ecc(:,1),...
                        int_EMG_OLP_6_ecc(:,1), int_EMG_OLP_7_ecc(:,1),↙
int_EMG_OLP_8_ecc(:,1), int_EMG_OLP_9_ecc(:,1), int_EMG_OLP_10_ecc(:,1),...
                        int_EMG_OLP_11_ecc(:,1), int_EMG_OLP_12_ecc(:,1),↙
int_EMG_OLP_13_ecc(:,1), int_EMG_OLP_14_ecc(:,1), int_EMG_OLP_15_ecc(:,1),...
                        int_EMG_OLP_16_ecc(:,1), int_EMG_OLP_17_ecc(:,1),↙
int_EMG_OLP_18_ecc(:,1), int_EMG_OLP_19_ecc(:,1), int_EMG_OLP_20_ecc(:,1)];
add_long_EMG_OLP_con = [int_EMG_OLP_1_con(:,1), int_EMG_OLP_2_con(:,1),↙
int_EMG_OLP_3_con(:,1), int_EMG_OLP_4_con(:,1), int_EMG_OLP_5_con(:,1),...
                        int_EMG_OLP_6_con(:,1), int_EMG_OLP_7_con(:,1),↙
int_EMG_OLP_8_con(:,1), int_EMG_OLP_9_con(:,1), int_EMG_OLP_10_con(:,1),...
                        int_EMG_OLP_11_con(:,1), int_EMG_OLP_12_con(:,1),↙
int_EMG_OLP_13_con(:,1), int_EMG_OLP_14_con(:,1), int_EMG_OLP_15_con(:,1),...
                        int_EMG_OLP_16_con(:,1), int_EMG_OLP_17_con(:,1),↙
int_EMG_OLP_18_con(:,1), int_EMG_OLP_19_con(:,1), int_EMG_OLP_20_con(:,1)];
rec_fem_EMG_OLP_ecc = [int_EMG_OLP_1_ecc(:,2), int_EMG_OLP_2_ecc(:,2),↙
int_EMG_OLP_3_ecc(:,2), int_EMG_OLP_4_ecc(:,2), int_EMG_OLP_5_ecc(:,2),...
                        int_EMG_OLP_6_ecc(:,2), int_EMG_OLP_7_ecc(:,2),↙
int_EMG_OLP_8_ecc(:,2), int_EMG_OLP_9_ecc(:,2), int_EMG_OLP_10_ecc(:,2),...
                        int_EMG_OLP_11_ecc(:,2), int_EMG_OLP_12_ecc(:,2),↙
int_EMG_OLP_13_ecc(:,2), int_EMG_OLP_14_ecc(:,2), int_EMG_OLP_15_ecc(:,2),...
                        int_EMG_OLP_16_ecc(:,2), int_EMG_OLP_17_ecc(:,2),↙
int_EMG_OLP_18_ecc(:,2), int_EMG_OLP_19_ecc(:,2), int_EMG_OLP_20_ecc(:,2)];
rec_fem_EMG_OLP_con = [int_EMG_OLP_1_con(:,2), int_EMG_OLP_2_con(:,2),↙
int_EMG_OLP_3_con(:,2), int_EMG_OLP_4_con(:,2), int_EMG_OLP_5_con(:,2),...
                        int_EMG_OLP_6_con(:,2), int_EMG_OLP_7_con(:,2),↙
int_EMG_OLP_8_con(:,2), int_EMG_OLP_9_con(:,2), int_EMG_OLP_10_con(:,2),...
                        int_EMG_OLP_11_con(:,2), int_EMG_OLP_12_con(:,2),↙
int_EMG_OLP_13_con(:,2), int_EMG_OLP_14_con(:,2), int_EMG_OLP_15_con(:,2),...
                        int_EMG_OLP_16_con(:,2), int_EMG_OLP_17_con(:,2),↙
int_EMG_OLP_18_con(:,2), int_EMG_OLP_19_con(:,2), int_EMG_OLP_20_con(:,2)];
%%% OPHFA %%%
add_long_EMG_OPHFA_ecc = [int_EMG_OPHFA_1_ecc(:,1), int_EMG_OPHFA_2_ecc(:,1),↙
int_EMG_OPHFA_3_ecc(:,1), int_EMG_OPHFA_4_ecc(:,1), int_EMG_OPHFA_5_ecc(:,1),...
                          int_EMG_OPHFA_6_ecc(:,1), int_EMG_OPHFA_7_ecc(:,1),↙
int_EMG_OPHFA_8_ecc(:,1), int_EMG_OPHFA_9_ecc(:,1), int_EMG_OPHFA_10_ecc(:,1),...
                          int_EMG_OPHFA_11_ecc(:,1), int_EMG_OPHFA_12_ecc(:,1),↙
int_EMG_OPHFA_13_ecc(:,1), int_EMG_OPHFA_14_ecc(:,1), int_EMG_OPHFA_15_ecc(:,1),...
                          int_EMG_OPHFA_16_ecc(:,1), int_EMG_OPHFA_17_ecc(:,1),↙
int_EMG_OPHFA_18_ecc(:,1), int_EMG_OPHFA_19_ecc(:,1), int_EMG_OPHFA_20_ecc(:,1)];
add_long_EMG_OPHFA_con = [int_EMG_OPHFA_1_con(:,1), int_EMG_OPHFA_2_con(:,1),↙
int_EMG_OPHFA_3_con(:,1), int_EMG_OPHFA_4_con(:,1), int_EMG_OPHFA_5_con(:,1),...
                          int_EMG_OPHFA_6_con(:,1), int_EMG_OPHFA_7_con(:,1),↙
int_EMG_OPHFA_8_con(:,1), int_EMG_OPHFA_9_con(:,1), int_EMG_OPHFA_10_con(:,1),...
                          int_EMG_OPHFA_11_con(:,1), int_EMG_OPHFA_12_con(:,1),↙
int_EMG_OPHFA_13_con(:,1), int_EMG_OPHFA_14_con(:,1), int_EMG_OPHFA_15_con(:,1),...
                          int_EMG_OPHFA_16_con(:,1), int_EMG_OPHFA_17_con(:,1),↙
int_EMG_OPHFA_18_con(:,1), int_EMG_OPHFA_19_con(:,1), int_EMG_OPHFA_20_con(:,1)];
```

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rec_fem_EMG_OPHFA_ecc = [int_EMG_OPHFA_1_ecc(:,2), int_EMG_OPHFA_2_ecc(:,2),↙
int_EMG_OPHFA_3_ecc(:,2), int_EMG_OPHFA_4_ecc(:,2), int_EMG_OPHFA_5_ecc(:,2),...
                          int_EMG_OPHFA_6_ecc(:,2), int_EMG_OPHFA_7_ecc(:,2),↙
int_EMG_OPHFA_8_ecc(:,2), int_EMG_OPHFA_9_ecc(:,2), int_EMG_OPHFA_10_ecc(:,2),...
                          int_EMG_OPHFA_11_ecc(:,2), int_EMG_OPHFA_12_ecc(:,2),↙
int_EMG_OPHFA_13_ecc(:,2), int_EMG_OPHFA_14_ecc(:,2), int_EMG_OPHFA_15_ecc(:,2),...
                          int_EMG_OPHFA_16_ecc(:,2), int_EMG_OPHFA_17_ecc(:,2),↙
int_EMG_OPHFA_18_ecc(:,2), int_EMG_OPHFA_19_ecc(:,2), int_EMG_OPHFA_20_ecc(:,2)];
rec_fem_EMG_OPHFA_con = [int_EMG_OPHFA_1_con(:,2), int_EMG_OPHFA_2_con(:,2),↙
int_EMG_OPHFA_3_con(:,2), int_EMG_OPHFA_4_con(:,2), int_EMG_OPHFA_5_con(:,2),...
                          int_EMG_OPHFA_6_con(:,2), int_EMG_OPHFA_7_con(:,2),↙
int_EMG_OPHFA_8_con(:,2), int_EMG_OPHFA_9_con(:,2), int_EMG_OPHFA_10_con(:,2),...
                          int_EMG_OPHFA_11_con(:,2), int_EMG_OPHFA_12_con(:,2),↙
int_EMG_OPHFA_13_con(:,2), int_EMG_OPHFA_14_con(:,2), int_EMG_OPHFA_15_con(:,2),...
                          int_EMG_OPHFA_16_con(:,2), int_EMG_OPHFA_17_con(:,2),↙
int_EMG_OPHFA_18_con(:,2), int_EMG_OPHFA_19_con(:,2), int_EMG_OPHFA_20_con(:,2)];

%% Analyse normalized EMG in each exercise

% Variables
mean_EMG_add_long_CA1_ecc = zeros(int_nof,1);
mean_EMG_add_long_CA1_con = zeros(int_nof,1);
mean_EMG_rec_fem_CA1_ecc = zeros(int_nof,1);
mean_EMG_rec_fem_CA1_con = zeros(int_nof,1);
mean_EMG_add_long_CA2_ecc = zeros(int_nof,1);
mean_EMG_add_long_CA2_con = zeros(int_nof,1);
mean_EMG_rec_fem_CA2_ecc = zeros(int_nof,1);
mean_EMG_rec_fem_CA2_con = zeros(int_nof,1);
mean_EMG_add_long_OLP_ecc = zeros(int_nof,1);
mean_EMG_add_long_OLP_con = zeros(int_nof,1);
mean_EMG_rec_fem_OLP_ecc = zeros(int_nof,1);
mean_EMG_rec_fem_OLP_con = zeros(int_nof,1);
mean_EMG_add_long_OPHFA_ecc = zeros(int_nof,1);
mean_EMG_add_long_OPHFA_con = zeros(int_nof,1);
mean_EMG_rec_fem_OPHFA_ecc = zeros(int_nof,1);
mean_EMG_rec_fem_OPHFA_con = zeros(int_nof,1);
    % these variables are used to plot muscle activation normalized to time

% Mean normalized EMG during the CA1 exercise
for i = 1:int_nof
  % add long
  mean_EMG_add_long_CA1_ecc(i,1) = mean(nonzeros(add_long_EMG_CA1_ecc(i,:)));
  mean_EMG_add_long_CA1_con(i,1) = mean(nonzeros(add_long_EMG_CA1_con(i,:)));
  % rec fem
  mean_EMG_rec_fem_CA1_ecc(i,1) = mean(nonzeros(rec_fem_EMG_CA1_ecc(i,:)));
  mean_EMG_rec_fem_CA1_con(i,1) = mean(nonzeros(rec_fem_EMG_CA1_con(i,:)));
end
% Mean normalized EMG during the CA2 exercise
for i = 1:int_nof
  % add long
  mean_EMG_add_long_CA2_ecc(i,1) = mean(nonzeros(add_long_EMG_CA2_ecc(i,:)));
  mean_EMG_add_long_CA2_con(i,1) = mean(nonzeros(add_long_EMG_CA2_con(i,:)));
  % rec fem
  mean_EMG_rec_fem_CA2_ecc(i,1) = mean(nonzeros(rec_fem_EMG_CA2_ecc(i,:)));
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  mean_EMG_rec_fem_CA2_con(i,1) = mean(nonzeros(rec_fem_EMG_CA2_con(i,:)));
end
% Mean normalized EMG during the OLP exercise
for i = 1:int_nof
  % add long
  mean_EMG_add_long_OLP_ecc(i,1) = mean(nonzeros(add_long_EMG_OLP_ecc(i,:)));
  mean_EMG_add_long_OLP_con(i,1) = mean(nonzeros(add_long_EMG_OLP_con(i,:)));
  % rec fem
  mean_EMG_rec_fem_OLP_ecc(i,1) = mean(nonzeros(rec_fem_EMG_OLP_ecc(i,:)));
  mean_EMG_rec_fem_OLP_con(i,1) = mean(nonzeros(rec_fem_EMG_OLP_con(i,:)));
end
% Mean normalized EMG during the OPHFA exercise
for i = 1:int_nof
  % add long
  mean_EMG_add_long_OPHFA_ecc(i,1) = mean(nonzeros(add_long_EMG_OPHFA_ecc(i,:)));
  mean_EMG_add_long_OPHFA_con(i,1) = mean(nonzeros(add_long_EMG_OPHFA_con(i,:)));
  % rec fem
  mean_EMG_rec_fem_OPHFA_ecc(i,1) = mean(nonzeros(rec_fem_EMG_OPHFA_ecc(i,:)));
  mean_EMG_rec_fem_OPHFA_con(i,1) = mean(nonzeros(rec_fem_EMG_OPHFA_con(i,:)));
end

%% Find load/force data for each subject

% (force, normalized force, torque, normalized torque, distance,
% intersection point (x,y,x)

%%%%% Throughout the exercises %%%%%
% For the CA1 exercise
load_CA1_1 = CA1_1(1:markerframes_CA1(1,4),16:23);
load_CA1_2 = CA1_2(1:markerframes_CA1(2,4),16:23);
load_CA1_3 = CA1_3(1:markerframes_CA1(3,4),16:23);
load_CA1_4 = CA1_4(1:markerframes_CA1(4,4),16:23);
load_CA1_5 = CA1_5(1:markerframes_CA1(5,4),16:23);
load_CA1_6 = CA1_6(1:markerframes_CA1(6,4),16:23);
load_CA1_7 = CA1_7(1:markerframes_CA1(7,4),16:23);
load_CA1_8 = zeros(1,3);
load_CA1_9 = CA1_9(1:markerframes_CA1(9,4),16:23);
load_CA1_10 = CA1_10(1:markerframes_CA1(10,4),16:23);
load_CA1_11 = zeros(1,3);
load_CA1_12 = CA1_12(1:markerframes_CA1(12,4),16:23);
load_CA1_13 = CA1_13(1:markerframes_CA1(13,4),16:23);
load_CA1_14 = CA1_14(1:markerframes_CA1(14,4),16:23);
load_CA1_15 = CA1_15(1:markerframes_CA1(15,4),16:23);
load_CA1_16 = CA1_16(1:markerframes_CA1(16,4),16:23);
load_CA1_17 = CA1_17(1:markerframes_CA1(17,4),16:23);
load_CA1_18 = CA1_18(1:markerframes_CA1(18,4),16:23);
load_CA1_19 = CA1_19(1:markerframes_CA1(19,4),16:23);
load_CA1_20 = CA1_20(1:markerframes_CA1(20,4),16:23);
% For the CA2 exercise
load_CA2_1 = CA2_1(1:markerframes_CA2(1,4),16:23);
load_CA2_2 = CA2_2(1:markerframes_CA2(2,4),16:23);
load_CA2_3 = CA2_3(1:markerframes_CA2(3,4),16:23);
load_CA2_4 = CA2_4(1:markerframes_CA2(4,4),16:23);
load_CA2_5 = CA2_5(1:markerframes_CA2(5,4),16:23);
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load_CA2_6 = CA2_6(1:markerframes_CA2(6,4),16:23);
load_CA2_7 = CA2_7(1:markerframes_CA2(7,4),16:23);
load_CA2_8 = zeros(1,3);
load_CA2_9 = CA2_9(1:markerframes_CA2(9,4),16:23);
load_CA2_10 = CA2_10(1:markerframes_CA2(10,4),16:23);
load_CA2_11 = zeros(1,3);
load_CA2_12 = CA2_12(1:markerframes_CA2(12,4),16:23);
load_CA2_13 = CA2_13(1:markerframes_CA2(13,4),16:23);
load_CA2_14 = CA2_14(1:markerframes_CA2(14,4),16:23);
load_CA2_15 = zeros(1,3);
load_CA2_16 = CA2_16(1:markerframes_CA2(16,4),16:23);
load_CA2_17 = CA2_17(1:markerframes_CA2(17,4),16:23);
load_CA2_18 = CA2_18(1:markerframes_CA2(18,4),16:23);
load_CA2_19 = CA2_19(1:markerframes_CA2(19,4),16:23);
load_CA2_20 = CA2_20(1:markerframes_CA2(20,4),16:23);
% For the OLP exercise
load_OLP_1 = OLP_1(1:markerframes_OLP(1,4),16:23);
load_OLP_2 = OLP_2(1:markerframes_OLP(2,4),16:23);
load_OLP_3 = OLP_3(1:markerframes_OLP(3,4),16:23);
load_OLP_4 = OLP_4(1:markerframes_OLP(4,4),16:23);
load_OLP_5 = OLP_5(1:markerframes_OLP(5,4),16:23);
load_OLP_6 = OLP_6(1:markerframes_OLP(6,4),16:23);
load_OLP_7 = OLP_7(1:markerframes_OLP(7,4),16:23);
load_OLP_8 = zeros(1,3);
load_OLP_9 = OLP_9(1:markerframes_OLP(9,4),16:23);
load_OLP_10 = OLP_10(1:markerframes_OLP(10,4),16:23);
load_OLP_11 = zeros(1,3);
load_OLP_12 = OLP_12(1:markerframes_OLP(12,4),16:23);
load_OLP_13 = OLP_13(1:markerframes_OLP(13,4),16:23);
load_OLP_14 = OLP_14(1:markerframes_OLP(14,4),16:23);
load_OLP_15 = OLP_15(1:markerframes_OLP(15,4),16:23);
load_OLP_16 = OLP_16(1:markerframes_OLP(16,4),16:23);
load_OLP_17 = OLP_17(1:markerframes_OLP(17,4),16:23);
load_OLP_18 = OLP_18(1:markerframes_OLP(18,4),16:23);
load_OLP_19 = OLP_19(1:markerframes_OLP(19,4),16:23);
load_OLP_20 = OLP_20(1:markerframes_OLP(20,4),16:23);
% For the OPHFA exercise
load_OPHFA_1 = OPHFA_1(1:markerframes_OPHFA(1,4),16:23);
load_OPHFA_2 = zeros(1,3);
load_OPHFA_3 = OPHFA_3(1:markerframes_OPHFA(3,4),16:23);
load_OPHFA_4 = OPHFA_4(1:markerframes_OPHFA(4,4),16:23);
load_OPHFA_5 = OPHFA_5(1:markerframes_OPHFA(5,4),16:23);
load_OPHFA_6 = zeros(1,3);
load_OPHFA_7 = OPHFA_7(1:markerframes_OPHFA(7,4),16:23);
load_OPHFA_8 = zeros(1,3);
load_OPHFA_9 = OPHFA_9(1:markerframes_OPHFA(9,4),16:23);
load_OPHFA_10 = zeros(1,3);
load_OPHFA_11 = zeros(1,3);
load_OPHFA_12 = OPHFA_12(1:markerframes_OPHFA(12,4),16:23);
load_OPHFA_13 = OPHFA_13(1:markerframes_OPHFA(13,4),16:23);
load_OPHFA_14 = OPHFA_14(1:markerframes_OPHFA(14,4),16:23);
load_OPHFA_15 = zeros(1,3);
load_OPHFA_16 = OPHFA_16(1:markerframes_OPHFA(16,4),16:23);
load_OPHFA_17 = OPHFA_17(1:markerframes_OPHFA(17,4),16:23);
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load_OPHFA_18 = OPHFA_18(1:markerframes_OPHFA(18,4),16:23);
load_OPHFA_19 = OPHFA_19(1:markerframes_OPHFA(19,4),16:23);
load_OPHFA_20 = OPHFA_20(1:markerframes_OPHFA(20,4),16:23);

%%%%% In the eccentric phase of the exercises %%%%%
% For the CA1 exercise
load_CA1_1_ecc = CA1_1(1:markerframes_CA1(1,5),16:23);
load_CA1_2_ecc = CA1_2(1:markerframes_CA1(2,5),16:23);
load_CA1_3_ecc = CA1_3(1:markerframes_CA1(3,5),16:23);
load_CA1_4_ecc = CA1_4(1:markerframes_CA1(4,5),16:23);
load_CA1_5_ecc = CA1_5(1:markerframes_CA1(5,5),16:23);
load_CA1_6_ecc = CA1_6(1:markerframes_CA1(6,5),16:23);
load_CA1_7_ecc = CA1_7(1:markerframes_CA1(7,5),16:23);
load_CA1_8_ecc = zeros(1,3);
load_CA1_9_ecc = CA1_9(1:markerframes_CA1(9,5),16:23);
load_CA1_10_ecc = CA1_10(1:markerframes_CA1(10,5),16:23);
load_CA1_11_ecc = zeros(1,3);
load_CA1_12_ecc = CA1_12(1:markerframes_CA1(12,5),16:23);
load_CA1_13_ecc = CA1_13(1:markerframes_CA1(13,5),16:23);
load_CA1_14_ecc = CA1_14(1:markerframes_CA1(14,5),16:23);
load_CA1_15_ecc = CA1_15(1:markerframes_CA1(15,5),16:23);
load_CA1_16_ecc = CA1_16(1:markerframes_CA1(16,5),16:23);
load_CA1_17_ecc = CA1_17(1:markerframes_CA1(17,5),16:23);
load_CA1_18_ecc = CA1_18(1:markerframes_CA1(18,5),16:23);
load_CA1_19_ecc = CA1_19(1:markerframes_CA1(19,5),16:23);
load_CA1_20_ecc = CA1_20(1:markerframes_CA1(20,5),16:23);
% For the CA2 exercise
load_CA2_1_ecc = CA2_1(1:markerframes_CA2(1,5),16:23);
load_CA2_2_ecc = CA2_2(1:markerframes_CA2(2,5),16:23);
load_CA2_3_ecc = CA2_3(1:markerframes_CA2(3,5),16:23);
load_CA2_4_ecc = CA2_4(1:markerframes_CA2(4,5),16:23);
load_CA2_5_ecc = CA2_5(1:markerframes_CA2(5,5),16:23);
load_CA2_6_ecc = CA2_6(1:markerframes_CA2(6,5),16:23);
load_CA2_7_ecc = CA2_7(1:markerframes_CA2(7,5),16:23);
load_CA2_8_ecc = zeros(1,3);
load_CA2_9_ecc = CA2_9(1:markerframes_CA2(9,5),16:23);
load_CA2_10_ecc = CA2_10(1:markerframes_CA2(10,5),16:23);
load_CA2_11_ecc = zeros(1,3);
load_CA2_12_ecc = CA2_12(1:markerframes_CA2(12,5),16:23);
load_CA2_13_ecc = CA2_13(1:markerframes_CA2(13,5),16:23);
load_CA2_14_ecc = CA2_14(1:markerframes_CA2(14,5),16:23);
load_CA2_15_ecc = zeros(1,3);
load_CA2_16_ecc = CA2_16(1:markerframes_CA2(16,5),16:23);
load_CA2_17_ecc = CA2_17(1:markerframes_CA2(17,5),16:23);
load_CA2_18_ecc = CA2_18(1:markerframes_CA2(18,5),16:23);
load_CA2_19_ecc = CA2_19(1:markerframes_CA2(19,5),16:23);
load_CA2_20_ecc = CA2_20(1:markerframes_CA2(20,5),16:23);
% For the OLP exercise
load_OLP_1_ecc = OLP_1(1:markerframes_OLP(1,5),16:23);
load_OLP_2_ecc = OLP_2(1:markerframes_OLP(2,5),16:23);
load_OLP_3_ecc = OLP_3(1:markerframes_OLP(3,5),16:23);
load_OLP_4_ecc = OLP_4(1:markerframes_OLP(4,5),16:23);
load_OLP_5_ecc = OLP_5(1:markerframes_OLP(5,5),16:23);
load_OLP_6_ecc = OLP_6(1:markerframes_OLP(6,5),16:23);
```

```
load_OLP_7_ecc = OLP_7(1:markerframes_OLP(7,5),16:23);
load_OLP_8_ecc = zeros(1,3);
load_OLP_9_ecc = OLP_9(1:markerframes_OLP(9,5),16:23);
load_OLP_10_ecc = OLP_10(1:markerframes_OLP(10,5),16:23);
load_OLP_11_ecc = zeros(1,3);
load_OLP_12_ecc = OLP_12(1:markerframes_OLP(12,5),16:23);
load_OLP_13_ecc = OLP_13(1:markerframes_OLP(13,5),16:23);
load_OLP_14_ecc = OLP_14(1:markerframes_OLP(14,5),16:23);
load_OLP_15_ecc = OLP_15(1:markerframes_OLP(15,5),16:23);
load_OLP_16_ecc = OLP_16(1:markerframes_OLP(16,5),16:23);
load_OLP_17_ecc = OLP_17(1:markerframes_OLP(17,5),16:23);
load_OLP_18_ecc = OLP_18(1:markerframes_OLP(18,5),16:23);
load_OLP_19_ecc = OLP_19(1:markerframes_OLP(19,5),16:23);
load_OLP_20_ecc = OLP_20(1:markerframes_OLP(20,5),16:23);
% For the OPHFA exercise
load_OPHFA_1_ecc = OPHFA_1(1:markerframes_OPHFA(1,5),16:23);
load_OPHFA_2_ecc = zeros(1,3);
load_OPHFA_3_ecc = OPHFA_3(1:markerframes_OPHFA(3,5),16:23);
load_OPHFA_4_ecc = OPHFA_4(1:markerframes_OPHFA(4,5),16:23);
load_OPHFA_5_ecc = OPHFA_5(1:markerframes_OPHFA(5,5),16:23);
load_OPHFA_6_ecc = zeros(1,3);
load_OPHFA_7_ecc = OPHFA_7(1:markerframes_OPHFA(7,5),16:23);
load_OPHFA_8_ecc = zeros(1,3);
load_OPHFA_9_ecc = OPHFA_9(1:markerframes_OPHFA(9,5),16:23);
load_OPHFA_10_ecc = zeros(1,3);
load_OPHFA_11_ecc = zeros(1,3);
load_OPHFA_12_ecc = OPHFA_12(1:markerframes_OPHFA(12,5),16:23);
load_OPHFA_13_ecc = OPHFA_13(1:markerframes_OPHFA(13,5),16:23);
load_OPHFA_14_ecc = OPHFA_14(1:markerframes_OPHFA(14,5),16:23);
load_OPHFA_15_ecc = zeros(1,3);
load_OPHFA_16_ecc = OPHFA_16(1:markerframes_OPHFA(16,5),16:23);
load_OPHFA_17_ecc = OPHFA_17(1:markerframes_OPHFA(17,5),16:23);
load_OPHFA_18_ecc = OPHFA_18(1:markerframes_OPHFA(18,5),16:23);
load_OPHFA_19_ecc = OPHFA_19(1:markerframes_OPHFA(19,5),16:23);
load_OPHFA_20_ecc = OPHFA_20(1:markerframes_OPHFA(20,5),16:23);

%%%%% In the concentric phase of the exercises %%%%%
% For the CA1 exercise
load_CA1_1_con = CA1_1(markerframes_CA1(1,5):markerframes_CA1(1,4),16:23);
load_CA1_2_con = CA1_2(markerframes_CA1(2,5):markerframes_CA1(2,4),16:23);
load_CA1_3_con = CA1_3(markerframes_CA1(3,5):markerframes_CA1(3,4),16:23);
load_CA1_4_con = CA1_4(markerframes_CA1(4,5):markerframes_CA1(4,4),16:23);
load_CA1_5_con = CA1_5(markerframes_CA1(5,5):markerframes_CA1(5,4),16:23);
load_CA1_6_con = CA1_6(markerframes_CA1(6,5):markerframes_CA1(6,4),16:23);
load_CA1_7_con = CA1_7(markerframes_CA1(7,5):markerframes_CA1(7,4),16:23);
load_CA1_8_con = zeros(1,3);
load_CA1_9_con = CA1_9(markerframes_CA1(9,5):markerframes_CA1(9,4),16:23);
load_CA1_10_con = CA1_10(markerframes_CA1(10,5):markerframes_CA1(10,4),16:23);
load_CA1_11_con = zeros(1,3);
load_CA1_12_con = CA1_12(markerframes_CA1(12,5):markerframes_CA1(12,4),16:23);
load_CA1_13_con = CA1_13(markerframes_CA1(13,5):markerframes_CA1(13,4),16:23);
load_CA1_14_con = CA1_14(markerframes_CA1(14,5):markerframes_CA1(14,4),16:23);
load_CA1_15_con = CA1_15(markerframes_CA1(15,5):markerframes_CA1(15,4),16:23);
load_CA1_16_con = CA1_16(markerframes_CA1(16,5):markerframes_CA1(16,4),16:23);
```

```
load_CA1_17_con = CA1_17(markerframes_CA1(17,5):markerframes_CA1(17,4),16:23);
load_CA1_18_con = CA1_18(markerframes_CA1(18,5):markerframes_CA1(18,4),16:23);
load_CA1_19_con = CA1_19(markerframes_CA1(19,5):markerframes_CA1(19,4),16:23);
load_CA1_20_con = CA1_20(markerframes_CA1(20,5):markerframes_CA1(20,4),16:23);
% For the CA2 exercise
load_CA2_1_con = CA2_1(markerframes_CA2(1,5):markerframes_CA2(1,4),16:23);
load_CA2_2_con = CA2_2(markerframes_CA2(2,5):markerframes_CA2(2,4),16:23);
load_CA2_3_con = CA2_3(markerframes_CA2(3,5):markerframes_CA2(3,4),16:23);
load_CA2_4_con = CA2_4(markerframes_CA2(4,5):markerframes_CA2(4,4),16:23);
load_CA2_5_con = CA2_5(markerframes_CA2(5,5):markerframes_CA2(5,4),16:23);
load_CA2_6_con = CA2_6(markerframes_CA2(6,5):markerframes_CA2(6,4),16:23);
load_CA2_7_con = CA2_7(markerframes_CA2(7,5):markerframes_CA2(7,4),16:23);
load_CA2_8_con = zeros(1,3);
load_CA2_9_con = CA2_9(markerframes_CA2(9,5):markerframes_CA2(9,4),16:23);
load_CA2_10_con = CA2_10(markerframes_CA2(10,5):markerframes_CA2(10,4),16:23);
load_CA2_11_con = zeros(1,3);
load_CA2_12_con = CA2_12(markerframes_CA2(12,5):markerframes_CA2(12,4),16:23);
load_CA2_13_con = CA2_13(markerframes_CA2(13,5):markerframes_CA2(13,4),16:23);
load_CA2_14_con = CA2_14(markerframes_CA2(14,5):markerframes_CA2(14,4),16:23);
load_CA2_15_con = zeros(1,3);
load_CA2_16_con = CA2_16(markerframes_CA2(16,5):markerframes_CA2(16,4),16:23);
load_CA2_17_con = CA2_17(markerframes_CA2(17,5):markerframes_CA2(17,4),16:23);
load_CA2_18_con = CA2_18(markerframes_CA2(18,5):markerframes_CA2(18,4),16:23);
load_CA2_19_con = CA2_19(markerframes_CA2(19,5):markerframes_CA2(19,4),16:23);
load_CA2_20_con = CA2_20(markerframes_CA2(20,5):markerframes_CA2(20,4),16:23);
% For the OLP exercise
load_OLP_1_con = OLP_1(markerframes_OLP(1,5):markerframes_OLP(1,4),16:23);
load_OLP_2_con = OLP_2(markerframes_OLP(2,5):markerframes_OLP(2,4),16:23);
load_OLP_3_con = OLP_3(markerframes_OLP(3,5):markerframes_OLP(3,4),16:23);
load_OLP_4_con = OLP_4(markerframes_OLP(4,5):markerframes_OLP(4,4),16:23);
load_OLP_5_con = OLP_5(markerframes_OLP(5,5):markerframes_OLP(5,4),16:23);
load_OLP_6_con = OLP_6(markerframes_OLP(6,5):markerframes_OLP(6,4),16:23);
load_OLP_7_con = OLP_7(markerframes_OLP(7,5):markerframes_OLP(7,4),16:23);
load_OLP_8_con = zeros(1,3);
load_OLP_9_con = OLP_9(markerframes_OLP(9,5):markerframes_OLP(9,4),16:23);
load_OLP_10_con = OLP_10(markerframes_OLP(10,5):markerframes_OLP(10,4),16:23);
load_OLP_11_con = zeros(1,3);
load_OLP_12_con = OLP_12(markerframes_OLP(12,5):markerframes_OLP(12,4),16:23);
load_OLP_13_con = OLP_13(markerframes_OLP(13,5):markerframes_OLP(13,4),16:23);
load_OLP_14_con = OLP_14(markerframes_OLP(14,5):markerframes_OLP(14,4),16:23);
load_OLP_15_con = OLP_15(markerframes_OLP(15,5):markerframes_OLP(15,4),16:23);
load_OLP_16_con = OLP_16(markerframes_OLP(16,5):markerframes_OLP(16,4),16:23);
load_OLP_17_con = OLP_17(markerframes_OLP(17,5):markerframes_OLP(17,4),16:23);
load_OLP_18_con = OLP_18(markerframes_OLP(18,5):markerframes_OLP(18,4),16:23);
load_OLP_19_con = OLP_19(markerframes_OLP(19,5):markerframes_OLP(19,4),16:23);
load_OLP_20_con = OLP_20(markerframes_OLP(20,5):markerframes_OLP(20,4),16:23);
% For the OPHFA exercise
load_OPHFA_1_con = OPHFA_1(markerframes_OPHFA(1,5):markerframes_OPHFA(1,4),16:23);
load_OPHFA_2_con = zeros(1,3);
load_OPHFA_3_con = OPHFA_3(markerframes_OPHFA(3,5):markerframes_OPHFA(3,4),16:23);
load_OPHFA_4_con = OPHFA_4(markerframes_OPHFA(4,5):markerframes_OPHFA(4,4),16:23);
load_OPHFA_5_con = OPHFA_5(markerframes_OPHFA(5,5):markerframes_OPHFA(5,4),16:23);
load_OPHFA_6_con = zeros(1,3);
load_OPHFA_7_con = OPHFA_7(markerframes_OPHFA(7,5):markerframes_OPHFA(7,4),16:23);
```

```
load_OPHFA_8_con = zeros(1,3);
load_OPHFA_9_con = OPHFA_9(markerframes_OPHFA(9,5):markerframes_OPHFA(9,4),16:23);
load_OPHFA_10_con = zeros(1,3);
load_OPHFA_11_con = zeros(1,3);
load_OPHFA_12_con = OPHFA_12(markerframes_OPHFA(12,5):markerframes_OPHFA(12,4),16:↙
23);
load_OPHFA_13_con = OPHFA_13(markerframes_OPHFA(13,5):markerframes_OPHFA(13,4),16:↙
23);
load_OPHFA_14_con = OPHFA_14(markerframes_OPHFA(14,5):markerframes_OPHFA(14,4),16:↙
23);
load_OPHFA_15_con = zeros(1,3);
load_OPHFA_16_con = OPHFA_16(markerframes_OPHFA(16,5):markerframes_OPHFA(16,4),16:↙
23);
load_OPHFA_17_con = OPHFA_17(markerframes_OPHFA(17,5):markerframes_OPHFA(17,4),16:↙
23);
load_OPHFA_18_con = OPHFA_18(markerframes_OPHFA(18,5):markerframes_OPHFA(18,4),16:↙
23);
load_OPHFA_19_con = OPHFA_19(markerframes_OPHFA(19,5):markerframes_OPHFA(19,4),16:↙
23);
load_OPHFA_20_con = OPHFA_20(markerframes_OPHFA(20,5):markerframes_OPHFA(20,4),16:↙
23);


%% Find peak normTorque

normPeakTorque = [max(load_CA1_1(:,4)), max(load_CA2_1(:,4)), max(load_OLP_1(:,4)),↙
max(load_OPHFA_1(:,4));
    max(load_CA1_2(:,4)), max(load_CA2_2(:,4)), max(load_OLP_2(:,4)), zeros(1,1);
    max(load_CA1_3(:,4)), max(load_CA2_3(:,4)), max(load_OLP_3(:,4)), max↙
(load_OPHFA_3(:,4));
    max(load_CA1_4(:,4)), max(load_CA2_4(:,4)), max(load_OLP_4(:,4)), max↙
(load_OPHFA_4(:,4));
    max(load_CA1_5(:,4)), max(load_CA2_5(:,4)), max(load_OLP_5(:,4)), max↙
(load_OPHFA_5(:,4));
    max(load_CA1_6(:,4)), max(load_CA2_6(:,4)), max(load_OLP_6(:,4)), zeros(1,1);
    max(load_CA1_7(:,4)), max(load_CA2_7(:,4)), max(load_OLP_7(:,4)), max↙
(load_OPHFA_7(:,4));
    zeros(1,1), zeros(1,1), zeros(1,1), zeros(1,1);
    max(load_CA1_9(:,4)), max(load_CA2_9(:,4)), max(load_OLP_9(:,4)), max↙
(load_OPHFA_9(:,4));
    max(load_CA1_10(:,4)), max(load_CA2_10(:,4)), max(load_OLP_10(:,4)), zeros(1,1);
    zeros(1,1), zeros(1,1), zeros(1,1), zeros(1,1);
    max(load_CA1_12(:,4)), max(load_CA2_12(:,4)), max(load_OLP_12(:,4)), max↙
(load_OPHFA_12(:,4));
    max(load_CA1_13(:,4)), max(load_CA2_13(:,4)), max(load_OLP_13(:,4)), max↙
(load_OPHFA_13(:,4));
    max(load_CA1_14(:,4)), max(load_CA2_14(:,4)), max(load_OLP_14(:,4)), max↙
(load_OPHFA_14(:,4));
    max(load_CA1_15(:,4)), zeros(1,1), max(load_OLP_15(:,4)), zeros(1,1);
    max(load_CA1_16(:,4)), max(load_CA2_16(:,4)), max(load_OLP_16(:,4)), max↙
(load_OPHFA_16(:,4));
    max(load_CA1_17(:,4)), max(load_CA2_17(:,4)), max(load_OLP_17(:,4)), max↙
(load_OPHFA_17(:,4));
    max(load_CA1_18(:,4)), max(load_CA2_18(:,4)), max(load_OLP_18(:,4)), max↙
```

```
(load_OPHFA_18(:,4));
    max(load_CA1_19(:,4)), max(load_CA2_19(:,4)), max(load_OLP_19(:,4)), max↙
(load_OPHFA_19(:,4));
    max(load_CA1_20(:,4)), max(load_CA2_20(:,4)), max(load_OLP_20(:,4)), max↙
(load_OPHFA_20(:,4))];

%% Find mean normTorque

normMeanTorque = [mean(load_CA1_1(:,4)), mean(load_CA2_1(:,4)), mean(load_OLP_1(:,↙
4)), mean(load_OPHFA_1(:,4));
    mean(load_CA1_2(:,4)), mean(load_CA2_2(:,4)), mean(load_OLP_2(:,4)), zeros(1,1);
    mean(load_CA1_3(:,4)), mean(load_CA2_3(:,4)), mean(load_OLP_3(:,4)), mean↙
(load_OPHFA_3(:,4));
    mean(load_CA1_4(:,4)), mean(load_CA2_4(:,4)), mean(load_OLP_4(:,4)), mean↙
(load_OPHFA_4(:,4));
    mean(load_CA1_5(:,4)), mean(load_CA2_5(:,4)), mean(load_OLP_5(:,4)), mean↙
(load_OPHFA_5(:,4));
    mean(load_CA1_6(:,4)), mean(load_CA2_6(:,4)), mean(load_OLP_6(:,4)), zeros(1,1);
    mean(load_CA1_7(:,4)), mean(load_CA2_7(:,4)), mean(load_OLP_7(:,4)), mean↙
(load_OPHFA_7(:,4));
    zeros(1,1), zeros(1,1), zeros(1,1), zeros(1,1);
    mean(load_CA1_9(:,4)), mean(load_CA2_9(:,4)), mean(load_OLP_9(:,4)), mean↙
(load_OPHFA_9(:,4));
    mean(load_CA1_10(:,4)), mean(load_CA2_10(:,4)), mean(load_OLP_10(:,4)), zeros↙
(1,1);
    zeros(1,1), zeros(1,1), zeros(1,1), zeros(1,1);
    mean(load_CA1_12(:,4)), mean(load_CA2_12(:,4)), mean(load_OLP_12(:,4)), mean↙
(load_OPHFA_12(:,4));
    mean(load_CA1_13(:,4)), mean(load_CA2_13(:,4)), mean(load_OLP_13(:,4)), mean↙
(load_OPHFA_13(:,4));
    mean(load_CA1_14(:,4)), mean(load_CA2_14(:,4)), mean(load_OLP_14(:,4)), mean↙
(load_OPHFA_14(:,4));
    mean(load_CA1_15(:,4)), zeros(1,1), max(load_OLP_15(:,4)), zeros(1,1);
    mean(load_CA1_16(:,4)), mean(load_CA2_16(:,4)), mean(load_OLP_16(:,4)), mean↙
(load_OPHFA_16(:,4));
    mean(load_CA1_17(:,4)), mean(load_CA2_17(:,4)), mean(load_OLP_17(:,4)), mean↙
(load_OPHFA_17(:,4));
    mean(load_CA1_18(:,4)), mean(load_CA2_18(:,4)), mean(load_OLP_18(:,4)), mean↙
(load_OPHFA_18(:,4));
    mean(load_CA1_19(:,4)), mean(load_CA2_19(:,4)), mean(load_OLP_19(:,4)), mean↙
(load_OPHFA_19(:,4));
    mean(load_CA1_20(:,4)), mean(load_CA2_20(:,4)), mean(load_OLP_20(:,4)), mean↙
(load_OPHFA_20(:,4))];

% Standard deviation
std_normMeanTorque = [std(load_CA1_1(:,4)), std(load_CA2_1(:,4)), std(load_OLP_1(:,↙
4)), std(load_OPHFA_1(:,4));
    std(load_CA1_2(:,4)), std(load_CA2_2(:,4)), std(load_OLP_2(:,4)), zeros(1,1);
    std(load_CA1_3(:,4)), std(load_CA2_3(:,4)), std(load_OLP_3(:,4)), std↙
(load_OPHFA_3(:,4));
    std(load_CA1_4(:,4)), std(load_CA2_4(:,4)), std(load_OLP_4(:,4)), std↙
(load_OPHFA_4(:,4));
    std(load_CA1_5(:,4)), std(load_CA2_5(:,4)), std(load_OLP_5(:,4)), std↙
(load_OPHFA_5(:,4));
```

```
    std(load_CA1_6(:,4)), std(load_CA2_6(:,4)), std(load_OLP_6(:,4)), zeros(1,1);
    std(load_CA1_7(:,4)), std(load_CA2_7(:,4)), std(load_OLP_7(:,4)), std↙
(load_OPHFA_7(:,4));
    zeros(1,1), zeros(1,1), zeros(1,1), zeros(1,1);
    std(load_CA1_9(:,4)), std(load_CA2_9(:,4)), std(load_OLP_9(:,4)), std↙
(load_OPHFA_9(:,4));
    std(load_CA1_10(:,4)), std(load_CA2_10(:,4)), std(load_OLP_10(:,4)), zeros(1,1);
    zeros(1,1), zeros(1,1), zeros(1,1), zeros(1,1);
    std(load_CA1_12(:,4)), std(load_CA2_12(:,4)), std(load_OLP_12(:,4)), std↙
(load_OPHFA_12(:,4));
    std(load_CA1_13(:,4)), std(load_CA2_13(:,4)), std(load_OLP_13(:,4)), std↙
(load_OPHFA_13(:,4));
    std(load_CA1_14(:,4)), std(load_CA2_14(:,4)), std(load_OLP_14(:,4)), std↙
(load_OPHFA_14(:,4));
    std(load_CA1_15(:,4)), zeros(1,1), max(load_OLP_15(:,4)), zeros(1,1);
    std(load_CA1_16(:,4)), std(load_CA2_16(:,4)), std(load_OLP_16(:,4)), std↙
(load_OPHFA_16(:,4));
    std(load_CA1_17(:,4)), std(load_CA2_17(:,4)), std(load_OLP_17(:,4)), std↙
(load_OPHFA_17(:,4));
    std(load_CA1_18(:,4)), std(load_CA2_18(:,4)), std(load_OLP_18(:,4)), std↙
(load_OPHFA_18(:,4));
    std(load_CA1_19(:,4)), std(load_CA2_19(:,4)), std(load_OLP_19(:,4)), std↙
(load_OPHFA_19(:,4));
    std(load_CA1_20(:,4)), std(load_CA2_20(:,4)), std(load_OLP_20(:,4)), std↙
(load_OPHFA_20(:,4))];


%% Results torque

%%% Average of mean values %%%
mean_normTorque_CA1 = mean(nonzeros(normMeanTorque(:,1)));
mean_normTorque_CA2 = mean(nonzeros(normMeanTorque(:,2)));
mean_normTorque_OLP = mean(nonzeros(normMeanTorque(:,3)));
mean_normTorque_OPHFA = mean(nonzeros(normMeanTorque(:,4)));

% standard deviation
nT_CA1 = (markerframes_CA1(:,4)-1) .* (std_normMeanTorque(:,1).^2);
nT_CA2 = (markerframes_CA2(:,4)-1) .* (std_normMeanTorque(:,2).^2);
nT_OLP = (markerframes_OLP(:,4)-1) .* (std_normMeanTorque(:,3).^2);
nT_OPHFA = (markerframes_OPHFA(:,4)-1) .* (std_normMeanTorque(:,4).^2);

std_mean_normTorque_CA1 = sqrt(sum(nT_CA1,'omitnan')/sum(markerframes_CA1(:,4)↙
-1,'omitnan'));
std_mean_normTorque_CA2 = sqrt(sum(nT_CA2,'omitnan')/sum(markerframes_CA2(:,4)↙
-1,'omitnan'));
std_mean_normTorque_OLP = sqrt(sum(nT_OLP,'omitnan')/sum(markerframes_OLP(:,4)↙
-1,'omitnan'));
std_mean_normTorque_OPHFA = sqrt(sum(nT_OPHFA,'omitnan')/sum(markerframes_OPHFA(:,4)↙
-1,'omitnan'));

%%% Average of peak values %%%
peak_normTorque_CA1 = mean(nonzeros(normPeakTorque(:,1)));
peak_normTorque_CA2 = mean(nonzeros(normPeakTorque(:,2)));
peak_normTorque_OLP = mean(nonzeros(normPeakTorque(:,3)));
```

```
peak_normTorque_OPHFA = mean(nonzeros(normPeakTorque(:,4)));

% standard deviation
std_peak_normTorque_CA1 = std(nonzeros(normPeakTorque(:,1)));
std_peak_normTorque_CA2 = std(nonzeros(normPeakTorque(:,2)));
std_peak_normTorque_OLP = std(nonzeros(normPeakTorque(:,3)));
std_peak_normTorque_OPHFA = std(nonzeros(normPeakTorque(:,4)));

% Collect the results in table
exercises = ["CA1";"CA2";"OLP";"OPHFA"];

peak_torque = [peak_normTorque_CA1;peak_normTorque_CA2;peak_normTorque_OLP;↙
peak_normTorque_OPHFA];
std_peak_torque = [std_peak_normTorque_CA1;std_peak_normTorque_CA2;↙
std_peak_normTorque_OLP;std_peak_normTorque_OPHFA];
mean_torque = [mean_normTorque_CA1;mean_normTorque_CA2;mean_normTorque_OLP;↙
mean_normTorque_OPHFA];
std_mean_torque = [std_mean_normTorque_CA1;std_mean_normTorque_CA2;↙
std_mean_normTorque_OLP;std_mean_normTorque_OPHFA];

table_torque_total = table(exercises,peak_torque,std_peak_torque,mean_torque,↙
std_mean_torque);

cd 'C:\Users\Helena\Documents\Master\'
writetable(table_torque_total,'result_torquetotal.xlsx');

%% Interpolated torque data

int_nof = 50001;

%%%%% Interpolation of eccentric phase %%%%%
% For the CA1 exercise
int_load_CA1_1_ecc = interp1(1:markerframes_CA1(1,5),load_CA1_1_ecc,linspace(1,↙
markerframes_CA1(1,5),int_nof));
int_load_CA1_2_ecc = interp1(1:markerframes_CA1(2,5),load_CA1_2_ecc,linspace(1,↙
markerframes_CA1(2,5),int_nof));
int_load_CA1_3_ecc = interp1(1:markerframes_CA1(3,5),load_CA1_3_ecc,linspace(1,↙
markerframes_CA1(3,5),int_nof));
int_load_CA1_4_ecc = interp1(1:markerframes_CA1(4,5),load_CA1_4_ecc,linspace(1,↙
markerframes_CA1(4,5),int_nof));
int_load_CA1_5_ecc = interp1(1:markerframes_CA1(5,5),load_CA1_5_ecc,linspace(1,↙
markerframes_CA1(5,5),int_nof));
int_load_CA1_6_ecc = interp1(1:markerframes_CA1(6,5),load_CA1_6_ecc,linspace(1,↙
markerframes_CA1(6,5),int_nof));
int_load_CA1_7_ecc = interp1(1:markerframes_CA1(7,5),load_CA1_7_ecc,linspace(1,↙
markerframes_CA1(7,5),int_nof));
int_load_CA1_8_ecc = zeros(int_nof,6);
int_load_CA1_9_ecc = interp1(1:markerframes_CA1(9,5),load_CA1_9_ecc,linspace(1,↙
markerframes_CA1(9,5),int_nof));
int_load_CA1_10_ecc = interp1(1:markerframes_CA1(10,5),load_CA1_10_ecc,linspace(1,↙
markerframes_CA1(10,5),int_nof));
int_load_CA1_11_ecc = zeros(int_nof,6);
int_load_CA1_12_ecc = interp1(1:markerframes_CA1(12,5),load_CA1_12_ecc,linspace(1,↙
markerframes_CA1(12,5),int_nof));
```

```
int_load_CA1_13_ecc = interp1(1:markerframes_CA1(13,5),load_CA1_13_ecc,linspace(1,↙
markerframes_CA1(13,5),int_nof));
int_load_CA1_14_ecc = interp1(1:markerframes_CA1(14,5),load_CA1_14_ecc,linspace(1,↙
markerframes_CA1(14,5),int_nof));
int_load_CA1_15_ecc = interp1(1:markerframes_CA1(15,5),load_CA1_15_ecc,linspace(1,↙
markerframes_CA1(15,5),int_nof));
int_load_CA1_16_ecc = interp1(1:markerframes_CA1(16,5),load_CA1_16_ecc,linspace(1,↙
markerframes_CA1(16,5),int_nof));
int_load_CA1_17_ecc = interp1(1:markerframes_CA1(17,5),load_CA1_17_ecc,linspace(1,↙
markerframes_CA1(17,5),int_nof));
int_load_CA1_18_ecc = interp1(1:markerframes_CA1(18,5),load_CA1_18_ecc,linspace(1,↙
markerframes_CA1(18,5),int_nof));
int_load_CA1_19_ecc = interp1(1:markerframes_CA1(19,5),load_CA1_19_ecc,linspace(1,↙
markerframes_CA1(19,5),int_nof));
int_load_CA1_20_ecc = interp1(1:markerframes_CA1(20,5),load_CA1_20_ecc,linspace(1,↙
markerframes_CA1(20,5),int_nof));
% For the CA2 exercise
int_load_CA2_1_ecc = interp1(1:markerframes_CA2(1,5),load_CA2_1_ecc,linspace(1,↙
markerframes_CA2(1,5),int_nof));
int_load_CA2_2_ecc = interp1(1:markerframes_CA2(2,5),load_CA2_2_ecc,linspace(1,↙
markerframes_CA2(2,5),int_nof));
int_load_CA2_3_ecc = interp1(1:markerframes_CA2(3,5),load_CA2_3_ecc,linspace(1,↙
markerframes_CA2(3,5),int_nof));
int_load_CA2_4_ecc = interp1(1:markerframes_CA2(4,5),load_CA2_4_ecc,linspace(1,↙
markerframes_CA2(4,5),int_nof));
int_load_CA2_5_ecc = interp1(1:markerframes_CA2(5,5),load_CA2_5_ecc,linspace(1,↙
markerframes_CA2(5,5),int_nof));
int_load_CA2_6_ecc = interp1(1:markerframes_CA2(6,5),load_CA2_6_ecc,linspace(1,↙
markerframes_CA2(6,5),int_nof));
int_load_CA2_7_ecc = interp1(1:markerframes_CA2(7,5),load_CA2_7_ecc,linspace(1,↙
markerframes_CA2(7,5),int_nof));
int_load_CA2_8_ecc = zeros(int_nof,6);
int_load_CA2_9_ecc = interp1(1:markerframes_CA2(9,5),load_CA2_9_ecc,linspace(1,↙
markerframes_CA2(9,5),int_nof));
int_load_CA2_10_ecc = interp1(1:markerframes_CA2(10,5),load_CA2_10_ecc,linspace(1,↙
markerframes_CA2(10,5),int_nof));
int_load_CA2_11_ecc = zeros(int_nof,6);
int_load_CA2_12_ecc = interp1(1:markerframes_CA2(12,5),load_CA2_12_ecc,linspace(1,↙
markerframes_CA2(12,5),int_nof));
int_load_CA2_13_ecc = interp1(1:markerframes_CA2(13,5),load_CA2_13_ecc,linspace(1,↙
markerframes_CA2(13,5),int_nof));
int_load_CA2_14_ecc = interp1(1:markerframes_CA2(14,5),load_CA2_14_ecc,linspace(1,↙
markerframes_CA2(14,5),int_nof));
int_load_CA2_15_ecc = zeros(int_nof,6);
int_load_CA2_16_ecc = interp1(1:markerframes_CA2(16,5),load_CA2_16_ecc,linspace(1,↙
markerframes_CA2(16,5),int_nof));
int_load_CA2_17_ecc = interp1(1:markerframes_CA2(17,5),load_CA2_17_ecc,linspace(1,↙
markerframes_CA2(17,5),int_nof));
int_load_CA2_18_ecc = interp1(1:markerframes_CA2(18,5),load_CA2_18_ecc,linspace(1,↙
markerframes_CA2(18,5),int_nof));
int_load_CA2_19_ecc = interp1(1:markerframes_CA2(19,5),load_CA2_19_ecc,linspace(1,↙
markerframes_CA2(19,5),int_nof));
int_load_CA2_20_ecc = interp1(1:markerframes_CA2(20,5),load_CA2_20_ecc,linspace(1,↙
markerframes_CA2(20,5),int_nof));
```

```
% For the OLP exercise
int_load_OLP_1_ecc = interp1(1:markerframes_OLP(1,5),load_OLP_1_ecc,linspace(1,↙
markerframes_OLP(1,5),int_nof));
int_load_OLP_2_ecc = interp1(1:markerframes_OLP(2,5),load_OLP_2_ecc,linspace(1,↙
markerframes_OLP(2,5),int_nof));
int_load_OLP_3_ecc = interp1(1:markerframes_OLP(3,5),load_OLP_3_ecc,linspace(1,↙
markerframes_OLP(3,5),int_nof));
int_load_OLP_4_ecc = interp1(1:markerframes_OLP(4,5),load_OLP_4_ecc,linspace(1,↙
markerframes_OLP(4,5),int_nof));
int_load_OLP_5_ecc = interp1(1:markerframes_OLP(5,5),load_OLP_5_ecc,linspace(1,↙
markerframes_OLP(5,5),int_nof));
int_load_OLP_6_ecc = interp1(1:markerframes_OLP(6,5),load_OLP_6_ecc,linspace(1,↙
markerframes_OLP(6,5),int_nof));
int_load_OLP_7_ecc = interp1(1:markerframes_OLP(7,5),load_OLP_7_ecc,linspace(1,↙
markerframes_OLP(7,5),int_nof));
int_load_OLP_8_ecc = zeros(int_nof,6);
int_load_OLP_9_ecc = interp1(1:markerframes_OLP(9,5),load_OLP_9_ecc,linspace(1,↙
markerframes_OLP(9,5),int_nof));
int_load_OLP_10_ecc = interp1(1:markerframes_OLP(10,5),load_OLP_10_ecc,linspace(1,↙
markerframes_OLP(10,5),int_nof));
int_load_OLP_11_ecc = zeros(int_nof,6);
int_load_OLP_12_ecc = interp1(1:markerframes_OLP(12,5),load_OLP_12_ecc,linspace(1,↙
markerframes_OLP(12,5),int_nof));
int_load_OLP_13_ecc = interp1(1:markerframes_OLP(13,5),load_OLP_13_ecc,linspace(1,↙
markerframes_OLP(13,5),int_nof));
int_load_OLP_14_ecc = interp1(1:markerframes_OLP(14,5),load_OLP_14_ecc,linspace(1,↙
markerframes_OLP(14,5),int_nof));
int_load_OLP_15_ecc = interp1(1:markerframes_OLP(15,5),load_OLP_15_ecc,linspace(1,↙
markerframes_OLP(15,5),int_nof));
int_load_OLP_16_ecc = interp1(1:markerframes_OLP(16,5),load_OLP_16_ecc,linspace(1,↙
markerframes_OLP(16,5),int_nof));
int_load_OLP_17_ecc = interp1(1:markerframes_OLP(17,5),load_OLP_17_ecc,linspace(1,↙
markerframes_OLP(17,5),int_nof));
int_load_OLP_18_ecc = interp1(1:markerframes_OLP(18,5),load_OLP_18_ecc,linspace(1,↙
markerframes_OLP(18,5),int_nof));
int_load_OLP_19_ecc = interp1(1:markerframes_OLP(19,5),load_OLP_19_ecc,linspace(1,↙
markerframes_OLP(19,5),int_nof));
int_load_OLP_20_ecc = interp1(1:markerframes_OLP(20,5),load_OLP_20_ecc,linspace(1,↙
markerframes_OLP(20,5),int_nof));
% For the OPHFA exercise
int_load_OPHFA_1_ecc = interp1(1:markerframes_OPHFA(1,5),load_OPHFA_1_ecc,linspace↙
(1,markerframes_OPHFA(1,5),int_nof));
int_load_OPHFA_2_ecc = zeros(int_nof,6);
int_load_OPHFA_3_ecc = interp1(1:markerframes_OPHFA(3,5),load_OPHFA_3_ecc,linspace↙
(1,markerframes_OPHFA(3,5),int_nof));
int_load_OPHFA_4_ecc = interp1(1:markerframes_OPHFA(4,5),load_OPHFA_4_ecc,linspace↙
(1,markerframes_OPHFA(4,5),int_nof));
int_load_OPHFA_5_ecc = interp1(1:markerframes_OPHFA(5,5),load_OPHFA_5_ecc,linspace↙
(1,markerframes_OPHFA(5,5),int_nof));
int_load_OPHFA_6_ecc = zeros(int_nof,6);
int_load_OPHFA_7_ecc = interp1(1:markerframes_OPHFA(7,5),load_OPHFA_7_ecc,linspace↙
(1,markerframes_OPHFA(7,5),int_nof));
int_load_OPHFA_8_ecc = zeros(int_nof,6);
int_load_OPHFA_9_ecc = interp1(1:markerframes_OPHFA(9,5),load_OPHFA_9_ecc,linspace↙
```

```
(1,markerframes_OPHFA(9,5),int_nof));
int_load_OPHFA_10_ecc = zeros(int_nof,6);
int_load_OPHFA_11_ecc = zeros(int_nof,6);
int_load_OPHFA_12_ecc = interp1(1:markerframes_OPHFA(12,5),load_OPHFA_12_ecc,↙
linspace(1,markerframes_OPHFA(12,5),int_nof));
int_load_OPHFA_13_ecc = interp1(1:markerframes_OPHFA(13,5),load_OPHFA_13_ecc,↙
linspace(1,markerframes_OPHFA(13,5),int_nof));
int_load_OPHFA_14_ecc = interp1(1:markerframes_OPHFA(14,5),load_OPHFA_14_ecc,↙
linspace(1,markerframes_OPHFA(14,5),int_nof));
int_load_OPHFA_15_ecc = zeros(int_nof,6);
int_load_OPHFA_16_ecc = interp1(1:markerframes_OPHFA(16,5),load_OPHFA_16_ecc,↙
linspace(1,markerframes_OPHFA(16,5),int_nof));
int_load_OPHFA_17_ecc = interp1(1:markerframes_OPHFA(17,5),load_OPHFA_17_ecc,↙
linspace(1,markerframes_OPHFA(17,5),int_nof));
int_load_OPHFA_18_ecc = interp1(1:markerframes_OPHFA(18,5),load_OPHFA_18_ecc,↙
linspace(1,markerframes_OPHFA(18,5),int_nof));
int_load_OPHFA_19_ecc = interp1(1:markerframes_OPHFA(19,5),load_OPHFA_19_ecc,↙
linspace(1,markerframes_OPHFA(19,5),int_nof));
int_load_OPHFA_20_ecc = interp1(1:markerframes_OPHFA(20,5),load_OPHFA_20_ecc,↙
linspace(1,markerframes_OPHFA(20,5),int_nof));


%%%%% Interpolation og concentric phase %%%%%
% For the CA1 exercise
int_load_CA1_1_con = interp1(1:markerframes_CA1(1,6),load_CA1_1_con,linspace(1,↙
markerframes_CA1(1,6),int_nof));
int_load_CA1_2_con = interp1(1:markerframes_CA1(2,6),load_CA1_2_con,linspace(1,↙
markerframes_CA1(2,6),int_nof));
int_load_CA1_3_con = interp1(1:markerframes_CA1(3,6),load_CA1_3_con,linspace(1,↙
markerframes_CA1(3,6),int_nof));
int_load_CA1_4_con = interp1(1:markerframes_CA1(4,6),load_CA1_4_con,linspace(1,↙
markerframes_CA1(4,6),int_nof));
int_load_CA1_5_con = interp1(1:markerframes_CA1(5,6),load_CA1_5_con,linspace(1,↙
markerframes_CA1(5,6),int_nof));
int_load_CA1_6_con = interp1(1:markerframes_CA1(6,6),load_CA1_6_con,linspace(1,↙
markerframes_CA1(6,6),int_nof));
int_load_CA1_7_con = interp1(1:markerframes_CA1(7,6),load_CA1_7_con,linspace(1,↙
markerframes_CA1(7,6),int_nof));
int_load_CA1_8_con = zeros(int_nof,6);
int_load_CA1_9_con = interp1(1:markerframes_CA1(9,6),load_CA1_9_con,linspace(1,↙
markerframes_CA1(9,6),int_nof));
int_load_CA1_10_con = interp1(1:markerframes_CA1(10,6),load_CA1_10_con,linspace(1,↙
markerframes_CA1(10,6),int_nof));
int_load_CA1_11_con = zeros(int_nof,6);
int_load_CA1_12_con = interp1(1:markerframes_CA1(12,6),load_CA1_12_con,linspace(1,↙
markerframes_CA1(12,6),int_nof));
int_load_CA1_13_con = interp1(1:markerframes_CA1(13,6),load_CA1_13_con,linspace(1,↙
markerframes_CA1(13,6),int_nof));
int_load_CA1_14_con = interp1(1:markerframes_CA1(14,6),load_CA1_14_con,linspace(1,↙
markerframes_CA1(14,6),int_nof));
int_load_CA1_15_con = interp1(1:markerframes_CA1(15,6),load_CA1_15_con,linspace(1,↙
markerframes_CA1(15,6),int_nof));
int_load_CA1_16_con = interp1(1:markerframes_CA1(16,6),load_CA1_16_con,linspace(1,↙
markerframes_CA1(16,6),int_nof));
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int_load_CA1_17_con = interp1(1:markerframes_CA1(17,6),load_CA1_17_con,linspace(1,↙
markerframes_CA1(17,6),int_nof));
int_load_CA1_18_con = interp1(1:markerframes_CA1(18,6),load_CA1_18_con,linspace(1,↙
markerframes_CA1(18,6),int_nof));
int_load_CA1_19_con = interp1(1:markerframes_CA1(19,6),load_CA1_19_con,linspace(1,↙
markerframes_CA1(19,6),int_nof));
int_load_CA1_20_con = interp1(1:markerframes_CA1(20,6),load_CA1_20_con,linspace(1,↙
markerframes_CA1(20,6),int_nof));
% For the CA2 exercise
int_load_CA2_1_con = interp1(1:markerframes_CA2(1,6),load_CA2_1_con,linspace(1,↙
markerframes_CA2(1,6),int_nof));
int_load_CA2_2_con = interp1(1:markerframes_CA2(2,6),load_CA2_2_con,linspace(1,↙
markerframes_CA2(2,6),int_nof));
int_load_CA2_3_con = interp1(1:markerframes_CA2(3,6),load_CA2_3_con,linspace(1,↙
markerframes_CA2(3,6),int_nof));
int_load_CA2_4_con = interp1(1:markerframes_CA2(4,6),load_CA2_4_con,linspace(1,↙
markerframes_CA2(4,6),int_nof));
int_load_CA2_5_con = interp1(1:markerframes_CA2(5,6),load_CA2_5_con,linspace(1,↙
markerframes_CA2(5,6),int_nof));
int_load_CA2_6_con = interp1(1:markerframes_CA2(6,6),load_CA2_6_con,linspace(1,↙
markerframes_CA2(6,6),int_nof));
int_load_CA2_7_con = interp1(1:markerframes_CA2(7,6),load_CA2_7_con,linspace(1,↙
markerframes_CA2(7,6),int_nof));
int_load_CA2_8_con = zeros(int_nof,6);
int_load_CA2_9_con = interp1(1:markerframes_CA2(9,6),load_CA2_9_con,linspace(1,↙
markerframes_CA2(9,6),int_nof));
int_load_CA2_10_con = interp1(1:markerframes_CA2(10,6),load_CA2_10_con,linspace(1,↙
markerframes_CA2(10,6),int_nof));
int_load_CA2_11_con = zeros(int_nof,6);
int_load_CA2_12_con = interp1(1:markerframes_CA2(12,6),load_CA2_12_con,linspace(1,↙
markerframes_CA2(12,6),int_nof));
int_load_CA2_13_con = interp1(1:markerframes_CA2(13,6),load_CA2_13_con,linspace(1,↙
markerframes_CA2(13,6),int_nof));
int_load_CA2_14_con = interp1(1:markerframes_CA2(14,6),load_CA2_14_con,linspace(1,↙
markerframes_CA2(14,6),int_nof));
int_load_CA2_15_con = zeros(int_nof,6);
int_load_CA2_16_con = interp1(1:markerframes_CA2(16,6),load_CA2_16_con,linspace(1,↙
markerframes_CA2(16,6),int_nof));
int_load_CA2_17_con = interp1(1:markerframes_CA2(17,6),load_CA2_17_con,linspace(1,↙
markerframes_CA2(17,6),int_nof));
int_load_CA2_18_con = interp1(1:markerframes_CA2(18,6),load_CA2_18_con,linspace(1,↙
markerframes_CA2(18,6),int_nof));
int_load_CA2_19_con = interp1(1:markerframes_CA2(19,6),load_CA2_19_con,linspace(1,↙
markerframes_CA2(19,6),int_nof));
int_load_CA2_20_con = interp1(1:markerframes_CA2(20,6),load_CA2_20_con,linspace(1,↙
markerframes_CA2(20,6),int_nof));
% For the OLP exercise
int_load_OLP_1_con = interp1(1:markerframes_OLP(1,6),load_OLP_1_con,linspace(1,↙
markerframes_OLP(1,6),int_nof));
int_load_OLP_2_con = interp1(1:markerframes_OLP(2,6),load_OLP_2_con,linspace(1,↙
markerframes_OLP(2,6),int_nof));
int_load_OLP_3_con = interp1(1:markerframes_OLP(3,6),load_OLP_3_con,linspace(1,↙
markerframes_OLP(3,6),int_nof));
int_load_OLP_4_con = interp1(1:markerframes_OLP(4,6),load_OLP_4_con,linspace(1,↙
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markerframes_OLP(4,6),int_nof));
int_load_OLP_5_con = interp1(1:markerframes_OLP(5,6),load_OLP_5_con,linspace(1,↙
markerframes_OLP(5,6),int_nof));
int_load_OLP_6_con = interp1(1:markerframes_OLP(6,6),load_OLP_6_con,linspace(1,↙
markerframes_OLP(6,6),int_nof));
int_load_OLP_7_con = interp1(1:markerframes_OLP(7,6),load_OLP_7_con,linspace(1,↙
markerframes_OLP(7,6),int_nof));
int_load_OLP_8_con = zeros(int_nof,6);
int_load_OLP_9_con = interp1(1:markerframes_OLP(9,6),load_OLP_9_con,linspace(1,↙
markerframes_OLP(9,6),int_nof));
int_load_OLP_10_con = interp1(1:markerframes_OLP(10,6),load_OLP_10_con,linspace(1,↙
markerframes_OLP(10,6),int_nof));
int_load_OLP_11_con = zeros(int_nof,6);
int_load_OLP_12_con = interp1(1:markerframes_OLP(12,6),load_OLP_12_con,linspace(1,↙
markerframes_OLP(12,6),int_nof));
int_load_OLP_13_con = interp1(1:markerframes_OLP(13,6),load_OLP_13_con,linspace(1,↙
markerframes_OLP(13,6),int_nof));
int_load_OLP_14_con = interp1(1:markerframes_OLP(14,6),load_OLP_14_con,linspace(1,↙
markerframes_OLP(14,6),int_nof));
int_load_OLP_15_con = interp1(1:markerframes_OLP(15,6),load_OLP_15_con,linspace(1,↙
markerframes_OLP(15,6),int_nof));
int_load_OLP_16_con = interp1(1:markerframes_OLP(16,6),load_OLP_16_con,linspace(1,↙
markerframes_OLP(16,6),int_nof));
int_load_OLP_17_con = interp1(1:markerframes_OLP(17,6),load_OLP_17_con,linspace(1,↙
markerframes_OLP(17,6),int_nof));
int_load_OLP_18_con = interp1(1:markerframes_OLP(18,6),load_OLP_18_con,linspace(1,↙
markerframes_OLP(18,6),int_nof));
int_load_OLP_19_con = interp1(1:markerframes_OLP(19,6),load_OLP_19_con,linspace(1,↙
markerframes_OLP(19,6),int_nof));
int_load_OLP_20_con = interp1(1:markerframes_OLP(20,6),load_OLP_20_con,linspace(1,↙
markerframes_OLP(20,6),int_nof));
% For the OPHFA exercise
int_load_OPHFA_1_con = interp1(1:markerframes_OPHFA(1,6),load_OPHFA_1_con,linspace↙
(1,markerframes_OPHFA(1,6),int_nof));
int_load_OPHFA_2_con = zeros(int_nof,6);
int_load_OPHFA_3_con = interp1(1:markerframes_OPHFA(3,6),load_OPHFA_3_con,linspace↙
(1,markerframes_OPHFA(3,6),int_nof));
int_load_OPHFA_4_con = interp1(1:markerframes_OPHFA(4,6),load_OPHFA_4_con,linspace↙
(1,markerframes_OPHFA(4,6),int_nof));
int_load_OPHFA_5_con = interp1(1:markerframes_OPHFA(5,6),load_OPHFA_5_con,linspace↙
(1,markerframes_OPHFA(5,6),int_nof));
int_load_OPHFA_6_con = zeros(int_nof,6);
int_load_OPHFA_7_con = interp1(1:markerframes_OPHFA(7,6),load_OPHFA_7_con,linspace↙
(1,markerframes_OPHFA(7,6),int_nof));
int_load_OPHFA_8_con = zeros(int_nof,6);
int_load_OPHFA_9_con = interp1(1:markerframes_OPHFA(9,6),load_OPHFA_9_con,linspace↙
(1,markerframes_OPHFA(9,6),int_nof));
int_load_OPHFA_10_con = zeros(int_nof,6);
int_load_OPHFA_11_con = zeros(int_nof,6);
int_load_OPHFA_12_con = interp1(1:markerframes_OPHFA(12,6),load_OPHFA_12_con,↙
linspace(1,markerframes_OPHFA(12,6),int_nof));
int_load_OPHFA_13_con = interp1(1:markerframes_OPHFA(13,6),load_OPHFA_13_con,↙
linspace(1,markerframes_OPHFA(13,6),int_nof));
int_load_OPHFA_14_con = interp1(1:markerframes_OPHFA(14,6),load_OPHFA_14_con,↙
```

```
linspace(1,markerframes_OPHFA(14,6),int_nof));
int_load_OPHFA_15_con = zeros(int_nof,6);
int_load_OPHFA_16_con = interp1(1:markerframes_OPHFA(16,6),load_OPHFA_16_con,↙
linspace(1,markerframes_OPHFA(16,6),int_nof));
int_load_OPHFA_17_con = interp1(1:markerframes_OPHFA(17,6),load_OPHFA_17_con,↙
linspace(1,markerframes_OPHFA(17,6),int_nof));
int_load_OPHFA_18_con = interp1(1:markerframes_OPHFA(18,6),load_OPHFA_18_con,↙
linspace(1,markerframes_OPHFA(18,6),int_nof));
int_load_OPHFA_19_con = interp1(1:markerframes_OPHFA(19,6),load_OPHFA_19_con,↙
linspace(1,markerframes_OPHFA(19,6),int_nof));
int_load_OPHFA_20_con = interp1(1:markerframes_OPHFA(20,6),load_OPHFA_20_con,↙
linspace(1,markerframes_OPHFA(20,6),int_nof));

% Collect all interpolated arrays for each exercise

%%% CA1 %%%
% Normalized torque in the eccentric phase of the CA1 exericise
nTorque_CA1_ecc = [int_load_CA1_1_ecc(:,4), int_load_CA1_2_ecc(:,4),↙
int_load_CA1_3_ecc(:,4), int_load_CA1_4_ecc(:,4), int_load_CA1_5_ecc(:,4), ...
    int_load_CA1_6_ecc(:,4), int_load_CA1_7_ecc(:,4), int_load_CA1_8_ecc(:,4),↙
int_load_CA1_9_ecc(:,4), int_load_CA1_10_ecc(:,4), ...
    int_load_CA1_11_ecc(:,4), int_load_CA1_12_ecc(:,4), int_load_CA1_13_ecc(:,4),↙
int_load_CA1_14_ecc(:,4), int_load_CA1_15_ecc(:,4), ...
    int_load_CA1_16_ecc(:,4), int_load_CA1_17_ecc(:,4), int_load_CA1_18_ecc(:,4),↙
int_load_CA1_19_ecc(:,4), int_load_CA1_20_ecc(:,4)];
% Normalized torque in the concentric phase of the CA1 exercise
nTorque_CA1_con = [int_load_CA1_1_con(:,4), int_load_CA1_2_con(:,4),↙
int_load_CA1_3_con(:,4), int_load_CA1_4_con(:,4), int_load_CA1_5_con(:,4), ...
    int_load_CA1_6_con(:,4), int_load_CA1_7_con(:,4), int_load_CA1_8_con(:,4),↙
int_load_CA1_9_con(:,4), int_load_CA1_10_con(:,4), ...
    int_load_CA1_11_con(:,4), int_load_CA1_12_con(:,4), int_load_CA1_13_con(:,4),↙
int_load_CA1_14_con(:,4), int_load_CA1_15_con(:,4), ...
    int_load_CA1_16_con(:,4), int_load_CA1_17_con(:,4), int_load_CA1_18_con(:,4),↙
int_load_CA1_19_con(:,4), int_load_CA1_20_con(:,4)];
%%% CA2 %%%
% Normalized torque in the eccentric phase of the CA2 exericise
nTorque_CA2_ecc = [int_load_CA2_1_ecc(:,4), int_load_CA2_2_ecc(:,4),↙
int_load_CA2_3_ecc(:,4), int_load_CA2_4_ecc(:,4), int_load_CA2_5_ecc(:,4), ...
    int_load_CA2_6_ecc(:,4), int_load_CA2_7_ecc(:,4), int_load_CA2_8_ecc(:,4),↙
int_load_CA2_9_ecc(:,4), int_load_CA2_10_ecc(:,4), ...
    int_load_CA2_11_ecc(:,4), int_load_CA2_12_ecc(:,4), int_load_CA2_13_ecc(:,4),↙
int_load_CA2_14_ecc(:,4), int_load_CA2_15_ecc(:,4), ...
    int_load_CA2_16_ecc(:,4), int_load_CA2_17_ecc(:,4), int_load_CA2_18_ecc(:,4),↙
int_load_CA2_19_ecc(:,4), int_load_CA2_20_ecc(:,4)];
% Normalized torque in the concentric phase of the CA2 exercise
nTorque_CA2_con = [int_load_CA1_2_con(:,4), int_load_CA2_2_con(:,4),↙
int_load_CA2_3_con(:,4), int_load_CA2_4_con(:,4), int_load_CA2_5_con(:,4), ...
    int_load_CA2_6_con(:,4), int_load_CA2_7_con(:,4), int_load_CA2_8_con(:,4),↙
int_load_CA2_9_con(:,4), int_load_CA2_10_con(:,4), ...
    int_load_CA2_11_con(:,4), int_load_CA2_12_con(:,4), int_load_CA2_13_con(:,4),↙
int_load_CA2_14_con(:,4), int_load_CA2_15_con(:,4), ...
    int_load_CA2_16_con(:,4), int_load_CA2_17_con(:,4), int_load_CA2_18_con(:,4),↙
int_load_CA2_19_con(:,4), int_load_CA2_20_con(:,4)];
%%% OLP %%%
```

```
% Normalized torque in the eccentric phase of the OLP exericise
nTorque_OLP_ecc = [int_load_OLP_1_ecc(:,4), int_load_OLP_2_ecc(:,4),↙
int_load_OLP_3_ecc(:,4), int_load_OLP_4_ecc(:,4), int_load_OLP_5_ecc(:,4), ...
    int_load_OLP_6_ecc(:,4), int_load_OLP_7_ecc(:,4), int_load_OLP_8_ecc(:,4),↙
int_load_OLP_9_ecc(:,4), int_load_OLP_10_ecc(:,4), ...
    int_load_OLP_11_ecc(:,4), int_load_OLP_12_ecc(:,4), int_load_OLP_13_ecc(:,4),↙
int_load_OLP_14_ecc(:,4), int_load_OLP_15_ecc(:,4), ...
    int_load_OLP_16_ecc(:,4), int_load_OLP_17_ecc(:,4), int_load_OLP_18_ecc(:,4),↙
int_load_OLP_19_ecc(:,4), int_load_OLP_20_ecc(:,4)];
% Normalized torque in the concentric phase of the OLP exercise
nTorque_OLP_con = [int_load_OLP_2_con(:,4), int_load_OLP_2_con(:,4),↙
int_load_OLP_3_con(:,4), int_load_OLP_4_con(:,4), int_load_OLP_5_con(:,4), ...
    int_load_OLP_6_con(:,4), int_load_OLP_7_con(:,4), int_load_OLP_8_con(:,4),↙
int_load_OLP_9_con(:,4), int_load_OLP_10_con(:,4), ...
    int_load_OLP_11_con(:,4), int_load_OLP_12_con(:,4), int_load_OLP_13_con(:,4),↙
int_load_OLP_14_con(:,4), int_load_OLP_15_con(:,4), ...
    int_load_OLP_16_con(:,4), int_load_OLP_17_con(:,4), int_load_OLP_18_con(:,4),↙
int_load_OLP_19_con(:,4), int_load_OLP_20_con(:,4)];
%%% OPHFA %%%
% Normalized torque in the eccentric phase of the OPHFA exericise
nTorque_OPHFA_ecc = [int_load_OPHFA_1_ecc(:,4), int_load_OPHFA_2_ecc(:,4),↙
int_load_OPHFA_3_ecc(:,4), int_load_OPHFA_4_ecc(:,4), int_load_OPHFA_5_ecc(:,4), ...
    int_load_OPHFA_6_ecc(:,4), int_load_OPHFA_7_ecc(:,4), int_load_OPHFA_8_ecc(:,4),↙
int_load_OPHFA_9_ecc(:,4), int_load_OPHFA_10_ecc(:,4), ...
    int_load_OPHFA_11_ecc(:,4), int_load_OPHFA_12_ecc(:,4), int_load_OPHFA_13_ecc(:,↙
4), int_load_OPHFA_14_ecc(:,4), int_load_OPHFA_15_ecc(:,4), ...
    int_load_OPHFA_16_ecc(:,4), int_load_OPHFA_17_ecc(:,4), int_load_OPHFA_18_ecc(:,↙
4), int_load_OPHFA_19_ecc(:,4), int_load_OPHFA_20_ecc(:,4)];
% Normalized torque in the concentric phase of the OPHFA exercise
nTorque_OPHFA_con = [int_load_OPHFA_2_con(:,4), int_load_OPHFA_2_con(:,4),↙
int_load_OPHFA_3_con(:,4), int_load_OPHFA_4_con(:,4), int_load_OPHFA_5_con(:,4), ...
    int_load_OPHFA_6_con(:,4), int_load_OPHFA_7_con(:,4), int_load_OPHFA_8_con(:,4),↙
int_load_OPHFA_9_con(:,4), int_load_OPHFA_10_con(:,4), ...
    int_load_OPHFA_11_con(:,4), int_load_OPHFA_12_con(:,4), int_load_OPHFA_13_con(:,↙
4), int_load_OPHFA_14_con(:,4), int_load_OPHFA_15_con(:,4), ...
    int_load_OPHFA_16_con(:,4), int_load_OPHFA_17_con(:,4), int_load_OPHFA_18_con(:,↙
4), int_load_OPHFA_19_con(:,4), int_load_OPHFA_20_con(:,4)];

%% Analyse normalized torque in each exercise

% Variables
mean_nTorque_CA1_ecc = zeros(int_nof,1);
mean_nTorque_CA1_con = zeros(int_nof,1);
mean_nTorque_CA2_ecc = zeros(int_nof,1);
mean_nTorque_CA2_con = zeros(int_nof,1);
mean_nTorque_OLP_ecc = zeros(int_nof,1);
mean_nTorque_OLP_con = zeros(int_nof,1);
mean_nTorque_OPHFA_ecc = zeros(int_nof,1);
mean_nTorque_OPHFA_con = zeros(int_nof,1);
    % these variables are used to plot torque normalized to time

% Normalized torque in the CA1 exercise
for i = 1:int_nof
    mean_nTorque_CA1_ecc(i,1) = mean(nonzeros(nTorque_CA1_ecc(i,:)));
```

```
    mean_nTorque_CA1_con(i,1) = mean(nonzeros(nTorque_CA1_con(i,:)));
end
% Normalized torque in the CA2 exercise
for i = 1:int_nof
    mean_nTorque_CA2_ecc(i,1) = mean(nonzeros(nTorque_CA2_ecc(i,:)));
    mean_nTorque_CA2_con(i,1) = mean(nonzeros(nTorque_CA2_con(i,:)));
end
% Normalized torque in the OLP exercise
for i = 1:int_nof
    mean_nTorque_OLP_ecc(i,1) = mean(nonzeros(nTorque_OLP_ecc(i,:)));
    mean_nTorque_OLP_con(i,1) = mean(nonzeros(nTorque_OLP_con(i,:)));
end
% Normalized torque in the OPHFA exercise
for i = 1:int_nof
    mean_nTorque_OPHFA_ecc(i,1) = mean(nonzeros(nTorque_OPHFA_ecc(i,:)));
    mean_nTorque_OPHFA_con(i,1) = mean(nonzeros(nTorque_OPHFA_con(i,:)));
end



%% Statistical analysis

% =============== ANOVA ===============
% Matrixes to use for ANOVA analysis
ANOVA_mean_add_long = [add_long_CA1(:,1), add_long_CA2(:,1), add_long_OLP(:,1),↙
add_long_OPHFA(:,1)];
ANOVA_mean_rec_fem = [rec_fem_CA1(:,1), rec_fem_CA2(:,1), rec_fem_OLP(:,1),↙
rec_fem_OPHFA(:,1)];
ANOVA_peak_add_long = [add_long_CA1(:,3), add_long_CA2(:,3), add_long_OLP(:,3),↙
add_long_OPHFA(:,3)];
ANOVA_peak_rec_fem = [rec_fem_CA1(:,3), rec_fem_CA2(:,3), rec_fem_OLP(:,3),↙
rec_fem_OPHFA(:,3)];
ANOVA_normPeakTorque = normPeakTorque;
ANOVA_normMeanTorque = normMeanTorque;
    % convert zeros to NaN-values
ANOVA_mean_add_long(ANOVA_mean_add_long == 0) = NaN;
ANOVA_mean_rec_fem(ANOVA_mean_rec_fem == 0) = NaN;
ANOVA_peak_add_long(ANOVA_peak_add_long == 0) = NaN;
ANOVA_peak_rec_fem(ANOVA_peak_rec_fem == 0) = NaN;
ANOVA_normPeakTorque(ANOVA_normPeakTorque == 0) = NaN;
ANOVA_normMeanTorque(ANOVA_normMeanTorque == 0) = NaN;
%%%
group = {'CA1','CA2','OLP','OPHFA'};
[p_mean_add_long,tbl_mean_add_long,stats_mean_add_long] = anova1↙
(ANOVA_mean_add_long,group);
[p_mean_rec_fem,tbl_mean_rec_fem,stats_mean_rec_fem] = anova1(ANOVA_mean_rec_fem,↙
group);
[p_peak_add_long,tbl_peak_add_long,stats_peak_add_long] = anova1↙
(ANOVA_peak_add_long,group);
[p_peak_rec_fem,tbl_peak_rec_fem,stats_peak_rec_fem] = anova1(ANOVA_peak_rec_fem,↙
group);
[p_MeanTorque,tbl_MeanTorque,stats_MeanTorque] = anova1(ANOVA_normMeanTorque,group);
[p_PeakTorque,tbl_PeakTorque,stats_PeakTorque] = anova1(ANOVA_normPeakTorque,group);
```

```
% =============== Post hoc ===============
[c_mean_add_long,m_mean_add_long,h_mean_add_long] = multcompare↙
(stats_mean_add_long);
[c_mean_rec_fem,m_mean_rec_fem,h_mean_rec_fem] = multcompare(stats_mean_rec_fem);
[c_peak_add_long,m_peak_add_long,h_peak_add_long] = multcompare↙
(stats_peak_add_long);
[c_peak_rec_fem,m_peak_rec_fem,h_peak_rec_fem] = multcompare(stats_peak_rec_fem);
```