Comparison And Correlation of Hamstring Reinforcing Exercise With Sprint In terms of Muscles Activity And Force Production

Author

Adnan Habib

Regn Number

00000329518

Supervisor

Dr. Asim Waris

DEPARTMENT OF BIOMEDICAL ENGINEERING AND SCIENCES

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

ISLAMABAD, PAKISTAN

July, 2023

Comparison And Correlation of Hamstring Reinforcing Exercise With Sprint In terms of Muscles Activity And Force Production

Author

Adnan Habib

Regn Number

00000329518

A thesis submitted in partial fulfillment of the requirements for the degree of

MS Biomedical Engineering

Thesis Supervisor:

Dr. Asim Waris

Thesis Supervisor's Signature:

____

DEPARTMENT OF BIOMEDICAL ENGINEERING AND SCIENCES

SCHOOL OF MECHANICAL & MANUFACTURING ENGINEERING

NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY

ISLAMABAD, PAKISTAN

July, 2023

FORM TH-4

MASTER THESIS WORK

We hereby recommend that the dissertation prepared under our supervision by: **Adnan Habib** Regn No. 00000329518

Titled: **Comparison And Correlation of Hamstring Reinforcing Exercise With Sprint In terms of Muscles Activity And Force Production** be accepted in partial fulfillment of the requirements for the award of **MS Biomedical Engineering** degree.

Examination Committee Members

1. Name: Dr. Syed Omer Gilani Signature:__

2. Name: Dr. Adeeb Shahzad Signature:__

Supervisor's name: Dr. Asim Waris Signature:__

Date:______

____

Head of Department

____

Date

COUNTERSINGED

Date:___________ Dean/Principal __

THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS thesis written by NS Adnan Habib (Registration No. 00000329518), of School of Mechanical and Manufacturing Engineering (SMME) has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within the similarity indices limit and is accepted as partial fulfillment for the award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

Signature:______________________________________

Name of Supervisor: Dr. Asim Waris

Date: ___________________________

Signature (HoD): ___________________________

Date: ____

Signature (Dean/Principal): ____________________

Date: ____

Declaration

I certify that this research work titled ***"Comparison And Correlation of Hamstring Reinforcing Exercise With Sprint In terms of Muscles Activity And Force Production"*** is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Signature of Student __________________

Adnan Habib

Regn No. 329518

MS Biomedical Engineering

Proposed Certificate for Plagiarism

It is certified that MS Thesis Titled Comparison And Correlation of Hamstring Reinforcing Exercise With Sprint In terms of Muscles Activity And Force Production by Adnan Habib has been examined by us. We undertake the follows:

a. Thesis has significant new work/knowledge as compared already published or are under consideration to be published elsewhere. No sentence, equation, diagram, table, paragraph or section has been copied verbatim from previous work unless it is placed under quotation marks and duly referenced.
b. The work presented is original and own work of the author (i.e., there is no plagiarism). No ideas, processes, results or words of others have been presented as Author own work.
c. There is no fabrication of data or results which have been compiled/analyzed.
d. There is no falsification by manipulating research materials, equipment or processes, or changing or omitting data or results such that the research is not accurately represented in the research record.
e. The thesis has been checked using TURNITIN (copy of originality report attached) and found within limits as per HEC plagiarism Policy and instructions issued from time to time.

Name & Signature of Supervisor

Dr. Asim Waris

Signature**:** _____________

Dedication

Dedicated to my Parents

Acknowledgments

My sincere thanks to my supervisor Dr. Asim Waris, for his useful guidance and constructive criticism needed in the completion of this research project.

I would like to thank my GCE members Dr. Adeeb Shahzad, and Dr. Syed Omer Gilani for guiding me throughout the whole research project.

I am also grateful to all my lab fellows and friends who made my research work experience a memorable one. Special thanks to my parents for their constant moral boosting and encouragement. I would like to thank all the participants for their willingness to participate in the study.

Abstract

Hamstring injuries are prevalent among athletes and anyone who engages in prolonged physical activity. Hamstring Strengthening courses should focus on movements that involve high hamstring activity to train the hamstring muscle specifically for sprinting. Therefore, the goals of this study were to evaluate the hamstring muscle activity during sprinting and the selected workouts, as well as to ex- amine the relationship between sprinting and hamstring strengthening workouts. Athletes, trainers, and rehabilitation professionals can create effective training plans by knowing which exercises cause the greatest muscle activity and force output. This study makes use of a comparative and corre- lational methodology, collecting electromyography (EMG) data during various hamstring exercises and sprinting, then analyzing and interpreting the data to assess muscle activity and the association between exercises and sprint performance. Studies discovered that various hamstring exercises pro- duced varying levels of muscle activation, with the slide leg bridge exercise generating the highest peak EMG activity. The Nordic exercise at 0 degrees showed a good association (0.57) with sprint performance, while the lying kick showed a weak correlation (0.19) with sprint performance. In conclusion, this investigation reveals valuable details regarding the relationship between several ham- string strengthening workouts and sprint efficiency, as well as the effectiveness of such exercises in terms of muscle contractions and exertion of force. The results indicate that while the Nordic exercise at 0 degrees correlates best with improved sprinting performance, the slide leg bridge exercise seems particularly advantageous for hamstring activation. These results can help in the creation of focused training protocols to improve sprint performance, hamstring strength, and avoiding injuries.

Keywords: Hamstring Injury, Hamstring Strengthening Exercises, EMG Activity, Sprinting, Treadmill

Table of Contents

List of Figures

List of Tables

Abbreviations

SM	Semimembranosus
ST	Semitendinosus
BF	Biceps Femoris
HS	Hamstrings
HMI	Hamstring Muscle Injuries
ROM	Range of Motion
MRI	Magnetic Resonance Imaging
RTP	Return to Play
EMG	Electromyography
NHE	Nordic Hamstring Exercise
UHEI	Upright Hip Extension Isometric
UHEC	Upright Hip Extension Concentric
SK	Standing Kick
SB	Side Leg Bridge
LK	Lying Kick

Chapter 1 Introduction

1.1 Hamstring Muscle and its Function

The hamstring (HS) muscle group is made up of the semimembranosus (SM), semitendinosus (ST), and biceps femoris (BF) muscles. The tibiofemoral and femoroacetabular joints are crossed by HS as it travels along the femur from the ischial tuberosity [1, 2]. The anatomical makeup of the HS muscle is depicted in Figure 1.

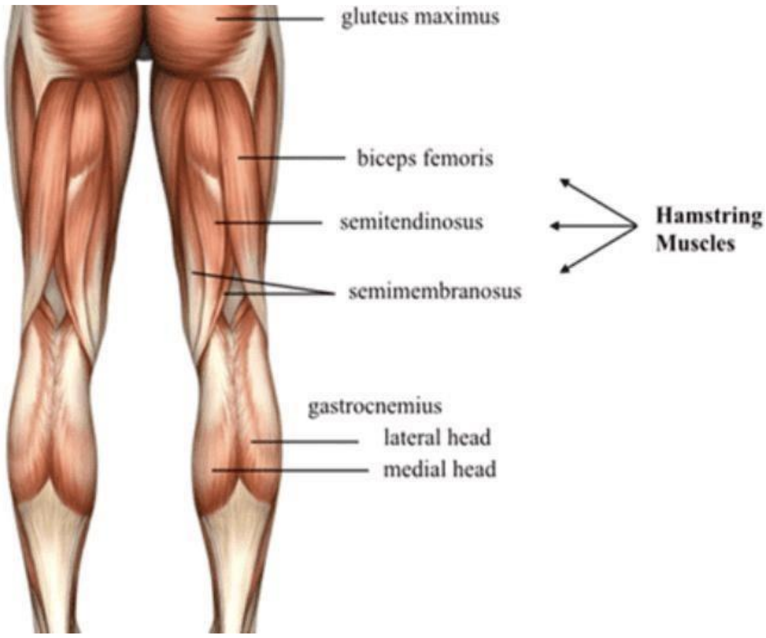


Figure 1: The diagram of the hamstring muscles is shown in this figure. Semitendinosus (ST), Semimembranosus (SM), and Biceps femoris (BF) muscles.

HS muscles play a major role in daily routine movements such as walking and standing. An extension moment is produced in the upright condition, as the center of mass is passed behind the hip, which needs to be outweighed by hip flexors. As opposed to this, the role of HS muscles is to act towards knee flexion. In the case of walking, during the phase of the final leg swing, HS acts on the hip and generates an eccentric action that deaccelerates the rate of hip flexion [3, 4, 5].

HS muscles are a hot topic in sports activities because they have an essential role in sports such as jumping, kicking, tackles, sprinting and cutting maneuvers. For example, kicking leg motion in soccer involves a backward and forward motion. HS muscles during the backward motion, act using concentric action in lateral rotation (only BF), knee flexion and hip extensions (along with gluteus maximus). In the case of forward motion, HS muscles act eccentrically to deaccelerate knee and hip during respective knee extension and hip flexion motion [5, 6, 7]. The deaccelerating action of HS muscles occurs at a point where the muscle reaches its maximum length i.e., it is stretched beyond its capacity. This is the main reason why HS muscles are more sensitive to injury because of the eccentric over-load at the end of swing phase during high-velocity sprinting and running [2, 8].

1.2 Hamstring Muscle Injuries (HMI)

Hamstring Muscle Wounds (HMI) are the most pervasive lower extremity bruise in sports including sprinting. They are a source of serious disability and impairment for athletes [9]. The incidence of muscle injuries in sports involving high-velocity movements (football, rugby, basketball) is extremely high. Muscle bruises are accountable for 10% to 50% among all sports injuries from which HMI represents 37% of injuries in professional sports activities [10 , 11].

To reduce the effects of HMI in athletes, various studies have been conducted to identify the risk factors of HMI [10]. The risk factors for HMI are characterized into two groups: Modifiable and Non-modifiable risk factors. The Modifiable group includes decreased muscle flexibility, Insufficient warming up, altered muscle length, anterior pelvic tilt, increased neural tension, and exhaustion all contribute to core weakness or instability and lumbar pathology. The un- modifiable risk factors include sex, age and race [12, 13].

Eccentric contractions in muscle lengthening (either tendon or muscle) can damage muscle fiber. The activation level of a muscle when eccentric contractions occur is directly proportional to the mechanical energy absorbed by the muscles before strain injury occurs. As a result, sudden activation in eccentric contraction leads to serious muscle injury [14]. HMI mechanism includes various sport activities including turning, stretching, twisting, jumping and sprinting. HMI occur frequently during sprinting. Almost 53% to 68% of HIS occurs during sprinting. The most injured muscle in sprinting is BF [15].

1.3 Diagnosis of Hamstring Injuries

A comprehensive knowledge of the anatomy, biomechanics, and pathophysiology of the HMI is necessary for its precise diagnosis. For a proper diagnosis, a clinical examination in view of an exhaustive clinical history and a nitty gritty actual assessment is carried out by the physician. The typical symptom is a sudden excruciating pain in the posterior thigh, which results in the immediate cutoff from competitive activity. However, it is not necessary that all posterior thigh pain occurs because of HMI [16]. The physical examination includes inspection of posture and gait, 'range of motion' tests (ROM tests), palpation (helps in identification of injury site) of muscle bellies, and manual testing of muscles. However, potential signs of ecchymosis and swelling usually arise after few days and are unnoticed at the initial examination. It is advised to perform active ROM after two days. Attractive Reverberation Imaging (MRI) is the generally involved imaging procedure for deciding the power of the HMI and whether surgical treatment is required or not [17].

1.4 Biomechanics of High-speed running Regarding Hamstring Muscle Injury

The contact phase and swing phase are the two key phases that make up a sprinter's whole running cycle (symmetrical and linear movement). The foot contacts the ground during the contact phase, and during the swing phase, the foot does not. Four sub-phases are further separated into these two primary phases: Early contact, often known as barking; Early swing, Early contact (population), and Late swing [18, 19, 20]. The two primary phases and their sub-phases are shown in Figure 2.

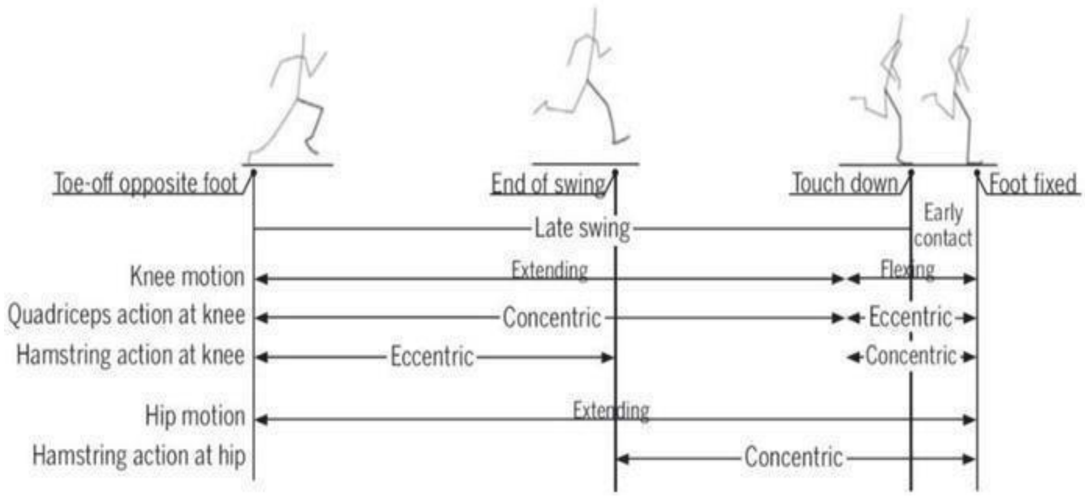


Figure 2: This figure shows the Prevailing quadriceps and hamstring constriction modes in the late swing and early contact periods of running

Sprinters who run at a fast rate of speed develop HMI. The mechanism behind this is linked to the muscle's twofold innervation, which produces a lot of power quickly, and its characteristic of being a biarticular muscle [21, 22]. The main role of HS muscles during the late swing period of a run is to quickly and concentrically bring the thigh back while going about as knee flexors to dial back the forward swing unpredictably in the lower leg. In contrast, during the initial contact phase, the HS muscles reduce the loss of running speed by engaging in concentric activity as hip extensor and knee flexor muscles. As a result, the body's center of gravity changes, allowing it to move forward smoothly. During sprinting, a significant amount of power is required to increase running speed [19, 23].

In full-speed running, the contractile activity of the quadriceps femoris muscle must be under control of a quick switch from eccentric to concentric contractions in the HS muscles (stretch-shortening cycle) from the late swing phase to the early contact phase. High forces are created as a result of these movements, which is thought to be related to HIS in sprinters [23]. Larger part of specialists dealing with examining the job of the hamstring during run accept that the late swing stage is probably going to be the point in the running cycle at which the hamstrings are more inclined to wounds however not many of them contend that the most elevated risk point in running is the early contact stage. The majority of HMI take place during the running's early contact and late swing phases [19, 23, 24, 25].

1.5 Why Hamstring Muscle Injuries are a Major Concern for Athletes?

These wounds can prompt both present moment and long-haul results in sports including running. HMI frequently brings about competitors being managed out of the rivalries which causes critical time misfortune for competitors, and it likewise puts monetary weight on sports associations [26]. HMI can be exceptionally baffling for a competitor and the treating doctor on the grounds that for least of about fourteen days instructional meetings or matches are missed because of its long recuperation time. The pace of repeat upon return to play (RTP) is nearly high. They can have a negative impact on the team's performance as well as the health and psychosocial well-being of the players [27]. Players are the most significant resources for the progress of pro athletics groups, HMI not just objective horrendous torment and handicap in players yet additionally goal a significant issue for the groups and clubs for which they are contending [28].

A prolonged period of increased risk of recurrence and a large recovery period are frequent outcomes of acute HMI. The majority of HMI recurrences—nearly one-third of them—occur within the first two weeks of a comeback. As players return too soon, this high recurrence rate demonstrates the need for an effective rehabilitation programmed [29]. Numerous studies have been conducted to understand the processes of HMI, specifically the injuries that happen while sprinting, in order to prevent HMI and for better rehabilitation outcomes. The results of these research indicate that the main mechanism of HMI is severe muscle strain during eccentric contraction or stretching. An intensive comprehension of the HMI systems is pivotal for improvement of reasonable procedures to keep away from and restore HI [30, 31].

1.6 Specific Hamstring Strengthening Exercise for Sprinters

The significant part of execution in many games is Run running speed increase. HS muscles assume a pivotal part in running. The hamstrings are the most sensitive muscles in sports, especially those involving high-speed running, and they play a crucial role in sprinting and athletes' performance. HMI can bring about a normal time deficiency of 24 days. It is necessary to look for advancements in HMI diagnosis, treatment, and prevention strategies in order to provide benefits in the future, reduce the incidence, risk of reinjury, and severity of HMI, minimize medical costs, and minimize time lost from sporting activities.

In addition, the HS muscles play a significant role in the generation of horizontal force, which is necessary for the relative maximum horizontal output during sprint acceleration. A particular hamstring-reinforcing exercise for runners is an activity that would enact the hamstring muscles fundamentally and focus on the creation of even power during running. These exercises will help improve horizontal force production from a performance strategy perspective, in addition to preventing primary and secondary HMIs. These strengthening exercises should primarily focus on those that are related to muscles specifically for sprinting [33, 34, 35].

1.7 Objectives of the Study

To gain useful information for HMI prevention strategies, it is necessary to conduct a study on sprinters for track and field. As already mentioned above, sprinting is the leading cause of HMI in athletes. One of the electrophysiological signals that represent the neuromuscular activity during movements is the electromyography (EMG) signal. It offers helpful details on muscular health. Robots used in rehabilitation are an example of application where EMG-based pattern recognition systems have been employed widely [36]. The aim of this study is to correlate hamstring strengthening exercises EMG activity with sprinting to reduce the incidence, reoccurrence, and recovery period of HMI in sprinters. This study will focus on how to optimize HMI rehabilitation and prevention strategies using hamstring-specific exercises.

[33] Conducted the same investigation. The principal objectives of this study were to view at hamstring muscle movement during running and HS-explicit reinforcing exercises as well as to investigate the relationship between force age limit during running and specific exercises. Six fortifying activities, including The performance of the hamstring muscles was assessed during solo exercises. The BF and ST hamstring muscles' EMG activity was captured. Regional level athletes who had never received any training before the experiment served as the study's subjects. With a few minor adjustments, we conducted the identical experiment in our study. The participants in our study were athletes who had been regular gym goers for the previous year without a history of HSI in the previous six months. Before the test, each athlete received a training session. Furthermore, we added a seventh exercise—the lying kick—to our protocol and carried out seven exercises overall, whereas [33] only carried out a total of six exercises. We recorded 60 m sprint data using a treadmill and previous study used Radar Stalker ATS II system to record 50m sprint data.

Chapter 2 Literature Review

In a concentrate by Suarez et al. [37], football competitors' solidarity during Nordic Hamstring Activities (NHEs) was inspected as well as the effect of the convention on running. 50 healthy professional football players are taking part in this study. They split into two Nordic Gatherings NG-1, NG-2, and a control group, respectively. They assessed the NHEs and linear sprints at the start of the season and at the conclusion of the intervention period (football training supplemented with an NHE regiment) (T5, T10, T20-m). There were 24 meetings for NG-1 and 22 meetings (without the utilization of the NHE) for NG-2 or control group. Sprint times were significantly reduced (ES from -2.240.75 to -0.600.37) in three groups. The sprint performance differences between NG-1 and control group were the same. Execution during runs and NHEs had no connection. There was a strong correlation between the players' and NHEs' body mass. Conclusion: There is no connection between run presentation and NHEs, and run enhancements are free of NHE modifications.

Drury et al. examined a six-week Nordic NHE program. 38] In their investigation of male youth soccer players. Players' formative stages were either less evolved (pre-top-level speed [PHV]) or more created (mid/post-PHV). 48 individuals were divided into two groups: pre-PHV and mid/post-PHV The individuals from these two gatherings were then parted into exploratory and control subgroups. The eccentric hamstring strength (NordBord) was tested both before and after the training plan. The players in the trial bunch went through a NHE program and performed a few times each week for a sum of about a month and a half. Prior to PHV, a greater impact was observed. This study demonstrated the way that male soccer players can expand their whimsical hamstring strength utilizing a 6-week NHE preparing. Players with less development acquired benefits. An NHE training program for young male soccer players could be based on the findings of the study.

The semitendinosus (ST), adductor magnus (AM), semimembranosus (SM), biceps femoris long head (BFl), and biceps femoris short head (BFs) were analyzed in a concentrate by Mendiguchia et al. [39] to decide the impacts of capricious leg twist (LC) and jump (L) exercises. Eleven expert male soccer players had their legs arbitrarily relegated to either the LC or the L work-out daily schedule (3 arrangements of 6 reiterations). Useful attractive reverberation imaging (fMRI) of the people's thighs was done when the mediation, which endured 48 hours. 15 axial scans of the right thigh were recorded, each spaced 1/15 of the length of the femur (Lf). They analyzed the fMRI information to search for varieties in signal strength. For SM and BFs, unquestionably the short tau reversal recuperation values didn't differ altogether. Tremendous changes were found in the ST (21-45%) from segments 4 to 10, AM (2-13%), and BFl (3 versus 8%) in areas 4, 6, and 7. During the LC exercises, all of the ST muscles were worked. The L exercises load the BFl and AM's proximal areas. The review's decisions were drawn, and it was proposed that they would be valuable while creating rules for the avoidance and restoration of HMI.

Which fortifying activities specifically draw in the BF muscle was the focal point of a concentrate by Bourne et al. [40]. 24 drew in male members were joined up. There were two halves to the study. In ten popular strengthening exercises, they examined the amplitudes and ratios of the lateral (BF) to medial (MH) hamstring normalised electromyography (nEMG) during the eccentric and concentric phases. The spatial patterns of HS activation during the two exercises that in part 1 most specifically and least specifically activated the BF were discovered using functional MRI (fMRI) in part 2. The 45° hip augmentation practice had the most noteworthy BF/MH nEMG proportion, as indicated by the outcomes, though the twisted knee scaffold and Nordic hamstring practices had the least. Concentrically, the rush and 45-degree hip expansion had the most noteworthy BF/MH nEMG proportion, while the leg twist and bowed knee span had the least. The 45° hip augmentation had bigger BF(LongHead) proportion enactment than the Nordic, as per fMRI discoveries (p 0.001). It was determined that Nordic exercise affected the semitendinosus, while hip extension exercise specifically stimulated the long hamstrings. These findings should be taken into consideration by specialists in the treatment of HMI as well as those working on prevention strategies.

Chapter 3 Methodology

3.1 Study Design and Area

A cross-sectional study including 12 healthy male and 8 healthy female sprinters (age 23.8 ± 2.12) was done. Participants completed a total of seven workouts that were chosen to focus on the ability of the HS muscles throughout one session, with a maximum of two sprints conducted. During sprinting and the workouts, HS muscle activity and force output was assessed. The specifications indicated by [41] for the suitability of the treadmill were followed. The Ethical approval was obtained from the local ethical committee of the National University of Sciences and Technology, NUST Approval no. ref no: NUST/SMME-BME/REC/000456/20012021. Informed written consent was obtained from all the participants. The re- search was carried out at the NUST Gymnasium from October to November 2021.

3.2 Participants Recruitment

Participants were recruited from the National University of Sciences and Technology (NUST), Islamabad Fitness Club. For the recruitment process, we followed inclusion-exclusion criteria. Only those participants, of all age groups, were included if they have been working out at the gym for the past year and were engaged in strength training every week. The study eliminated all people who had any history of HMI in the previous six months. Also, the subjects who reported any pain or discomfort which could have affected their ability to perform sprinting and selected exercises were also excluded. The purpose and significance of the study were explained in detail to all the participants. Those who were willing to participate were asked to fill out a written consent form. After written consent was obtained from the participants, they were then asked to fill out a questionnaire to collect socio-demographic information. The questionnaire comprised of demographic data of individuals like name, age, weight, and height. The data was kept confidential and used only for study purposes.

3.3 Experimental Protocol

Each subject underwent testing for one session in the gym. Testing was done for each participant on different days with the same weather (the experiment was performed in NUST gymnasium under controlled temperature. The gymnasium uses temperature sensors to maintain a constant room temperature). Candidates were required to wear their own attire and spiked running shoes. Seven exercises, two maximal sprints, a warm-up before the experiment, and data collecting made comprised the experiment's several phases, which were always carried out in the same order. It took an hour to complete.

Every participant was given a 30-minute warm-up plan designed specifically for them (running, accelerations, etc.). Participants had 5 to 10 free minutes to cool down after the warm-up. The participant’s dominant leg’s BF and ST were fitted with EMG Delsys Wireless Electrodes (2 channels) in a bipolar configuration at this time by a physiotherapist. Before applying the electrodes, the skin was cleaned with alcohol and then shaved. As recommended by SENIAM [42], standard procedures were followed for electrode implantation on BF as shown in Figure 3a and ST as shown in Figure 3b.

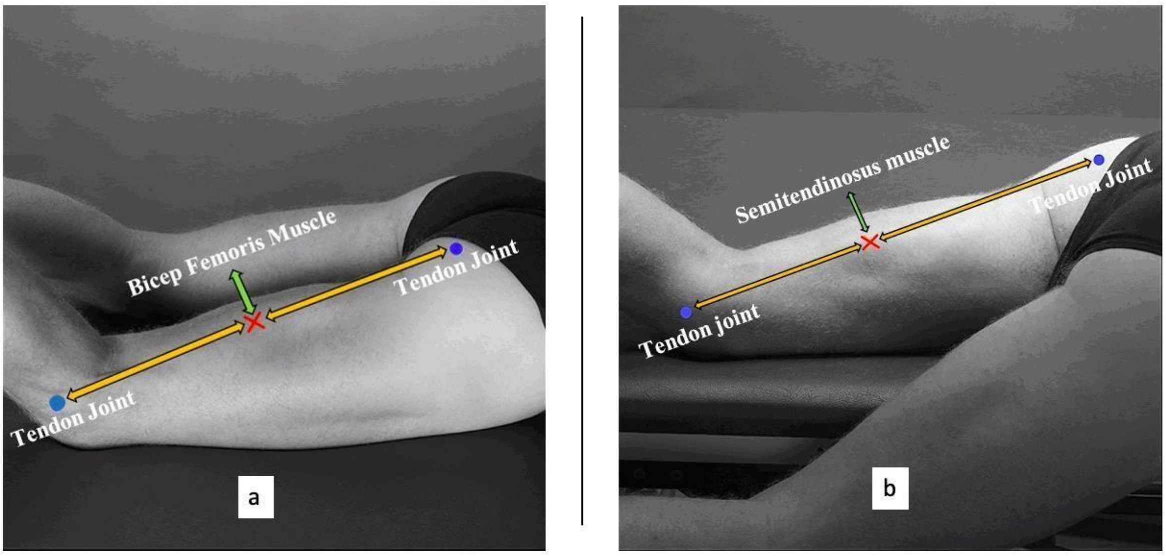


Figure 3: This Figure shows the Placement of the EMG Electrode for (a) Biceps Femoris (BF) and (b) Semitendinosus (ST)

Each participant then completed two 50 m treadmill sprints at their maximum speed after 15 minutes of rest. The two sprints were completed back-to-back with 3-5 minutes of rest in the same setting, at the same temperature, using identical gear. Before beginning the seven exercises, the participants were given 10 minutes of rest. Next, each participant completed seven exercises which were selected based on the findings of earlier research [33, 40, 43].

In a variety of ways, these workouts can target the HS muscles at various points in the sprint. Nordic Hamstring Exercise at 0°and 90°, Upright Hip Extension Isometric (UHEI) and Upright Hip Extension Con- centric (UHEC), Standing Kick (SK), Side Leg Bridge (SB), and Lying Kick (LK) were the seven exercises that were carried out. UHE was chosen because it could assess the HS muscles' capacity to generate force acting horizontally in a place like a sprint period of stance. Figure 4 shows the simplified flowchart of the experimental protocol.

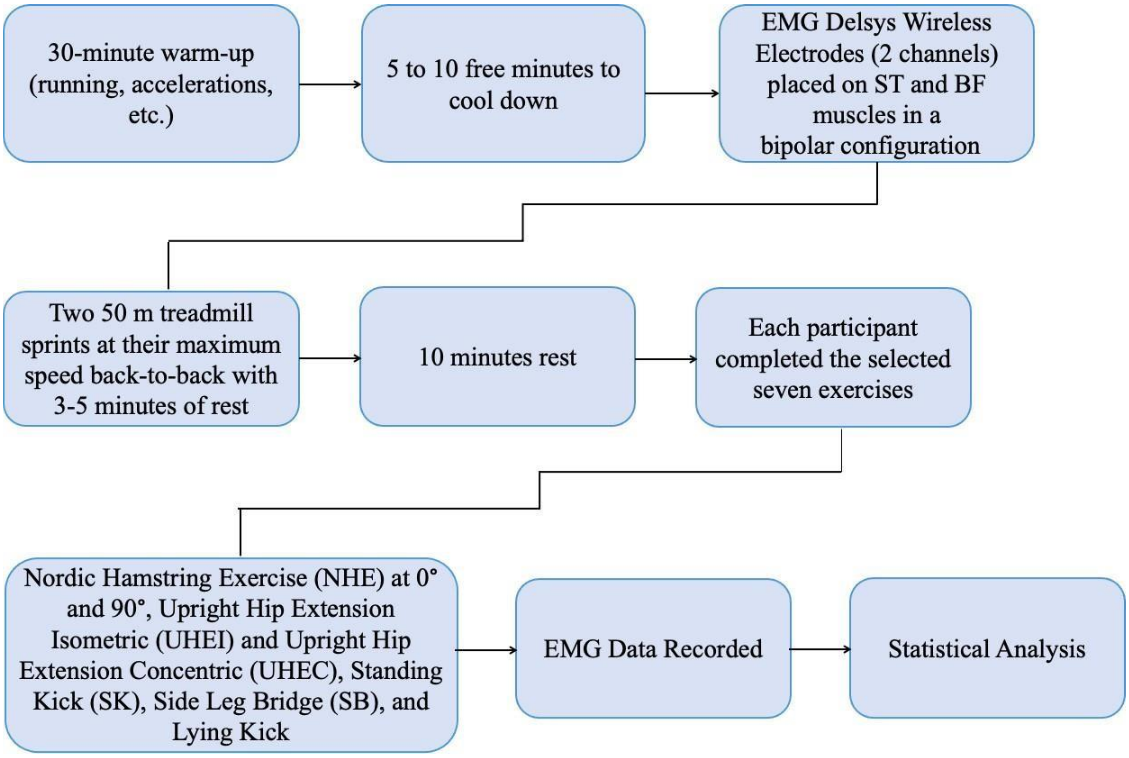


Figure 4: Flowchart of Experimental Protocol

SK was chosen to assess the indirect HS muscles' eccentric capacity at high velocity and late in the swing phase. SB and NHE were chosen because they can induce high levels of neuromuscular activity in the HS muscles and because they can assess the eccentric strength of the HS muscles at a slow speed. An explanation of each exercise is provided in detail in Figure 5, and participants were also given instructions. To prevent any bias due to weariness, participants completed the exercises three times at random following three training trials. Before the testing session, the participants underwent a 15-day training period. Figure 6 shows the overview of the proposed methodology.

	Sprint	Nordic 0°	Nordic 90°	Upright Hip Extension	Standing Kick	Slide Leg Bridge
	 **Electrodes Placement**  **Sprint**	 **Nordic 0°**	 **Nordic 90°**	 **Upright Hip Extension (Isometric)**  **Upright Hip Extension (Concentric)**	 **Standing Kick**	  **Slide Leg Bridge**
Hamstring Performance evaluation variables	Horizontal force production at low and high velocities	Hamstring muscle eccentric force production at low speed with higher or lower muscle lengths		Hamstring muscle concentric force production at low and high speed while standing straight	Indirect Hamstring muscle eccentric force production capability in the same lower limb configuration as for the end swing of the leg	Low maximal speed as an index of hamstring muscle eccentric force production capability
Placement	Athletes were asked to sprint at high and low speed for 10 seconds	Participant position – On knees with feet self-fixed while gradually falling forward in a slow manner with arms crossed and hips in a neutral position	Participant position – On knees with feet self-fixed while gradually falling forward in a slow manner with arms crossed and hips in a 90° position	Participation position – Standing on one foot with hands on his shoulder while doing hip extension at a fast speed while keeping the other leg straight	Participant position – Standing on non-dominant leg with hands on shoulder each at opposite side. Dominant leg is bent with the hip at 90° hip and knee flexion at a fast speed without losing balance	Subject is lying with his face facing upwards with one leg semi-bent with foot on ground. The other non-dominant leg is stretched in the air. Participant is asked to bring the semi-bent leg down slowly and gradually while stretching the knee.
Set Point	Run at low and fast speed as per the participants capacity at varying treadmill speed	"Fall forward gently by restraining your position with your thigh strength. When the tension becomes too much, you can let go and put your hands on the ground."		"Keep your non-dominant leg straight and your hands on your shoulder. Do a hip extension at a fast speed on your other leg without bending forward."	"Stay on one leg, maintain the balance and kick as fast as you can with the other leg"	"Keep one leg in the air and keep the dominant leg semi-bent on the ground. Maintain this position and bring the semi-bent leg down slowly until it becomes impossible to maintain the weight."
Parameters Measurement	Velocity	Break Angle		Maximum Velocity or Force	Maximum Velocity	
Tools utilized for evaluating	Treadmill	Video recording, 240 fps, kinematic analysis software			Linear encoder and LabVIEW program	

Figure 5: Details of placements, instructions, and measurements followed during the analysis protocol

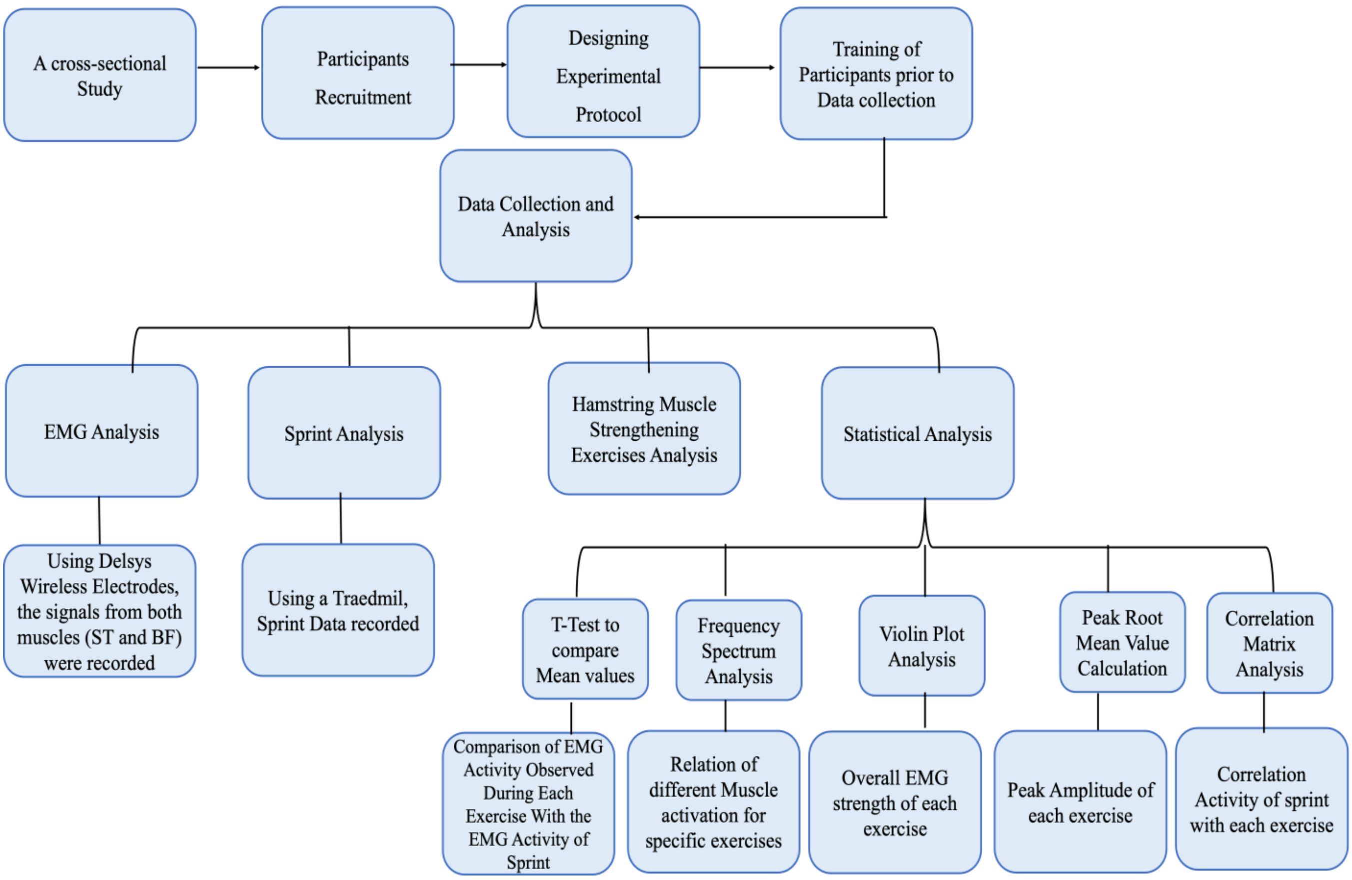


Figure 6: Summary of proposed work

3.4 The Gathering and Analysis of Data

3.4.1 EMG Analysis

Using Delsys Wireless Electrodes, the signals from both muscles (ST and BF) were recorded at 1946 Hz during the entirety of sprinting and exercising. Following that, the signals were corrected and smoothed using a 25-ms moving window before being passed through a low pass band filter with an 8 Hz cutoff frequency of the Butterworth type. Software called IBM SPSS Statistics 26.0 was used to examine the data. The smoothed, rectified, and the filtered signal was averaged over each burst. Over each burst, the signal was smoothed, corrected, and filtered. According to a recent analysis, EMG while sprinting is higher than it is during maximal voluntary contractions. Hence, we built a maximum value (100%) using higher EMG activity that was sustained across both sprints and then we assessed the muscle activity during various activities about that maximum value.

3.4.2 Sprint Analysis

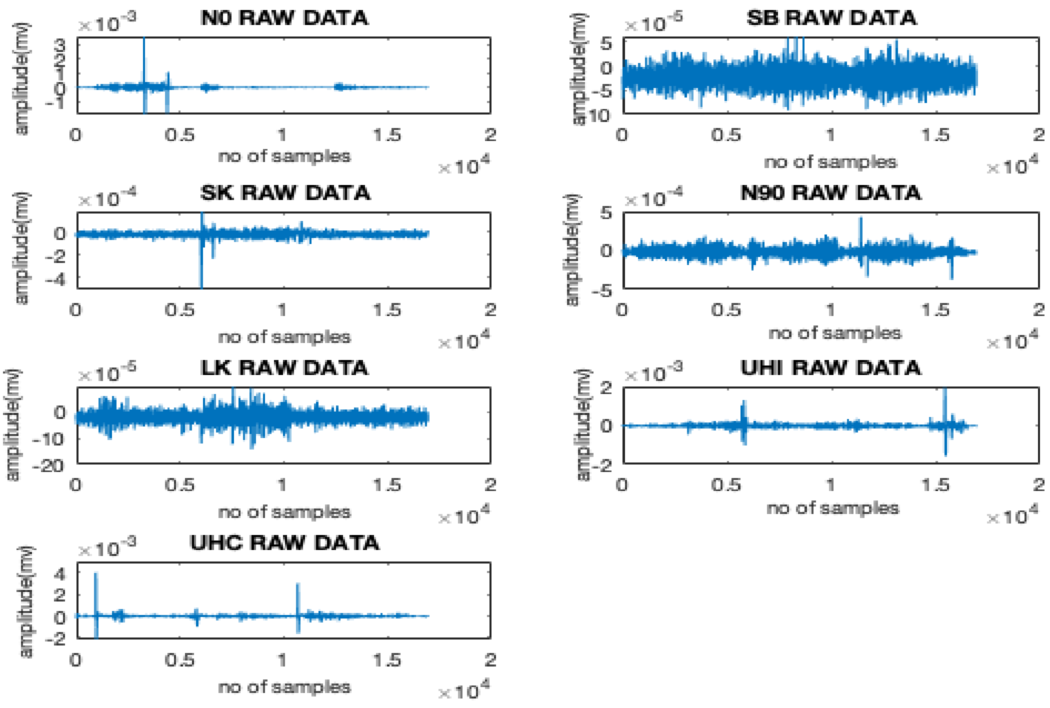
On a treadmill (Life Fitness) with a running surface measuring 152.4 cm in length and 50.8 cm in breadth, sprinting was practiced. The participants were instructed to sprint as hard as they could starting from a standing position and continuing until they had covered 60 meters. As it takes roughly 8 seconds to finish 60 meters, we captured the sprint data at 12 and 6 meters per second.

3.4.3. Hamstring Muscle Strengthening Exercise Analysis

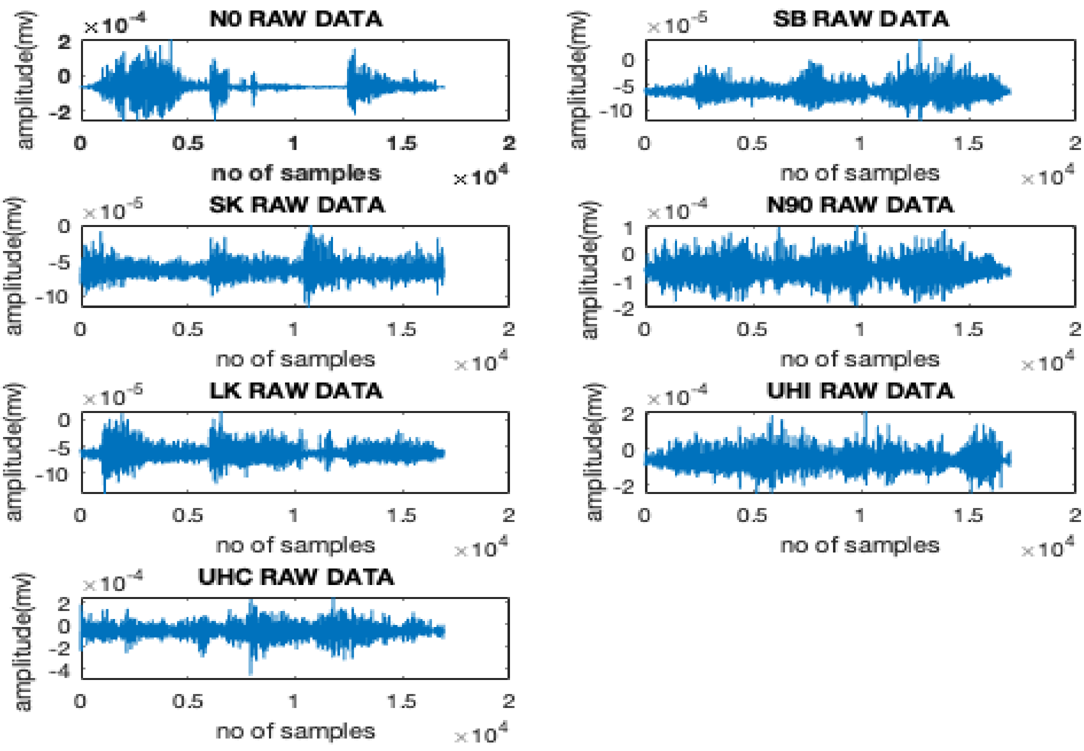
Figure 5 displays each exercise’s performance metrics, data gathering, and analysis.

3.4.4. Preprocessing of Data

Figure 7 shows the raw data for both muscles. We applied preprocessing techniques to filter out the noise in our EMG signals. Figure 8 shows the filtered data after preprocessing. Then the preprocessed filtered data was used to carry out the statistical analysis.

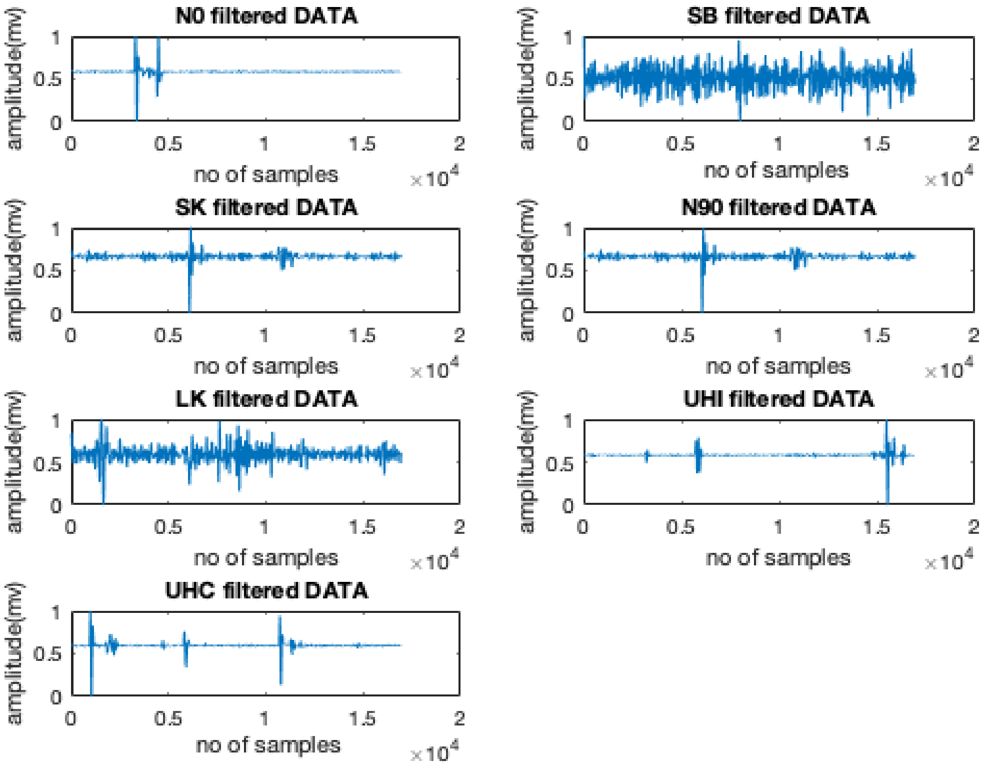


(a) Biceps femoris

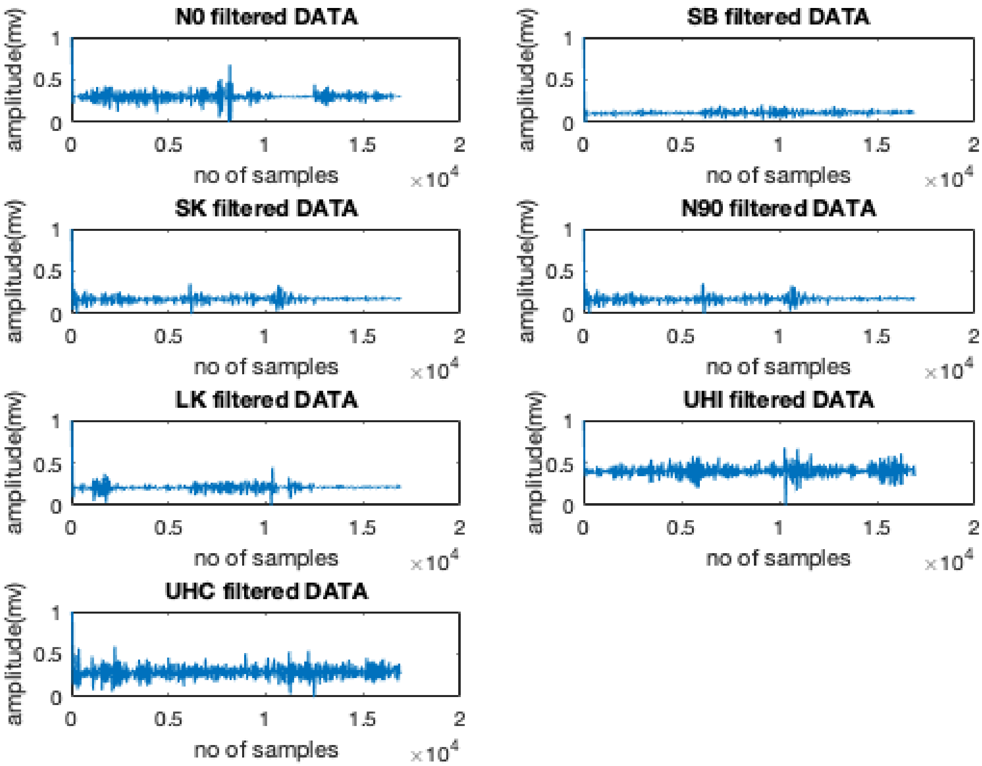


(b) semitendinosus

Figure 7: The raw data of Hamstring Muscles (a) biceps femoris and (b) semitendinosus



(a) Biceps femoris



(b) semitendinosus

Figure 8: Filtered data of Hamstring Muscles (a) biceps femoris and (b) semitendinosus

3.4.3 Statistical Analysis

The Shapiro-Wilk ordinariness test was utilized to guarantee that the information was appropriated typically. Factual Bundle for the Sociologies 26.0 (SPSS 26.0) was utilized to dissect the information that were accumulated for the review. Age was one of a few quantitative elements that were portrayed utilizing mean and standard deviation. We determined the intra-preliminary dependability of each mechanical variable from the test meeting utilizing the two maximal qualities. It was likewise processed to acquire the Intraclass Connection Coefficient (ICC). The Pearson's correlation tests (r) were used to investigate the connection between the horizontal force generation capacity (F0 and V0) during sprinting, as well as the performance of the HS muscles. Using confidence intervals (CI) of 95 percent, it was done. P 0.05 was picked as the limit for measurable importance. To analyze the EMG movement of the HS muscles at the hour of each activity to the pinnacle EMG action seen during the run (100 percent), we additionally utilized one-example Understudy t-tests

Chapter 4 Results

The statistical analysis of this study is presented in this part. This study included a total of 12 male and 8 Female healthy participants.

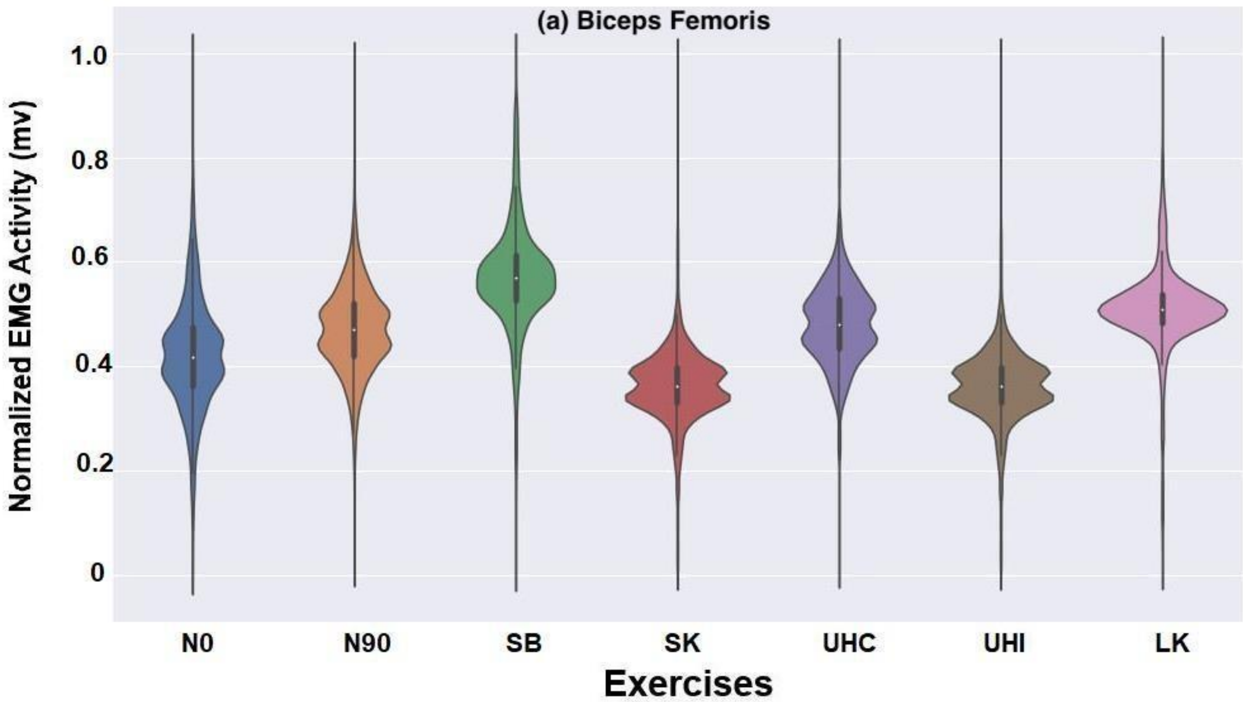
4.1. Comparing the EMG Activity of the HS Muscle

To compare the mean EMG readings of the HS muscles throughout each exercise to the sprint's 100% maximum EMG activity, we used a t-test. The results of one-sample Student t-tests are displayed in Table 1.

Table 1: Peak EMG Activity Normalized to Sprint (%)

	Biceps Femoris long head	**Semitendinosus**
sprint	100	100
NH 0	42.20 ± 10.8	46.70 ± 11.2
NH 90	47.13 ± 8.4	55 ± 8.9
UHI	36.50 ± 7.08	51.01± 12.4
UHC	48.17 ± 8.1	33.46 ± 7
SK	36.5 ± 7.0	46.67 ± 10.09
SB	34.28 ± 16.7	48.71 ± 10.9
LK	51 ± 8	40.6 ± 7.8

The results of the one-sample Student t-test show statistically significant differences ($p < 0.001$) between EMG activity during all exercises and the maximal EMG activity during the sprint (100%). The results are illustrated using violin plots as shown in Figure 9 a and b, for BF and ST respectively.



:

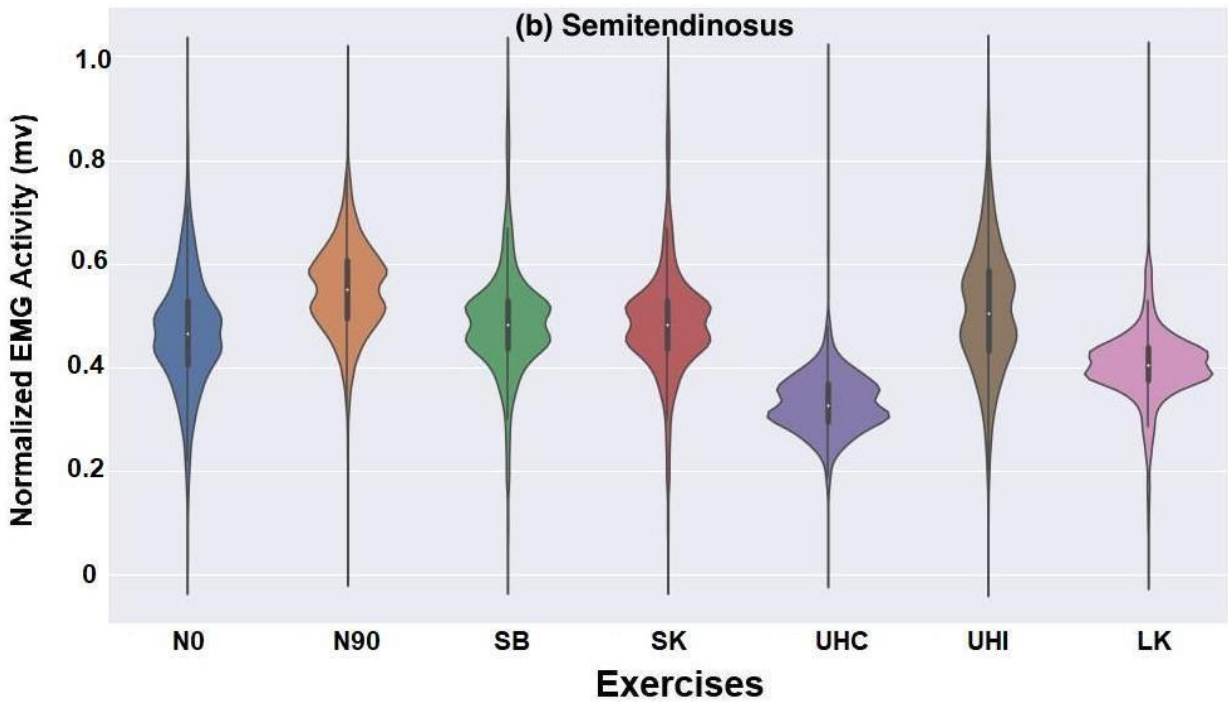


Figure 9: This figure shows (a) biceps femoris and (b) semitendinosus EMG activity for each exercise as a percentage of the sprint's peak activity (100%). a large deviation from 100% between this EMG activity ($p < 0.001$) was observed. Nordic Hamstring Exercise (NHE) at 0° and 90°, Side Leg Bridge (SB), Standing Kick(SK), Upright Hip Extension (UHE) Concentric and Isometric, and Lying Kick (LK)

4.2 Sprint EMG Correlation with each Exercise

We computed the correlation matrix of sprint EMG data with the EMG activity of all the selected exercises. The results are shown in Figure 10. The correlation matrix shows the correlation values, which express the linear strength of each pair of variable relationships. The correlation coefficients' values fall between -1 and +1. All the exercises showed a positive correlation with sprint. Maximum correlation (0.57) was observed between Nordic Hamstring Exercise at 0° (N0) and Sprinting whereas LK showed minimum correlation with sprinting (0.19).

Figure 10: The correlation matrix between the EMG activity during a sprint and each of the chosen exercises is displayed in this figure. The correlation coefficients for several variables are displayed here. The matrix shows how each conceivable pair of values in a table correlate with one another. Nordic Hamstring Exercise (NHE) at 0° and 90°, Side Leg Bridge (SB), Standing Kick (SK), Upright Hip Extension (UHE) Concentric and Isometric, and Lying Kick (LK).

4.3 Frequency Spectrum Analysis

The Frequency Spectrum analysis was performed on raw EMG signals from both muscles (ST and BF) for Upright Hip Extension (UHE) Concentric and Isometric Exercises collected with Delsys Wireless Electrodes using MATLAB Simulink R2022 software. Raw EMG signals from both muscles were filtered using Butterworth filter. The signals were then transformed into the frequency domain using Fourier transform. The graph in Figure 11 demonstrates that during these workouts. In the context of this study, analyzing the frequency spectrum can provide insights into the activation patterns of the hamstring muscles during different exercises. It helps determine which exercises elicit higher muscle activity on specific frequency ranges or bands compared to others. This information can be valuable in understanding the recruitment patterns of the hamstring muscles during different exercises and identifying exercises that target specific muscle fibers or motor units more effectively.

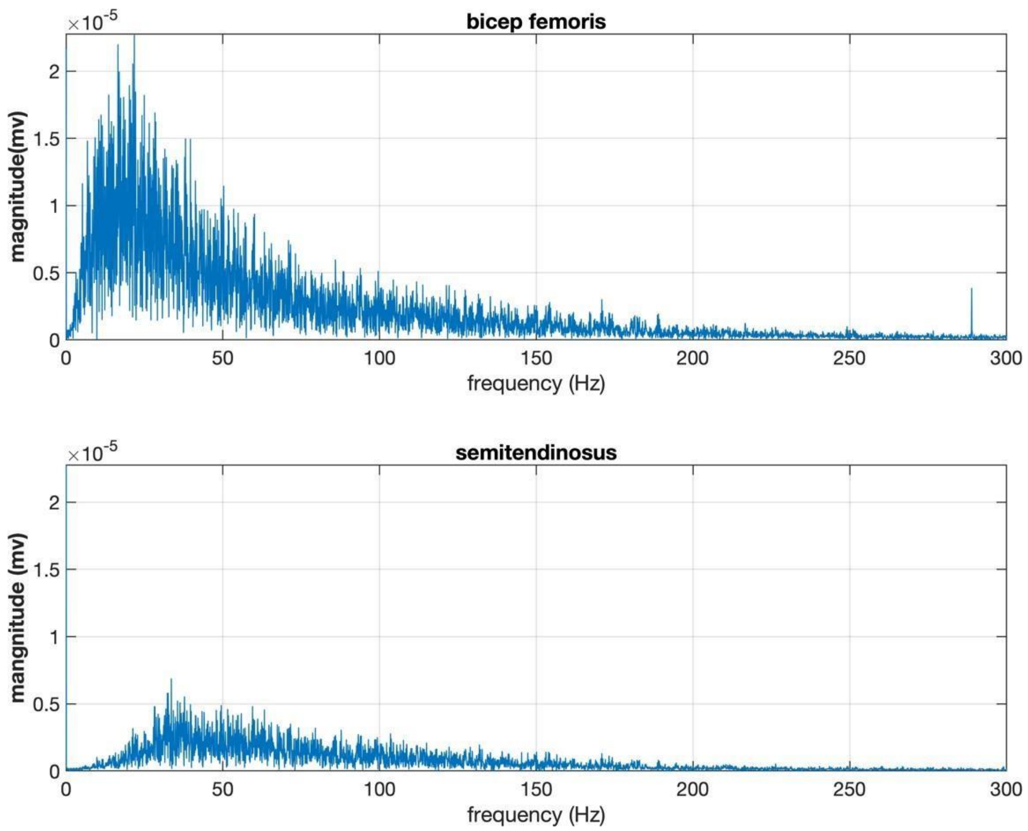


Figure 11: Frequency Spectrum Analysis of Hamstring Muscles BF and ST

In summary, the frequency spectrum analysis in MATLAB helps to reveal the distribution of energy across different frequencies in a signal, allowing researchers to understand the frequency characteristics and activation patterns of the hamstring muscles during various exercise.

4.4 Peak Root Mean Value Calculation

We calculated the Peak Root Mean Square (RMS) values of the sprint and selected exercises EMG activity. The results are shown in Figure 12. At one point SB generates greater EMG activity than sprinting in the ST muscle. Overall sprinting shows a higher EMG activity as compared to all other exercises.

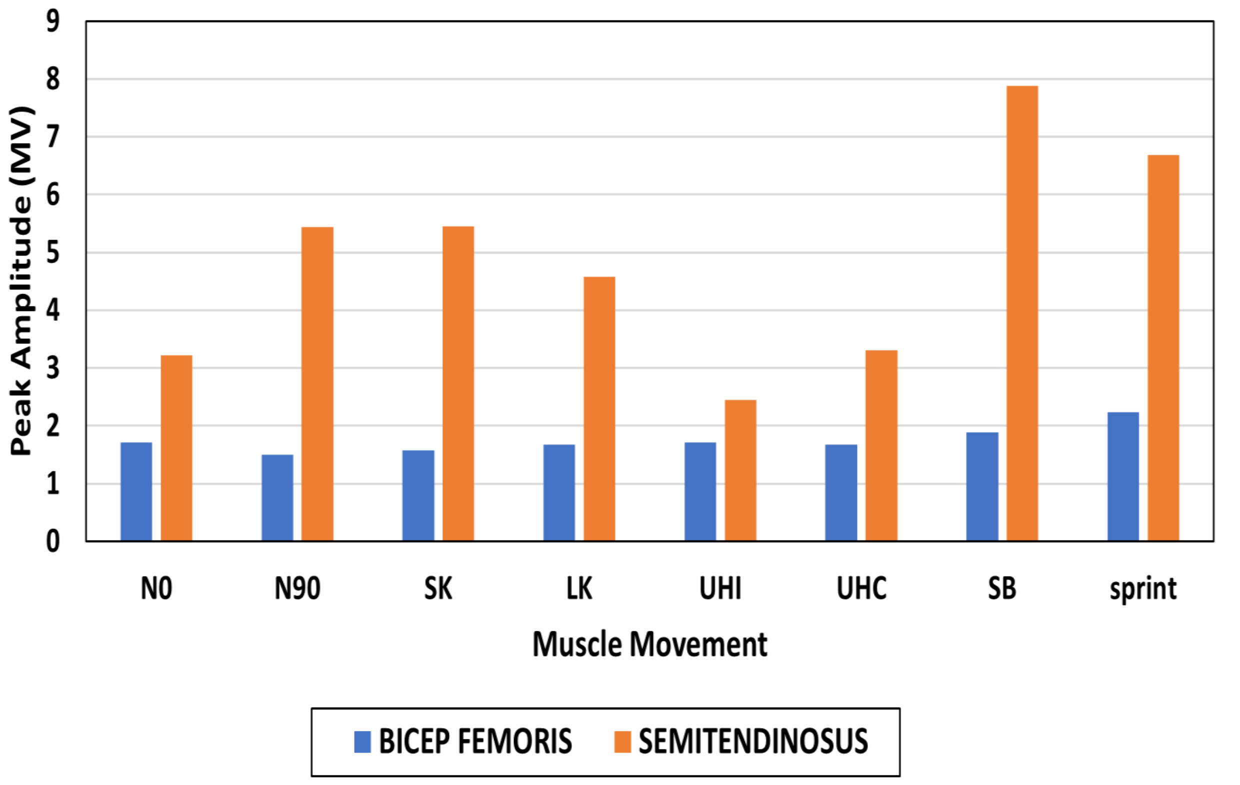


Figure 12: Peak Root Mean Square Values

Chapter 5 Discussion

The activation of the hamstring muscles after a variety of hamstring strengthening exercises and during a maximal sprint were compared in this study. The maximum EMG action during runs was utilized to communicate each activity for both HS muscles (BF and ST) as a probability of the maximum activation when running fast. In contrast with the hamstring-explicit activities, we found that maximal over-ground runs essentially expanded hamstring muscle actuation. That's what the essential discoveries were, contrasted with runs, which were respected to have 100 percent of maximal EMG action, the different hamstring activities' most extreme EMG ac-trinity went on normal between 41-57% for the biceps femoris and 40-55% for the semitendinosus as displayed in Table 1. The outcomes were statistically critical (p ¡ 0.001). For the biceps femoris or semitendinosus, neither of the workouts examined exceeded 57% of the maximum it could sustain during a sprint. These discoveries were reliable with those from concentrates on treadmill running by [8] and [33], who recorded their information utilizing the Radar Stalker ATS II framework. Consequently, our findings suggest that sprinting would be the most effective exercise for promoting muscle adaptation and activation of the hamstrings. As sprints entail quick hip and knee motions that heavily employ the hamstring, it was anticipated that hamstring activity during sprints would be the highest [8]. Table 2 and Table 3 shows the results. [33] performed sprinting at sprint- ing at low (F0) and high (V0) speeds but in our study, we observed that although EMG patterns appear to vary greatly among individuals, they are qualitatively constant between individuals at various running speeds. This indicates that slow running produces an activity pattern that is similar to high-speed. Further research should be carried out on how to train athletes after a HSI to prepare them for a high-speed running. Exercise SB for the BF muscle and Exercise NH90 for the ST muscle had the highest hamstring muscle activity. When we compared the EMG activity in NH90 Exercise, for BF (47%), and ST (55%) muscles with NH0, it was observed that EMG levels were lower in NH0 (42% for BF and 46% for ST muscles). These findings conflict with earlier research from [43] and [33] where NH0 showed a greater EMG activity than NH90. This finding can be used to create a combination of different HS strengthening exercises for a better treatment and rehabilitation plan. Our results showed that all seven exercises positively correlated with sprinting EMG activity. Sprinting and Nordic Hamstring Exercise at 0° (N0) had the highest association (0.57), whereas LK had the lowest correlation with sprinting (0.19). Future research might build on the findings of the current study to further our understanding of hamstring muscle activity and strengthening activities in several different areas. First, since there are numerous variations and changes that may be examined, future research could examine the EMG activity of other hamstring-strengthening activities. This would aid in determining the best hamstring activation and strengthening workouts. Second, studies might investigate how different hamstring- strengthening exercise volumes and intensities affect muscle strength and EMG activity. This would give more knowledge on how to create the best hamstring training regimens. Thirdly, studies might investigate the connection between ham- string muscle activity and specific performance metrics like sprint speed or jumping capacity. This would contribute to proving the significance of hamstring muscle strength in athletic performance and offer new infor- mation on how to work on and strengthen this muscle group. The effectiveness of includinghigh-EMG hamstring strengthening exercises in an injury prevention program for people at risk of hamstring

injuries, such as athletes or those with a history of hamstring strains, could also be studied in the future. This would aid in figuring out whether specific strengthening workouts can lower the risk of injury and enhance general function. A few restrictions must be considered while interpreting the ramifications of this work. Initially, the study only included healthy, injury-free participants. At the time of testing, none of the subjects were injured and hadn't suffered a hamstring injury in the previous six months. Although this study demonstrated that these exercises significantly stimulated HS muscles in a population of healthy individuals, it is unknown how this protocol will affect the injured individuals.

Table 2: Comparison with other studies

	Bicep femoris			**Semitendinosus**		
	Prince et al., 2021	**Van den Tillaar et al., 2017**	**Our Results**	**Prince et al., 2021**	**Van den Tillaar et al., 2017**	**Our Results**
Sprint	100	126 ± 28	100	100	120 ± 25	100
NH 0	46.1+_20.3	138 ± 24	42.20 ± 10.8	57.8 ± 18.3	135 ± 22	46.70 ± 11.2
NH 90	29.7+_9.4	41 ± 27	47.13 ± 8.4	40.8+_7.9	141 ± 26	55 ± 8.9
UHI	54+_27	-	36.50 ± 7.08	53.7+_20.7	-	51.01± 12.4
UHC	48.4+_22.9	-	48.17 ± 8.1	55.2+_22.3	-	33.46 ± 7
SK	27.4+_19.4	81 ± 30	36.5 ± 7.0	29.5+_16	80 ± 27	46.67 ± 10.09
SB	34.28+_16.7	-	34.28 ± 16.7	39.3+_13.4	-	48.71 ± 10.9
LK	-	134 ± 33	51 ± 8	-	132 ± 30	40.6 ± 7.8

Chapter 6 Conclusion

According to the current study's findings, compared to sprinting, SB and LK are the activities that most fully activate the BF muscles. The best outcomes for ST muscles were from NH90 and UHE-I. Coaches, athletic trainers, and physical therapists will be able to use the findings of this cross-sectional study to categorize various exercises according to how much of the hamstring muscles they activate, and they will be able to use this information to put into practice a progressive training approach that will increase hamstring strength and, consequently, athletic performance.

Chapter 7 References

[1] T. Kumazaki, Y. Ehara, and T. Sakai, “Anatomy and physiology of hamstring injury,” International journal of sports medicine, vol. 33, no. 12, pp. 950–954, 2012.

[2] H.J.Silvers-Granelli,M.Cohen,J.Espregueira-Mendes,andB.Mandelbaum,“Ham- string muscle injury in the athlete: state of the art,” Journal of ISAKOS, vol. 6, no. 3, pp. 170–181, 2021.

[3] P. Houglum, D. Bertoti, and S. Brunnstrom, “The movement system: Nerve and muscle physiology and the control of human movement,” Brunnstrom’s Clinical Kinesiology, 6e, 2012.

[4] T. Hogervorst and E. E. Vereecke, “Evolution of the human hip. part 2: muscling the double extension,” Journal of hip preservation surgery, vol. 2, no. 1, pp. 3–14, 2015.

[5] J. Afonso, S. Rocha-Rodrigues, F. M. Clemente, M. Aquino, P. T. Nikolaidis, H. Sar- mento, A. F´ılter, J. Olivares-Jabalera, and R. Ramirez-Campillo, “The hamstrings: anatomic and physiologic variations and their potential relationships with injury risk,” Frontiers in Physiology, vol. 12, 2021.

[6] K. B. Fields, O. J. Bloom, D. Priebe, and B. Foreman, “Basic biomechanics of the lower extremity,” Primary Care: Clinics in Office Practice, vol. 32, no. 1, pp. 245–251, 2005.

[7] J. Ekstrand, J. C. Healy, M. Walde´n, J. C. Lee, B. English, and M. Ha gglund, “Ham- string muscle injuries in professional football: the correlation of mri findings with re- turn to play,” British journal of sports medicine, vol. 46, no. 2, pp. 112–117, 2012.

[8] R.vandenTillaar,J.A.B.Solheim,andJ.Bencke,“Comparisonofhamstringmuscle activation during high-speed running and various hamstring strengthening exercises,” International journal of sports physical therapy, vol. 12, no. 5, p. 718, 2017.

[9] X.Wan,F.Qu,W.E.Garrett,H.Liu,andB.Yu,“Theeffectofhamstringflexibilityon peak hamstring muscle strain in sprinting,” Journal of sport and health science, vol. 6, no. 3, pp. 283–289, 2017.

[10] D.M.Medeiros,C.Marchiori,andB.M.Baroni,“Effectofnordichamstringexercise training on knee flexors eccentric strength and fascicle length: a systematic review and meta- analysis,” Journal of Sport Rehabilitation, vol. 30, no. 3, pp. 482–491, 2020.

[11] Ł.Oleksy,A.Mika,J.Pacana,O.Markowska,A.Stolarczyk,andR.Kielnar,“Whyis hamstring strain injury so common in sport despite numerous prevention methods? are there any missing pieces to this puzzle?,” Frontiers in Physiology, vol. 12, p. 586624, 2021.

[12] J. W. Orchard, A. Kountouris, and K. Sims, “Risk factors for hamstring injuries in australian male professional cricket players,” Journal of sport and health science, vol. 6, no. 3, pp. 271–274, 2017.

[13] H. Liu, W. E. Garrett, C. T. Moorman, and B. Yu, “Injury rate, mechanism, and risk factors of hamstring strain injuries in sports: A review of the literature,” Journal of sport and health science, vol. 1, no. 2, pp. 92–101, 2012.

[14] H. S. Al Mansoof, M. A. Almusallam, S. Nuhmani, et al., “Mechanism of hamstring strain injuries in sports: A narrative review,” Saudi Journal of Sports Medicine, vol. 21, no. 2, p. 39, 2021.

[15] A. J. Oakley, J. Jennings, and C. J. Bishop, “Holistic hamstring health: not just the nordic hamstring exercise,” 2018.

[16] G. Koulouris and D. Connell, “Hamstring muscle complex: an imaging review,” Radiographics, vol. 25, no. 3, pp. 571–586, 2005.

[17] G.M.Kerkhoffs,N.vanEs,T.Wieldraaijer,I.N.Sierevelt,J.Ekstrand,andC.N.van Dijk, “Diagnosis and prognosis of acute hamstring injuries in athletes,” Knee Surgery, Sports Traumatology, Arthroscopy, vol. 21, no. 2, pp. 500–509, 2013.

[18] R.M.Howard,R.Conway,andA.J.Harrison,“Muscleactivityinsprinting:areview,” Sports Biomechanics, vol. 17, no. 1, pp. 1–17, 2018.

[19] Y.Sugiura,Y.Takazawa,K.Yamazaki,andK.Sakuma,“Strategicpreventionprogram of hamstring injuries in sprinters,” 2022.

[20] Y. Sugiura, K. Sakuma, S. Fujita, K. Aoki, and Y. Takazawa, “Effects of various numbers of runs on the success of hamstring injury prevention program in sprinters,” International Journal of Environmental Research and Public Health, vol. 19, no. 15, p. 9375, 2022.

[21] T. O. Clanton and K. J. Coupe, “Hamstring strains in athletes: diagnosis and treatment,” JAAOS-Journal of the American Academy of Orthopaedic Surgeons, vol. 6, no. 4, pp. 237–248, 1998.

[22] J. Orchard, “Biomechanics of muscle strain injury,” NZJ Sports Med, vol. 30, pp. 92–98, 2002.

[23] A. Danielsson, A. Horvath, C. Senorski, E. Alentorn-Geli, W. E. Garrett, R. Cugat, K. Samuelsson, and E. Hamrin Senorski, “The mechanism of hamstring injuries–a systematic review,” BMC musculoskeletal disorders, vol. 21, no. 1, pp. 1–21, 2020.

[24] E. S. Chumanov, B. C. Heiderscheit, and D. G. Thelen, “Hamstring musculotendon dynamics during stance and swing phases of high speed running,” Medicine and science in sports and exercise, vol. 43, no. 3, p. 525, 2011.

[25] Y.Sugiura,K.Sakuma,S.Fujita,andK.Sakuraba,“Hamstringinjurypreventionpro- gram and recommendation for stride frequency during tow-training optimization,” Ap- plied Sciences, vol. 11, no. 14, p. 6500, 2021.

[26] X.Wan,S.Li,T.M.Best,H.Liu,H.Li,andB.Yu,“Effectsofflexibilityandstrength training on peak hamstring musculotendinous strains during sprinting,” Journal of sport and health science, vol. 10, no. 2, pp. 222–229, 2021.

[27] R. N. Kalema, A. G. Schache, M. D. Williams, B. Heiderscheit, G. Siqueira Trajano, and A. J. Shield, “Sprinting biomechanics and hamstring injuries: Is there a link? a literature review,” Sports, vol. 9, no. 10, p. 141, 2021.

[28] T.Foreman,T.Addy,S.Baker,J.Burns,N.Hill,andT.Madden,“Prospectivestudies into the causation of hamstring injuries in sport: a systematic review,” Physical Therapy in Sport, vol. 7, no. 2, pp. 101–109, 2006.

[29] L. N. Erickson and M. A. Sherry, “Rehabilitation and return to sport after hamstring strain injury,” Journal of sport and health science, vol. 6, no. 3, pp. 262–270, 2017.

[30] B. Yu, R. M. Queen, A. N. Abbey, Y. Liu, C. T. Moorman, and W. E. Garrett, “Hamstring muscle kinematics and activation during overground sprinting,” Journal of biomechanics, vol. 41, no. 15, pp. 3121–3126, 2008.

[31] B. Yu, H. Liu, and W. E. Garrett, “Mechanism of hamstring muscle strain injury in sprinting,” Journal of sport and health science, vol. 6, no. 2, p. 130, 2017.

[32] C. S. Ahmad, L. H. Redler, M. G. Ciccotti, N. Maffulli, U. G. Longo, and J. Bradley, “Evaluation and management of hamstring injuries,” The American journal of sports medicine, vol. 41, no. 12, pp. 2933–2947, 2013.

[33] C.Prince,J.-B.Morin,J.Mendiguchia,J.Lahti,K.Guex,P.Edouard,andP.Samozino, “Sprint specificity of isolated hamstring-strengthening exercises in terms of muscle activity and force production,” Frontiers in sports and active living, vol. 2, p. 211, 2021.

[34] J.-B. Morin, P. Gimenez, P. Edouard, P. Arnal, P. Jime´nez-Reyes, P. Samozino, M. Brughelli, and J. Mendiguchia, “Sprint acceleration mechanics: the major role of hamstrings in horizontal force production,” Frontiers in physiology, vol. 6, p. 404, 2015.

[35] J.Ekstrand,M.Walde´n,andM.Ha gglund,“Hamstringinjurieshaveincreasedby4% annually in men’s professional football, since 2001: a 13-year longitudinal analysis of the uefa

elite club injury study," British journal of sports medicine, vol. 50, no. 12, pp. 731–737, 2016.

[36] A.WarisandE.N.Kamavuako,"Effectofthresholdvaluesonthecombinationofemg time domain features: Surface versus intramuscular emg," Biomedical Signal Process- ing and Control, vol. 45, pp. 267–273, 2018.

[37] L. Suarez-Arrones, P. Lara-Lopez, P. Rodriguez-Sanchez, J. L. Lazaro-Ramirez, V. Di Salvo, M. Guitart, C. Fuentes-Nieto, G. Rodas, and A. Mendez-Villanueva, "Dis- sociation between changes in sprinting performance and nordic hamstring strength in professional male football players," PLoS One, vol. 14, no. 3, p. e0213375, 2019.

[38] B.Drury,T.Green,R.Ramirez-Campillo,andJ.Moran,"Influenceofmaturationsta- tus on eccentric hamstring strength improvements in youth male soccer players after the nordic hamstring exercise," International Journal of Sports Physiology and Perfor- mance, vol. 15, no. 7, pp. 990–996, 2020.

[39] J. Mendiguchia, M. A. Garrues, J. B. Cronin, B. Contreras, A. Los Arcos, N. Malliaropoulos, N. Maffulli, and F. Idoate, "Nonuniform changes in mri measure- ments of the thigh muscles after two hamstring strengthening exercises," The Journal of Strength & Conditioning Research, vol. 27, no. 3, pp. 574–581, 2013.

[40] M.N.Bourne,M.D.Williams,D.A.Opar,A.AlNajjar,G.K.Kerr,andA.J.Shield, "Impact of exercise selection on hamstring muscle activation," British journal of sports medicine, vol. 51, no. 13, pp. 1021–1028, 2017.

[41] J.Morin,P.Samozino,R.Bonnefoy,P.Edouard,andA.Belli,"Directmeasurementof power during one single sprint on treadmill," Journal of biomechanics, vol. 43, no. 10, pp. 1970–1975, 2010.

[42] H.J.Hermens,B.Freriks,C.Disselhorst-Klug,andG.Rau,"Developmentofrecom- mendations for semg sensors and sensor placement procedures," Journal of electromyo- graphy and Kinesiology, vol. 10, no. 5, pp. 361–374, 2000.

[43] A. Hegyi, D. Csala, A. Pe ́t er, T. Finni, and N. J. Cronin, "High-density electromyo- graphy activity in various hamstring exercises," Scandinavian journal of medicine & science in sports, vol. 29, no. 1, pp. 34–43, 2019.

[43] A. Hegyi, D. Csala, A. Pe ́t er, T. Finni, and N. J. Cronin, "High-density electromyo- graphy activity in various hamstring exercises," Scandinavian journal of medicine & science in sports, vol. 29, no. 1, pp. 34–43, 2019.