PJAHS
Philippine Journal of Allied Health Sciences

Original Article

Evaluating the Feasibility of a Motion Capture And SEMG Protocol for High-Speed Running Analysis

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Article Received: October 26, 2025

Article Accepted: April 16, 2025

Article Published: August 15, 2025

Abstract

Background: Feasibility studies are a necessary first step in assessing the practicality of methods and procedures used in a more extensive study. Others emphasize that feasibility studies aim to test the practical aspects of a future study and use the results to inform modifications that can enhance the study design and increase the chances of success in the more extensive study. Before conducting the main study, we rigorously refined data collection procedures based on the best available evidence, informed by the scoping review, expert consultation, and pilot testing. **Objectives**: To evaluate the feasibility and practicality of the proposed research methodology and to identify and address potential challenges associated with data collection. The specific objective is to determine the intra-rater reliability in determining MVIC, which is part of the procedure in the sEMG protocol. **Methods:** This study is composed of two phases: (Phase 1) a pragmatic pilot study using an experienced biomechanist to refine the protocol. Thorough preparation, including a dry run and expert review, preceded the pilot study. (Phase 2) a preliminary testing phase to evaluate the protocol and to assess the intra-rater reliability of the MVIC used in the sEMG protocol. A high speed treadmill, Nexus software, Vicon and Delsys sEMG systems were used to capture kinematic and muscle activity data during high-speed running, enabling a comprehensive biomechanical analysis. **Results:** The final protocol underwent a feasibility and acceptability assessment based on five pre-defined metrics: recruitment efficacy, optimization of data acquisition methodologies, data integrity and completeness, procedural tolerability, and resource allocation efficiency. Pilot testing anomalies and their respective corrective actions were systematically documented. Furthermore, the intra-rater reliability of the maximum voluntary isometric contraction (MVIC) measurement exhibited a range from moderate to excellent, as determined by statistical analysis. **Conclusion:** This study successfully demonstrated the feasibility and practicality of our research methods. We evaluated all identified parameters and completed the assessments on schedule. The feasibility study proved valuable in identifying and addressing challenges encountered during data collection, such as equipment malfunctions and logistical hurdles. The study also demonstrated a moderate to excellent intra-rater reliability of MVIC assessment.

***Key Words**: Feasibility Study; Recurrent Hamstring Strain Injury; Vicon Motion Capture; Delsys sEMG Trigno*

INTRODUCTION

Running-related athletes are highly susceptible to hamstring strain injuries (HSIs), which affect these sports more than any other injury type [1,2]. In football, HSIs account for 24% of all injuries [3], followed by 17% in track and field [4] and 22% in rugby union [5]. Most HSIs in athletes resolve within one to four weeks, leading to missed practice time. A significant 15-37% are more severe, demanding extended recovery periods and impacting participation significantly [6–8]. It is a costly burden in elite sports, causing athletes to miss training and competitions [9]. HSIs are also concerned not only for their initial impact but also for their high risk of re-injury [10], with rates ranging from 12% to a dramatic 63% [11–13]. Athletes recovering from HSI face a one-in-three chance of re-injury within a year, and these

repeat injuries often bring worse consequences than the first [11–14].

Many factors influencing recurrent HSIs are likely present even during the initial injury. The injury itself can also trigger additional factors that make HSIs chronic. These factors might involve changes in muscle tissue and how athletes move during their sport [15]. While putative risk factors for HSI are known, the role of biomechanics in both causing the injury initially and causing complications afterward is often understudied. A scoping review systematically analyzed selected articles about recurrent HSIs, identifying and summarizing the biomechanical variables most frequently investigated within the included literature [16]. This scoping review identified commonly assessed biomechanical variables and testing protocols for recurrent HSI in running athletes. However, the scarcity of research in this area, as determined by the review, necessitates further investigation into various kinematic, kinetic, and spatiotemporal variables to gain a more comprehensive understanding. Studies typically examine few parameters and offer limited insight into how these parameters change post-injury and contribute to recurrent issues [16]. Our planned cross-sectional study will assess kinematic parameters, including joint angles of the hip, knee, and ankle in three planes of movement, as well as spatiotemporal parameters such as step length, stride length, stance time, flight time, and velocity.

Additionally, the study will evaluate muscle activity of the lower extremity, including the gluteus maximus (GMax), gluteus medius (GMeds), biceps femoris (BF), semitendinosus (ST), gastrocnemius (Gas), rectus femoris (RF), vastus lateralis (VL), and tibialis anterior (TA). This study expands the scope of investigated biomechanical variables potentially associated with recurrent HSIs compared to previous research. Before the study, researchers developed a protocol based on the best available evidence, informed by the scoping review, expert consultation, and feasibility testing. We conducted a feasibility study to ensure our assessment protocol's efficacy.

The potential impact of the study's findings on rehabilitation protocols and injury prevention strategies for athletes was explored in the main study. By focusing on the clinical implications of the research, the results are intended to provide valuable insights for practitioners and athletes alike.

The research questions of these study are two-fold and are as follows: 1)What is the feasibility and practicality of the proposed research methodology in assessing the biomechanical parameters using VICON motion capture system and muscle activity of the lower extremity using Delsys surface EMG in participants with recurrent hamstrings injury? And 2)What are the potential challenges that will be identified in the proposed research methods and possible solution to these challenges?

This study was designed to fulfill two primary objectives: (a) to evaluate the feasibility and practicality of the proposed research methodology and (b) to identify and address potential challenges associated with data collection. The specific objective is to determine the intra-rater reliability in determining MVIC, which is part of the procedure in the sEMG protocol.

METHODS

Ethics approval was obtained from the Faculty of Pharmacy's Ethics Board of the University of Santo Tomas.

Type of Study. Feasibility study

Setting. Human Performance Laboratory, Roque Ruano Building, University of Santo Tomas

This study is composed of two phases: (a) a pragmatic pilot study using an experienced biomechanist to refine the protocol and (b) a preliminary testing phase to evaluate the protocol and to assess the intra-rater reliability of the MVIC used in the sEMG protocol.

Phase 1: Pilot and Protocol Refinement

The development of the original protocol was informed by a scoping review conducted by the research team [16] and aligned with established standards for motion capture and sEMG systems, ensuring a robust evidence-based approach. The scoping review synthesized the available evidence regarding the types of machines

employed, participant preparation protocols, electrode replacement procedures, running protocols utilized in data acquisition, outcome measures, and data processing techniques.

Equipment. We employed a dual-system approach to comprehensively understand lower extremity biomechanics during high-speed running. The Vicon Motion Capture System recorded kinematic parameters such as joint angles and spatiotemporal data, while the Delsys Trigno sEMG System simultaneously measured muscle activity. This combined approach allowed for a detailed analysis of the relationship between joint movements and muscle activation patterns during high-speed running [17]

Vicon Motion Capture Analysis: Participant Preparation. All participants wore compression shorts to ensure consistent clothing conditions and minimize movement artifacts. Female participants additionally wore one-piece bathing suits. Vicon markers were placed using the Plug-in Gait (PiG) model set within the Nexus software. These markers were secured to the body using double-sided tape to guarantee stability throughout the motion capture session.

Anthropometric Measurements: The NEXUS software required a comprehensive set of anthropometric measurements to establish accurate data capture during the motion capture process. These included height, body mass, leg lengths, shoulder offset, elbow width, wrist width, hand thickness, knee width, and ankle width (see Table 1 in the supplementary section). These measurements were crucial for tailoring the software's parameters to the individual participant's body dimensions, thereby enhancing the reliability and precision of the collected motion data.

Placement of Markers: Researchers placed markers on the participants according to the PiG model from Nexus software. This model is a widely used commercial tool for biomechanical analysis. PiG calculates joint kinematics using data captured with the Newington-Helen Hayes marker set. This standardized system places markers on specific anatomical landmarks during motion analysis, as described by Wright et al.[18]. This optimized marker set, adapted from the NEXUS plug-in gait reference guide [19], provides consistent data collection and improves the reliability of biomechanical analysis. In the supplementary section, image 1 and Table 2 list the marker placement locations using the PiG model.

Treadmill High-Speed Running Protocol: Warm-up and stretching procedures were implemented before assessing maximum running speed. This assessment for maximum running speed involved a 20-meter sprint test. The test layout included timing lights at the starting (0-meter) and finishing (20-meter) lines. Athletes began in a stationary, upright position with their leading foot on the starting line and their body aligned with the starting gate. Participants were instructed to give their all during the test to encourage maximum effort and potentially improve performance, as suggested by Tanner and Gore[20]. Three trials of the sprint test were conducted, and the average time across these trials was calculated. Finally, the maximum speed was determined by dividing the covered distance (20 meters) by the average time. The calculated top speed was converted from meters per second to kilometers per hour [21].

Before the main high-speed running session, participants completed a standardized 10-minute jogging routine on a high-speed treadmill. They wore the same passive motion capture markers during this jog, ensuring a seamless transition into the testing phase. The initial jogging speed was calculated based on each participant's established maximum speed from previous testing to personalize the warm-up intensity. This starting speed was set at 35% of the participant's maximum speed, followed by incremental increases of 0.5 kilometers per hour (kph) until reaching 50% of their maximum speed. Following this warm-up phase, the subject will be given 5 minutes of dedicated stretching to prepare their muscles for the upcoming tests.

Following a 10-minute warm-up, the participant completed the first trial, running at 80% of their maximum effort for 60 seconds. A 5-minute rest period was provided before proceeding to the subsequent trial. The participant then ran at 90% and 100% of their maximum speed. These running speeds were chosen based on the study of Thelen et al.[22]. After each trial, data quality was verified for both motion capture and sEMG recordings. Data for all body segments and

muscle activity was completed throughout the trials.

Kinematic Data Acquisition: The Nexus software was used to reconstruct three-dimensional joint angles of the hip, knee, and ankle in the three planes of movement during the running gait cycle's late swing and early stance phases. Additionally, spatiotemporal parameters were collected, including stride length, step length, flight time, and stance time (see Table 1 in the supplementary section). The data captured was processed using MATLAB.

Data Extraction: For data cleaning, occluded markers were filled using the Nexus software's gap-filling function. Subsequently, the running cycle phases were marked using the same software. The cleaned data was then processed using MATLAB to extract essential information and synchronize it with sEMG data. Data to be extracted includes hip, knee, and ankle joint angles in the sagittal, frontal, and transverse planes, as well as step length, stride length, stance time, and flight time. These parameters were selected based on the findings of the scoping review conducted by Espino et al. (2024)[16].

Surface Electromyography Analysis.
Participant Preparation. For optimal sEMG signal capture, participants' skin was prepared by shaving and lightly abrading areas where the electrodes were placed.

Placement of Electrodes. Muscle activities of the lower limb were recorded using surface electromyography (Delsys sEMG Trigno system) placed on eight key muscles: Biceps femoris (BF), Semitendinosus (ST), vastus lateralis (VL), Rectus Femoris (RF), Gastrocnemius (Gastrocs), Gluteus Medius (GMeds), and Gluteus Maximus (GMax). These muscles were tested based on the study of Silder et al. (2010) [24]. For accurate sensor placement and optimal data collection, we followed the established SENIAM technique [24]. The specific placement details for each muscle group are outlined in Table 3 and illustrated in Image 2 (see Table 3 and Image 2 in the supplementary section).

Static Maximum Voluntary Isometric Contraction. To further enhance data reliability, researchers used EMG normalization. This reduces variations within and between individuals across different studies [25,26]. The most common method, maximal voluntary isometric contraction (MVIC) (see Table 1 in the supplementary section), involves participants exerting maximum force against an immovable object [27–29].

A standardized MVIC protocol elicited maximal effort and minimized fatigue [27–29]. Each muscle group underwent three trials of 6-second isometric contractions with 1-minute rest periods. During each trial, examiners provided real-time verbal encouragement and visual feedback on the participant's force output, facilitating optimal engagement and accurate data collection. The detailed descriptions of the optimal anatomical positioning adopted for MVIC evaluation of various muscle groups can be seen in Table 4 (see Table 4 in the supplementary section). This adheres to established best practices and international standards for accurate and reproducible assessment of maximal voluntary force production [30].

Muscle Activity Measurement: BF, ST, VL, RF, Gastrocs, GMeds, and GMax were assessed. Peak muscle activation patterns of each muscle were quantified during the late swing and early stance phases of the running gait cycle. EMG signals were captured using Nexus software, processed using EMG works, and exported for data synchronization in MATLAB.

Data extraction: During various running speeds, the EMG activity of relevant muscles was measured and recorded in millivolts. The acquired EMG data was processed using the EMG works software and then imported and analyzed using MATLAB for synchronization with Vicon data.

The research protocol was submitted for review to an expert in biomechanics from Niigata University of Health and Welfare in Japan. His research specializes in motion analysis, focusing on athletes and the general population.

An initial project meeting was conducted in December 2022 via a Zoom video conference. During this meeting, the research team reviewed the draft data collection protocol. Valuable feedback was provided, leading to several suggestions for improving the efficiency of data

collection procedures. Several revisions were incorporated into the protocol. The Vicon marker placement was adjusted from the Oxford foot model to the Plug-in Gait model due to the Oxford foot model's unavailability in the Nexus software package.

Additionally, the number of trials for the main running protocol was reduced to minimize fatigue. Based on expert advice, at least 20-50 strides were necessary for reliable sEMG and Vicon motion capture data. Increasing the number of trials beyond this range could potentially compromise data quality. Complete details of the initial and revised data collection protocol can be seen in Table 5 below.

Phase 2: Training of the Protocol, Feasibility Study Proper, and Intra-rater reliability of MVIC

The biomechanics expert arrived in Manila, Philippines, in September 2023 to facilitate protocol training and pilot testing. Before commencing the pilot study, a thorough dry run of each phase was conducted to identify potential operational challenges and develop corresponding contingency plans after a detailed discussion of the research team with the biomechanics expert. The pilot study was formally initiated upon finalization of the refined protocol and contingency measures.

Data gathering for the participants was completed in one day. Data was collected at the Human Performance Laboratory at the Roque Ruano Bldg., University of Santo Tomas, Manila, Philippines. A physician conducted the initial screening. This screening comprised a comprehensive history taking, focusing on the participant's past injuries and athletic participation duration. A licensed physical therapist performed a physical examination. The developed protocol was tested.

Intra-rater reliability of the MVIC acquisition. Intra-rater reliability was conducted for the MVIC assessment since only the primary author tested the MVIC of the participants during data gathering. The muscles tested included GMax, GMeds, BF, ST, RF, VL, TA, and Gastrocs. Five participants were recruited to participate in the testing.

Methods. Before each trial, the assessor positioned the limb for testing and guided the participant in performing a submaximal contraction at approximately 50% of their maximum effort. This warm-up correctly understood the isometric contraction and adequate joint stabilization. During the MVIC trials, participants were instructed to exert maximum effort while pushing or pulling against the assessor's hand. Visual feedback was provided using the Delsys sEMG software to maximize performance and ensure maximal contraction, which was projected onto an LCD monitor. Standardized verbal encouragement, such as "Go, push/pull harder, as hard as you can," was provided throughout the six-second contraction period, gradually escalating in intensity and tone. Three trials were performed for each muscle group. Each trial was followed by a one-minute rest period.

Statistical Analysis. All data were encoded in an Excel worksheet. The average of the three force values collected from each side was calculated for each participant and muscle group. Means, standard deviation, and 95% confidence interval were used for descriptive data and MVIC results. To analyze intra-rater reliability, a two-way mixed effects agreement intraclass correlation model with a 95% confidence interval was utilized. Intra-rater reliability was classified as poor, moderate, and excellent if the ICC was <0.40, 0.40-0.75, and > 0.75, respectively. SPSS version 25 was used to analyze the data [31].

RESULTS

Convenience sampling was employed in this study. Two male collegiate athletes (Age: 21.5 $\pm$ 0.71, Ht: 172.2 cm $\pm$ 13.72; Wt: 73.7 kg $\pm$ 13.01) volunteered to participate in this pilot study. The inclusion and exclusion criteria for participants are presented in Table 6. One participant was a collegiate football player with a history of recurrent HSI, while the other was a collegiate basketball player with no prior history of HSI. All participants were informed about the study protocol before their inclusion, ensuring they fully understood the nature of the research, its risks, and potential benefits. Additionally, informed consent documentation provided the right to withdraw from the study at any point

Table 5. Initial and Revised Data Collection Protocol

Initial Protocol	Problems that might be Encountered	Revised	Reason For Revising The Protocol	Final Protocol
Vicon Marker Placement				
Oxford foot model lower body AI for gait analysis. Adapted from "Repeatability of a model for measuring multi-segment foot" by [6], Science Direct. Copyright 2005 Elsevier	The Nexus software does not include the Oxford foot model for gait analysis.	Vicon Plug-In Gait (PiG) model (Nexus, 2021)	The absence of the Oxford foot model in the Nexus software package makes it challenging to accurately label markers and reconstruct the model for analysis. In addition, the Oxford foot model is primarily used to identify foot deformities.	Vicon Plug-In Gait (PiG) model (Nexus, 2021)
sEMG Electrode Placement				
SENIAM Electrode Placement (Merletti et al., 2011)	None	SENIAM Electrode Placement (Merletti et al., 2011)	No Change	SENIAM Electrode Placement (Merletti et al., 2011)
Normalization of sEMG Data				
Static Maximum Voluntary Isometric Contraction [7]	None	Static Maximum Voluntary Isometric Contraction [7]	No Change	Static Maximum Voluntary Isometric Contraction [7]
Main Running Protocol				
80%, 85%, 90%, 95% and 100% of maximum running speed [adapted directly from the study of [8,9]	Thelen et al. (2005) and Silder et al. (2010) did not specify the number of strides analyzed per trial as well as the complete details of the protocol.	80%, 90%, and 100% of maximum running speed captured for a duration of 45 seconds to 1 minute or at least 50 strides [based on the scoping review (Espino, et al., 2024)]	To minimize fatigue, we reduced the number of trials in the running assessment. In addition, based on team discussions and expert consultation, we determined that at least 20-50 strides are necessary, as recommended by our biomechanics expert/consultant from Niigata University in Japan, for reliable sEMG and Vicon motion capture data, therefore doing more trials can lead to lesser quality data.	80%, 90%, and 100% of maximum running speed captured for a duration of 45 seconds to 1 minute or at least 50 strides [based on the scoping review (Espino, et al., 2024)]
Data Acquisition				
Nexus Software (Nexus, 2021)	Marker Occlusion during the data capture. Marker occlusion was addressed during data capture by adjusting camera settings and using the software's gap-filling feature	Nexus Software (Nexus, 2021)	No change	Nexus Software (Nexus, 2021)
Vicon and sEMG Data Analysis				
EMG Works for sEMG Data Processing	None	EMG Works for sEMG Data Processing	No change	EMG Works for sEMG Data Processing

MatLab for sEMG and Vicon Data Synchronization	MatLab for sEMG and Vicon Data Synchronization	MatLab for sEMG and Vicon Data Synchronization

Table 6. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Male or female running-related athletes (track and field, football, soccer, basketball, baseball, and softball) in the official roster of any collegiate and national team • Age 18 to 35 years old • With subacute hamstring injury defined as injury for the past 2-6 weeks, or chronic injury (injury > 6 weeks) • Had previously suffered a medically diagnosed unilateral grade 2 or a lesser degree grade 3 hamstring injury at least once within the last two years • Had no prior surgical history in their lower extremity and no other lower extremity injury or pain likely to adversely affect their running mechanics for at least 6 months. • Are competent in sprinting on high-speed treadmills • Should be fully active in their sport at the time of testing	• The presence of lower extremity fractures and dislocations that would adversely impact the study's outcome • Those with other and/or concurrent lower extremity musculoskeletal conditions, such as patellar tendinopathy, anterior and posterior cruciate ligament tears, medial and lateral collateral ligament tears, meniscal tears, and other hip and ankle injuries. • Those who had hip, knee, or ankle surgery in the previous year from the implementation date.

Table 7. Feasibility and Acceptability of the Final Protocols Used in the Main Study

Recruitment Capability	To ensure the optimum data acquisition of the main study, successful participant recruitment is crucial. This involves considering factors such as recruitment rates, eligibility criteria, and the relevance of the assessment procedures to the target population. We propose to recruit collegiate or national training pool athletes for our main study. This population offers a promising pool of participants due to their potential interest in research and diverse athletic backgrounds. To ensure an appropriate sample size and quality, we will also implement clear inclusion and exclusion criteria and utilize active recruitment methods to reach specific target groups. It is suggested in several published articles that a direct approach within a familiar environment, such as among friends, teammates, or within teams can facilitate the informed consent process and potentially lead to a snowball effect of increased participation [11]. This will help us find solutions to potential participant recruitment challenges in the next phase of our research project. Additionally, key point person will be identified within potential institutions and organizations to facilitate participant recruitment for the main study. Meetings will be scheduled to ensure these partner institutions understand the research process.
Refinement of Data Collection Procedures	A primary concern was the appropriateness of the data collection procedures and outcome measures for the intended participants, as well as their ability to complete the assessments. Additionally, we considered the quantity of data collection and the suitability of the measures for the specific population. To address these concerns, a detailed discussion with Prof. Kubo (biomechanics expert and consultant) and the research team led to a thorough dry run of each phase, identifying potential operational challenges and developing corresponding contingency plans. Upon finalizing the refined protocol and contingency measures, the pilot study was formally initiated.
Data Quality and Completeness	High-quality kinematic and spatiotemporal data were collected for all participants during all protocol trials. We successfully captured hip, knee, and ankle joint angles in three planes of movement. Marker occlusion issues, a common challenge in motion capture studies, were addressed and resolved (see Table 7 for the solutions). Reliable muscle activity data, including sEMG and MVIC, was obtained for all participants, with minimal data loss due to equipment malfunction. Equipment-related issues were addressed and resolved during the study (see Table 7 for the solutions).
Acceptability of Procedures	Key concerns included the suitability and acceptability of the study procedures for participants, adherence rates to the protocol, the time and capacity required to complete assessments, participant burden, the acceptability and satisfaction of the intervention, and potential safety issues or adverse events. To address these, an orientation was conducted among the participants to explain the procedures and their duration. Following the assessments, participants were interviewed to gauge their satisfaction. While the six-hour protocol was demanding, participant comfort and safety were prioritized by providing food, a monetary token, and ample recovery time. No adverse events were reported throughout the feasibility study.

Resource Utilization	The research team utilized the university's human performance laboratory, equipped with reliable and valid equipment for the necessary assessments. The research team, composed of experienced physicians, licensed physical therapists, sports scientists, and engineers, was well-prepared to conduct the study. Ethical approval was obtained to ensure the safety and ethical conduct of the research. Additionally, the biomechanics expert/consultant provided training to the research team members.

Table 8. Problems encountered during pilot testing and given solutions

Problems Encountered	Solutions
Vicon Marker Occlusion	Marker occlusions were mitigated using the Nexus software's gap-filling feature, adjusting camera height, and ensuring proper calibration and setup for each trial.
Vicon Marker Placement	Before each trial began, a thorough inspection of the markers were conducted. This involved checking for any loose markers that might detach during movement. Vicon markers were attached to the skin using double sided tapes *with an addition of leukoplast tapes.*
sEMG Electrode placement	To ensure optimal data collection, the skin was first cleaned to remove sweat and create a clear surface for attachment. The skin was also shaved and slightly abraded. *Leukoplast tapes were then used to securely fasten the markers and electrodes in place.*
Post trial data quality check	Following each trial, both the motion data captured by the Vicon system and the sEMG data collected from the electrodes underwent a quality check. This step verified that all data points were successfully recorded throughout the trial, ensuring the completeness of the dataset.

Table 9. Intra rater reliability for Maximum Voluntary Isometric Contraction (MVIC)

Muscle Group	Trial 1 (mv) mean (SD)	Trial 1 (mv) mean (SD)	Trial 1 (mv) mean (SD)	ICC (95% Confidence Interval)	P value	Interpretation
Left-Gluteus Maximus	0.000363179 (0.000127480)	0.000389145 (0.000154091)	0.00026440176 (0.000264456)	0.537 (95% CI: 0.016, 0.927)	0.03*	moderate
Left-Gluteus Medius	0.0007169126 (0.000312828)	0.0004316266 (0.000170254)	0.0005210734 (0.000275462)	0.614 (95% CI: 0.086, 0.942)	0.002*	moderate
Left-Biceps Femoris	0.00023336628 (0.000186946)	0.0002862192 (0.000172032)	0.0003027799 (0.000193158)	0.891(95% CI: 0.602, 0.987)	0.000*	excellent
Left-Semitendinosus	0.0003395844 (0.000131230)	0.0003484158 (0.000104055)	0.0003491664 (0.000160752)	0.640 (95% CI: 0.020, 0.951)	0.022*	moderate
Left-Rectus Femoris	0.0005772728 (0.000315206)	0.0005740734 (0.000285124)	0.0005956058 (0.000342898)	0.910 (95% CI: 0.630, 0.989)	0.000*	excellent
Left-Vastus Lateralis	0.0003587016 (0.000243029)	0.000337103 (0.000142489)	0.0003512404 (0.000164779)	0.756 (95% CI: 0.227, 0.969)	0.006*	excellent
Left-Tibialis Anterior	0.0025394984 (0.001675227)	0.001630749 (0.000979530)	0.0018263528 (0.001088739)	0.674 (95% CI: 0.188, 0.953)	0.004*	moderate
Left-Gastrocnemius	0.0005249084 (0.000206496)	0.000495621 (0.000353819)	0.0005546422 (0.000298480)	0.804 (95% CI: 0.353, 0.975)	0.002*	excellent
Right- Gluteus Maximus	0.0003793996 (0.000205964)	0.000403944 (0.000241199)	0.000345218 (0.000112887)	0.825 (95% CI: 0.431, 0.978)	0.002*	excellent
Right- Gluteus Medius	0.0005382862 (0.000281076)	0.0003965062 (0.000165109)	0.0003985054 (0.000201873)	0.754 (95% CI: 0.275, 0.967)	0.001*	excellent
Right- Biceps Femoris	0.0003686292 (0.000122310)	0.0003563894 (0.000191743)	0.000388913 (0.000292479)	0.691 (95% CI: 0.111, 0.959)	0.013*	moderate

Right-Semitendinosus	0.000470694 (0.000125727)	0.0005180642 (0.000258691)	0.0004318732 (0.000193335)	0.778 (95% CI: 0.345, 0.971)	*0.002**	excellent
Right- Rectus Femoris	0.0005280608 (0.000318833)	0.0005566122 (0.000162756)	0.0005491988 (0.000266118)	0.676 (95% CI: 0.080, 0.956)	*0.015**	moderate
Right- Vastus Lateralis	0.00032336486 (0.000232950)	0.00026964058 (0.000273832)	0.00029284452 (0.000188876)	0.851 (95% CI: 0.483, 0.982)	*0.001**	excellent
Right- Tibialis Anterior	0.0017107252 (0.001190077)	0.0017396656 (0.001220887)	0.001524056 (0.000702929)	0.921 (95% CI: 0.699, 0.991)	*0.000**	excellent
Right-Gastrocnemius	0.0005033374 (0.000231889)	0.000494857 (0.000153250)	0.0004553842 (0.000228744)	0.901 (95% CI: 0.636, 0.988)	*0.000**	excellent

ICC = < 0.40 poor, 0.40-0.75 moderate, and > 0.75 excellent

without incurring any adverse consequences. After the testing, a meeting was held with the biomechanics expert and the research team to discuss the possible difficulties that will be encountered during data gathering (Table 6).

Feasibility And Acceptability Of The Final Protocols Used In The Main Study

Table 7 summarizes the feasibility study's evaluation of the protocol's applicability and suitability for assessing the necessary outcome measures and the proposed solutions.

Problems Encountered During Pilot Testing And Given Solutions

During the pilot testing, the problems encountered were Vicon marker placement, occlusion, and sEMG electrode placement. Solutions to address the challenges are tabulated in Table 8.

Intra-rater reliability for Maximum Voluntary Isometric Contraction (MVIC)

Five male collegiate athletes (Age: 18.8 $\pm$ 0.84, Ht: 166.78 cm $\pm$ 7.06; Wt: 60.20 kg $\pm$ 9.51) volunteered to participate in the intra-rater reliability assessment for MVIC. The intra-rater assessment demonstrated moderate reliability for the Left GMax, Left GMeds, Left ST, Left TA, Right BF, and Right RF, with ICC ranging from 0.537 to 0.691. The remaining muscle groups exhibited excellent reliability, with ICC values ranging from 0.754 to 0.921. Overall, the assessor assigned to conduct MVIC assessments during the trial exhibited reliable performance. The results of the intra-rater reliability testing are detailed in Table 9.

DISCUSSION

This feasibility study was able to achieve its objectives. We evaluated the feasibility and practicality of our research methods, assessed all identified parameters, and completed the assessments within the designated timeframe. The feasibility study proved valuable in identifying and addressing challenges encountered during data collection, such as equipment malfunctions and logistical hurdles. The study also showed moderate to excellent intra-rater reliability for MVIC acquisition.

To efficiently test the protocol for this feasibility study, we recruited participants using a convenience sampling method. Since the feasibility study's primary focus was evaluating the protocol procedures, not the equipment's psychometric properties, it is essential to acknowledge this small sample size as a limitation of this study. We could not identify clear trends or statistically significant differences with only two participants. This is a common challenge in feasibility studies designed to test methods before more extensive studies.

Feasibility Study vs Pilot Study

For our study, we employed a feasibility study design, prioritizing the assessment of the process over the outcomes of the procedures. This aligns with Orsmond et al. (2015)[32], who posit that feasibility studies primarily focus on developing and implementing an intervention, providing a preliminary assessment of participant responses [33]. In contrast, pilot studies emphasize outcomes and involve a more controlled evaluation of participant responses.

As defined by the British National Institute for Health Research (NIHR), a feasibility study examines the practicality of a research project, while a pilot study is a smaller-scale version of the main study designed to test its component [32,34]. Thus, feasibility studies are conducted initially to evaluate the research and intervention process, followed by pilot studies to assess the intervention outcomes in a smaller-scale RCT setting[32]. A key distinction between the two, especially for novel interventions, is that feasibility studies are iterative, formative, and adaptable [35], while pilot studies incorporate more rigorous methodological components [36].

Protocol Evaluation

One of the challenges we encountered during the trial was Vicon marker occlusions, primarily in the hip area. This was due to the railings and attachments on the high-speed treadmill, which partially obscured the markers. To address the issue of marker occlusions, we implemented several strategies. First, we utilized the gap-filling feature of the NEXUS software. Second, we adjusted the height of the treadmill's railings and attachments. Third, we modified the camera position. Finally, we implemented strict camera calibration before the trial to ensure data accuracy. Marker-based movement analysis, commonly used for running and gait analysis tasks, often encounters challenges due to marker occlusions. Several published studies have highlighted this issue as a recurring problem in various applications, from elite athletes to special populations [37–39]. These articles have presented several solutions such as manual gap-filling, using the software's gap-filling feature [37], an automated gap-filling method that utilizes inverse kinematics for automated error reduction [40], using multiple cameras [38], and integrating vision-based motion capture with wearable inertial sensor technologies to improve accuracy [39].

In addition, to address the challenges of marker occlusions, some studies have advocated for markerless systems in human movement analysis [37,41,42]. However, while markerless methods offer potential advantages, they have limitations. Inconsistent segment pose estimations, particularly in the center of mass, can lead to systematic differences in joint moments and powers compared to marker-based systems. Despite their promising clinical applications, the systematic overestimation observed in markerless systems warrants further investigation [41].

Another challenge was ensuring the Vicon markers remained securely in place throughout the high-speed running trial. To address this, we used double-sided tape and leukoplast. The same solutions were presented by several studies to secure the markers in place [43–46].

Several preparatory steps were taken to safeguard optimal sEMG electrode adhesion during the trial. Initially, the skin was meticulously cleaned to eliminate sweat and create a smooth, suitable surface for attachment. Subsequently, the skin was gently shaved and abraded to enhance electrode adherence. Finally, sEMG double-sided and leukoplast tapes were strategically employed to securely affix the electrodes, ensuring their stability throughout the experiment. We also conducted electrode checks between trials, asking participants to perform slow jogs.

Additionally, we reviewed data quality after each trial and re-ran the trial if necessary. SENIAM guidelines were also followed for electrode placement. The skin preparation, electrode placement guidelines, and adhesive type employed in this study align with those utilized in several published research articles that successfully employed sEMG electrodes for muscle activity detection. This consistency enhances the reliability and comparability of our findings with existing literature [47–49].

To maintain data reliability, intra-rater reliability testing was conducted for the MVIC assessment using the Delsys Trigno sEMG system despite its reputation as a highly reliable and widely used tool. This additional intra-rater testing for MVIC assessment reinforces the confidence in the accuracy and consistency of our data collection methods. One reason for variability in MVIC assessments is that individuals naturally differ in muscle strength, neuromuscular control, and other physiological factors. This is supported by the findings of Norcross et al. (2010)[50], who demonstrated that variations in muscle coordination strategies can influence MVIC normalization reference values and,

consequently, the interpretation of normalized EMG activity during experimental tasks [50].

The Vicon motion capture system was not tested for reliability due to its established status as the gold standard in motion capture technology. Researchers frequently use Vicon to validate and compare the reliability of other motion capture technologies [51,52]. This focus on accurate movement analysis is crucial in quantitative running gait analysis, which has gained traction in clinical and performance settings [53–55]. This approach improves running efficiency, leading to better performance [56] and a reduced risk of injuries.

CONCLUSION

This study successfully demonstrated the feasibility and practicality of our research protocol. We evaluated all identified parameters and completed the assessments on schedule. The feasibility study proved valuable in identifying and addressing challenges encountered during data collection, such as equipment malfunctions and logistical hurdles. The study also demonstrated a moderate to excellent intra-rater reliability of MVIC assessment.

Several recommendations were presented to address the identified problems in each protocol stage. The main limitation of this study was the small sample size. Future studies focusing on the outcome measures related to the main study should consider using a larger sample size.

Individual Author's Contributions

All authors contributed equally to this study.

Disclosure Statement

This study is funded by DOST-SEI.

Conflicts of interest

Some of the authors of this paper are part of the PJAHS editorial board (CS, RVE).

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the author(s) used GEMINI to IMPROVE READABILITY AND LANGUAGE. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

Supplementary Materials

Supplementary Materials. Tables and Figures

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