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Original Article

Influence of Hamstring Injuries and Vision on Posterior Chain Muscle Activation during Challenging Single-Limb Balance Control among Athletes with Hamstring Strain Injuries

Amornthep Jankaew[1], **Yih-Kuen Jan**[2], **Tai-Hua Yang**[3,4], **Hong-Wen Wu**[5], **Cheng-Feng Lin**[1,6]

[1]Department of Physical Therapy, College of Medicine, National Cheng Kung University, Tainan, Taiwan;
[2]Department of Kinesiology and Community Health, College of Applied Health Sciences, University of Illinois at Urbana-Champaign, Champaign, IL, United States;
[3]Department of Orthopedics, National Cheng Kung University Hospital, Tainan, Taiwan;
[4]Department of Biomedical Engineering, College of Engineering, National Cheng Kung University, Tainan, Taiwan;
[5]Department of Physical Education, College of Sport Education, National Taiwan University of Sport, Taichung, Taiwan;
[6]Physical Therapy Center, National Cheng Kung University Hospital, Tainan, Taiwan

Abstract

Objectives: This study investigated the impact of hamstring strain injuries (HSI) and vision on muscle recruitment and postural control in athletes with HSI. **Methods**: Fourteen athletes with HSI and fourteen healthy controls performed a single-leg balance task under eyes-closed and eyes-open conditions while leaning to the maximum forward and backward. The root-mean-square electromyography (EMG), median frequency, and center of pressure (COP) trajectories were calculated for 15 seconds. A two-way repeated measures ANOVA was conducted to assess differences between the groups and eye conditions. **Results**: Individuals with HSI exhibited lower hamstring activation during postural leans in the lateral hamstring ($p = 0.009$) during forward lean and both lateral ($p = 0.001$) and medial hamstring ($p < 0.001$) during backward lean. There were no significant changes in median frequency between the groups. Consequently, this resulted in a greater sway range and a larger 95% confidence ellipse area. The eye conditions primarily affected EMG frequency and COP parameters during leaning in both directions. **Conclusion**: Athletes with HSI exhibit a persistent deficit in hamstring activation, adversely affecting their postural control. These muscle impairments may compromise balance control and may impact sports performance. Therefore, implementing balance training programs should be considered in clinical rehabilitation for HSI.

Keywords: Activation Deficits, Balance Control, Hamstring Injuries, Hamstring Recruitment, Single-Leg

Introduction

Postural stability, the ability to sustain the vertical projection of the center of gravity within the limits of the support surface, is a crucial element necessary for various sports activities[1]. It involves a sophisticated process that demands integrating central nervous systems, sensory systems, and musculoskeletal components to maintain an upright posture[2]. Before engaging in sports activities, athletes need to possess the capability to maintain their balance and posture in both static and dynamic conditions. This is essential not only to prevent injury risks in sports but also to ensure efficient movement skills[3,4]. A previous study reported that expert athletes demonstrating remarkable motor skills must also possess proficient postural ability. These abilities allow them to efficiently preserve their balance across different postures, whether in static or dynamic movements, while optimizing energy usage[3]. For this reason, the effectiveness of maintaining postural stability is vital for the athletic population in order to achieve independence and success in sports movement and performance[5].

The hamstrings are crucial in maintaining human postural

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Corresponding author: Cheng-Feng Lin, PT, Ph.D. Department of Physical Therapy, College of Medicine, National Cheng Kung University, No. 1, University Road, Tainan 70101, Taiwan
E-mail: connie@mail.ncku.edu.tw

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Table 1. Participant characteristics of the HSI and control groups.

	HSI group (N = 14)	Control group (N = 14)	p values
Age (years)	22.43 ± 3.08	21.64 ± 1.28	0.386
Weight (kg)	68.21 ± 6.20	67.90 ± 10.73	0.925
Height (m)	1.76 ± 0.06	1.71 ± 0.06	0.053
BMI (kg/m^2)	22.08 ± 1.18	23.11 ± 2.88	0.230
Sports experience (years)	5.36 ± 2.47	4.04 ± 2.15	0.143
Training hours (days/week)	3.86 ± 1.17	3.29 ± 1.27	0.226
Muscle strain (medial/lateral)	8 / 6		
Injury history (months)	9.00 ± 4.80		
Time to return to sports (weeks)	3.21 ± 2.67		

HSI: hamstring strain injury.

control in the sagittal plane by stabilizing the hip joint in a standing upright position[6]. The muscles act as the anticipatory and compensatory postural adjustment muscles to maintain and reactivate balance control during challenging dynamic kinematic activities involving ankle and hip strategies[7,8]. Different hamstring morphologies have been demonstrated to be associated with distinct levels of postural control. For instance, Palmer et al.[9] discovered that the quality of the hamstring muscle, including measures of muscle fat and fibrous tissue content assessed by echo intensity, was associated with postural balance in healthy older male participants when visual feedback was absent. Rhodes and colleagues[10] reported a positive correlation between the functional eccentric hamstring strength and dynamic stability in the posterior direction using the Y balance test among elite academy footballers. Therefore, based on the previous findings, it is essential to acknowledge that the hamstring muscles' function could directly impact postural performance in both static and dynamic conditions[9,10].

Hamstring strain injury (HSI) becomes the most common lower limb strain in both contact and non-contact sports, affecting athletes at all levels who engage in high-speed running, kicking, and tackling movements[11]. The HSI significantly leads to training absences, demanding extensive rehabilitation, and adversely impacting athletic fitness and sports performance. A recent systematic review of the HSI points out that even if successful rehabilitation can be carried out and athletes can return to sports with no symptoms, certain muscle impairments may persist due to incomplete recovery of the neuromuscular and motor systems. Specifically, a decrease in the intensity of muscle activity in the injured hamstring and its associated coordinating muscles during eccentric contractions[12], along with altered motor control function, such as lower levels of voluntary activation[13] and increased short interval intracortical inhibition[14], is observed due to neuromuscular inhibition following the hamstring strain. It could potentially manifest that neuromuscular inhibition, combined with motor control adaptation, could potentially limit players from a full recovery during rehabilitation[15], consequently leading to diminished sports performance and negatively affecting team performance[16]. While extensive research has discussed the effects of HSI on the hamstring and its associated muscle activity during dynamic performance[17-19], there remains a gap in the literature concerning hamstring and coordinated muscle activation in athletes with HSI during postural control and how these neuromuscular adaptations influence their balance control. Hence, it is crucial to investigate muscle activation of the HSI in the context of balance control, which is a prerequisite for enhancing the regulation of voluntary movements in sports activities and, consequently, improving athletic performance[20].

Therefore, this study aims to scrutinize activation profiles of the hamstrings and associated posterior chain coordination muscles in individuals with HSI compared to healthy controls during challenging single-limb anterior and posterior leans. Additionally, we investigated the impact of vision during postural control by conducting the experiment under eyes-closed and eyes-open conditions. It is hypothesized that athletes with HSI would exhibit lower hamstring activation and compensatory patterns in the associated muscles than healthy controls. Simultaneously, the vision factor may impair balance ability in both groups. Alterations in neuromuscular function and vision could compromise postural control ability and reveal compensation strategies used by athletes with HSI during challenging single-limb balance control. Gaining insight into neuromuscular adaptations and their contribution to postural control ability can provide valuable information about the mechanisms of neurophysiological inhibition. This understanding can potentially enhance the design of early rehabilitation programs aimed at restoring muscle function, improving sports performance, as well as preventing related injuries.

Materials and Methods

Participants

Twenty-eight male participants (14 athletes with chronic HSI and 14 healthy controls with matched sports) from track and field sports were recruited to a single-session laboratory

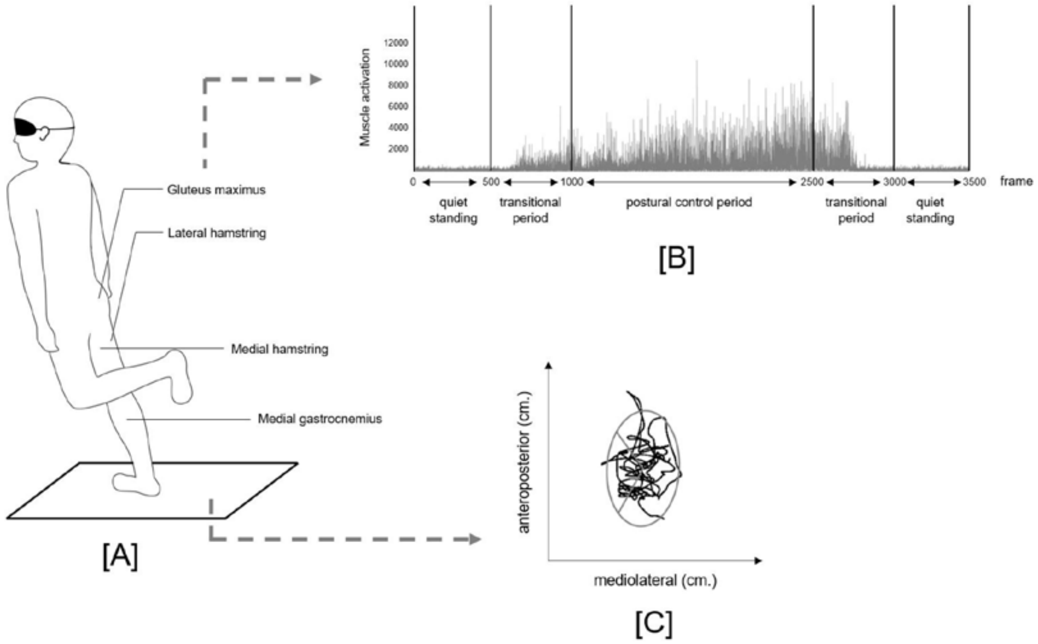

Figure 1. Experimental setup for the postural control test [A]. EMG analysis of the posterior chain coordination muscles during challenging single-limb balance control [B]. Center of pressure displacement in the anteroposterior and mediolateral directions during challenging balance control [C].

study based on their injury history (Table 1). In the current study, HSI is defined as "a sudden pain at the back of the thigh resulting from a strain or tear in the muscle and tendon while sprinting, kicking, or changing directions, which restricts the athlete from participating in training or matches for at least one entire week"[21]. The inclusion criteria were male athletes who experienced once or multiple strain injuries at the lateral hamstring (LH) or medial hamstring (MH) between 3-24 months, complete recovery with no symptoms at the hamstrings, and fully returned to sports activities at the testing date. The exclusion criteria were athletes who currently present posterior thigh pain from hamstring injuries or other causes from the lower back or the hip.

Procedures

Alcohol pads were used to clean the muscle bellies of the interested muscles to minimize skin impedance before the electrode placement. Four surface EMG electrodes (Trigno Wireless EMG System, Delsys Inc., Boston, MA, USA) were placed on the muscle bellies of the LH, MH, and associated posterior chain coordination muscles, involving the gluteus maximus (GM), and medial gastrocnemius (MG) muscles of the injured leg in the injured group and on the corresponding leg (either dominant or non-dominant limb) in the control group. The belly of the GM, LH, and MH were calculated from 50% of the muscle length from the origin to the insertion. In contrast, the attachment of the MG was determined from the most prominent bulge of the medial head, estimated at 30% of the lower leg length from the medial popliteal fossa to the calcaneal insertion. The same investigator performed the surface electrode attachment to all participants and confirmed their placement by conducting a maximum voluntary isometric contraction to ensure accurate positioning of the muscle bellies.

In the present study, a single-leg balance test was chosen due to its challenging nature, demanding heightened proprioceptive input and greater neuromuscular coordination. It specifically targets stability in the hip, knee, and ankle within a limited base of support[22,23]. Four testing conditions were designed and executed in a random sequence: eyes-open and eyes-closed during forward leans and eyes-open and eyes-closed during backward leans. The experiment commenced with subjects standing barefoot on a single-leg at the center of the force platform (Type 9281B, Kistler Instrument Corp., Winterthur, Switzerland). The investigator verbally instructed the subjects to lean their bodies to the maximum extent, either in the anterior or posterior direction (under both eye conditions for both directions). The subjects were required to maintain an upright posture with their specific body segments, including the torso, hips, and stance leg, aligned in a straight line. At the same time, they were instructed to maintain continuous contact between their foot and the force platform, sustaining balance for a minimum of 15 seconds while placing their arms beside their body during the balance test (Figure 1). Finally, they were instructed to

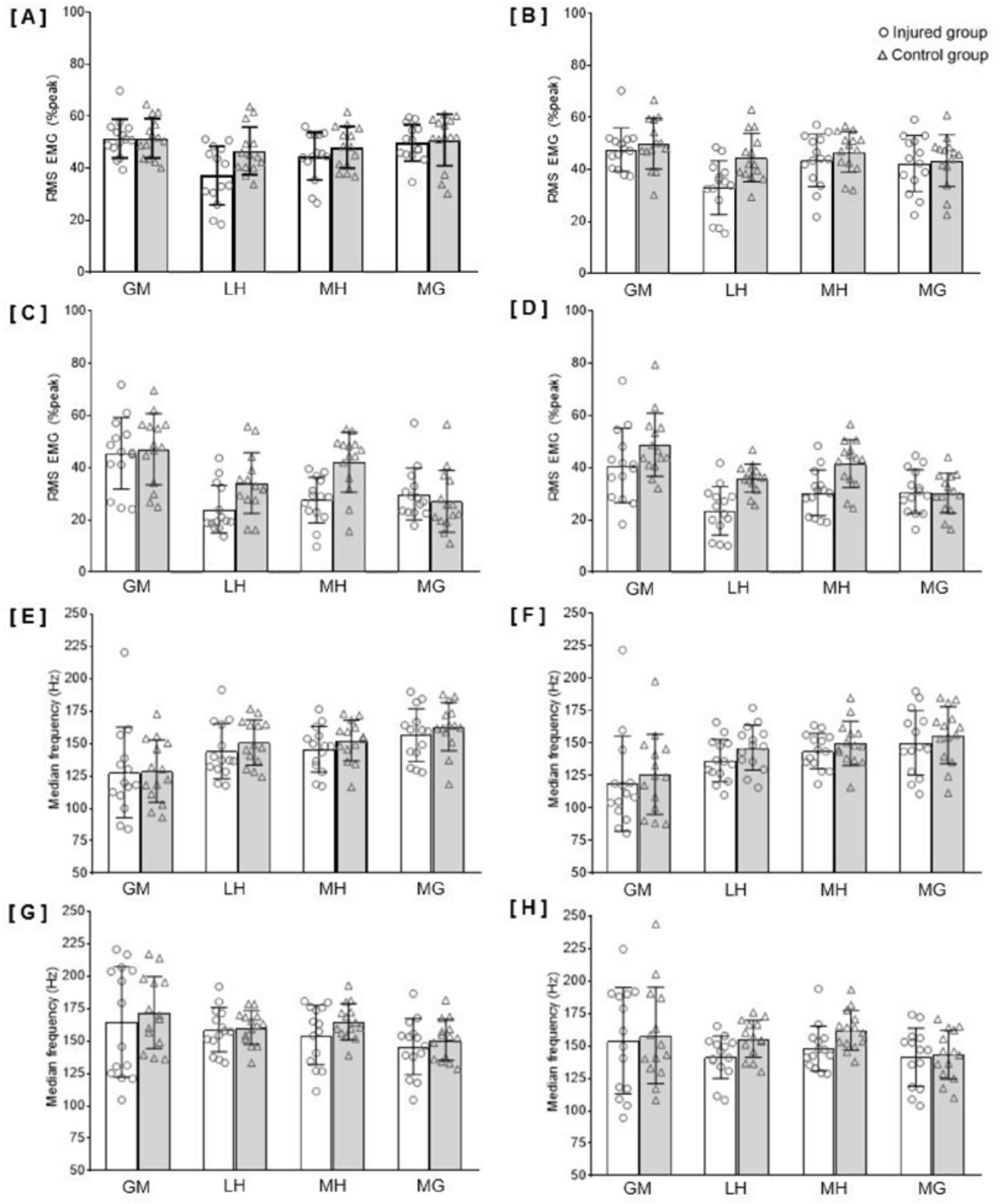

Figure 2. Comparison of normalized RMS EMG of the muscles during a single-leg forward lean with eyes-open [A] and eyes-closed [B], as well as a single-leg backward lean with eyes-open [C] and eyes-closed [D], and comparison of median power frequency of the muscles during a single-leg forward lean with eyes-open [E] and eyes-closed [F], as well as a single-leg backward lean with eyes-open [G] and eyes-closed [H], between the injured and healthy control groups.

return to a single-leg standing as the initial position. No limit point to look at the eyes-open condition, whereas they wore a blindfold to eliminate visual feedback during the eyes-closed condition. The research assistant stood near the subjects to prevent falls during the experimental testing for all conditions. The subjects performed three trials in each condition with a 1-2-minute rest between each trial to prevent neuromuscular fatigue. In the case of a failed trial, participants typically repeated extra trials until it was a success.

Data reduction

The Cortex system with a 16-bit analog-to-digital converter was used to collect data. The analog data were collected on collection software (EVaRT 4.4) and synchronized between the EMG and the force platform at a sampling rate of 1000 Hz. The raw EMG data were filtered at a frequency bandpass filter of 20-450 Hz using a fourth-order Butterworth filter with full-wave rectification

Table 2. Two-way repeated measures ANOVA of muscle activation and COP trajectory during a single-leg forward lean.

	Single-leg with eyes-open			Single-leg with eyes-closed			Interaction effect		Group effect		Eye effect	
	HSI	CON	ES	HSI	CON	ES	F	P	F	P	F	P
Normalized RMS electromyographical activity (% peak)												
GM	51.50 ± 7.45 (47.20-55.80)	51.58 ± 7.61 (47.18-55.97)	0.011	47.78 ± 8.35 (42.95-52.60)	49.98 ± 9.76 (44.34-55.62)	0.242	0.571	0.457	0.163	0.689	3.572	0.070
LH	37.25 ± 11.22 (30.77-43.72)	46.74 ± 9.16 (41.45-52.03)	0.927	32.99 ± 10.32 (27.03-38.94)	44.60 ± 9.29 (39.24-49.97)	1.182	0.889	0.355	8.095	**0.009***	8.499	**0.007***
MH	44.74 ± 9.19 (39.43-50.04)	48.12 ± 8.10 (43.44-52.79)	0.390	43.53 ± 10.14 (37.68-49.39)	46.85 ± 7.79 (42.35-51.35)	0.367	0.001	0.981	1.170	0.289	0.941	0.341
MG	49.84 ± 7.02 (45.79-53.90)	50.90 ± 9.90 (45.18-56.61)	0.124	42.34 ± 10.74 (36.14-48.54)	43.49 ± 10.00 (37.71-49.26)	0.111	0.001	0.973	0.109	0.744	30.081	**< 0.001***
Median power frequency (Hz)												
GM	129.47 ± 39.98 (106.38-152.56)	128.80 ± 24.10 (114.88-142.72)	0.020	120.52 ± 40.99 (96.86-144.19)	126.12 ± 30.89 (108.29-143.96)	0.154	1.346	0.256	0.037	0.849	4.622	**0.041**
LH	144.15 ± 21.26 (131.88-156.43)	150.81 ± 17.50 (140.70-160.91)	0.342	136.75 ± 16.19 (127.40-146.10)	146.64 ± 17.28 (136.67-156.62)	0.591	0.630	0.435	1.594	0.218	8.019	**0.009**
MH	145.62 ± 17.54 (135.49-155.75)	152.35 ± 15.67 (143.30-161.39)	0.405	143.93 ± 13.69 (136.03-151.83)	149.99 ±17.14 (140.09-159.88)	0.391	0.028	0.869	1.242	0.275	1.012	0.324
MG	156.56 ± 20.26 (144.86-168.25)	163.01 ± 18.73 (152.20-173.83)	0.331	150.36 ± 24.90 (135.99-164.73)	156.31 ± 21.88 (143.68-168.95)	0.254	0.020	0.888	0.609	0.442	13.128	**0.001***
COP parameters												
AP sway range (cm)	3.98 ± 0.69 (3.58-4.38)	3.69 ± 0.93 (3.15-4.23)	0.354	6.98 ± 1.94 (5.86-8.10)	5.92 ± 1.34 (5.15-6.69)	0.636	1.472	0.236	3.142	0.088	67.943	**< 0.001***
ML sway range (cm)	4.77 ± 1.27 (4.04-5.51)	3.84 ± 1.48 (2.98-4.69)	0.674	8.30 ± 3.49 (6.29-10.31)	5.83 ± 2.60 (4.32-7.33)	0.803	2.707	0.112	4.907	**0.036***	34.627	**< 0.001***
Mean velocity	1.65 ± 0.32 (1.46-1.83)	1.57 ± 0.40 (1.34-1.81)	0.221	2.99 ± 0.90 (2.47-3.51)	2.46 ± 0.48 (2.18-2.74)	0.735	2.691	0.113	3.255	0.083	65.410	**< 0.001***
RMS velocity	1.38 ± 0.24 (1.24-152)	1.21 ± 0.32 (1.02-1.39)	0.601	2.37 ± 0.78 (1.92-2.82)	1.81 ± 0.49 (1.53-2.09)	0.860	3.078	0.091	5.694	**0.025***	52.355	**< 0.001***
95% confidence ellipse area (cm^2)	10.67 ± 3.85 (8.46-12.90)	7.97 ± 3.93 (5.70-10.24)	0.694	37.91 ± 28.71 (21.33-54.49)	19.58 ± 9.94 (13.85-25.32)	0.853	3.860	0.060	6.057	**0.021***	23.884	**< 0.001***

** indicates statistically significant differences; HSI: hamstring strain injury; CON: control; ES: Cohen's d effect size; GM: gluteus maximus; LH: lateral hamstring; MH: medial hamstring; MG: medial gastrocnemius; AP: anteroposterior; ML: mediolateral; RMS: root-mean-square.*

(amplification = 1000, CMMR = -80 dB). The data, with a length of 15,000 points (15 seconds), was analyzed to assess the ability to maintain postural control in both groups (Figure 1). The root-mean-square (RMS) of the EMG was calculated using a moving window analysis with a duration of 100ms, and it was normalized using the peak values of the corresponding trial. The EMG median power frequency, defined as half of the total power, was computed from the rectified EMG signals using the Fast Fourier transform with a 100-ms Hanning window size application[24]. The EMG median frequency was determined as[25]:

$$MDF=\frac{1}{2}\sum_{j=1}^{M} P_j \ ;$$

The force platform data were filtered with a lowpass Butterworth digital filter with the cut-off frequency set at 100 Hz. COP outcomes, including anteroposterior (AP) and mediolateral (ML) sway range, mean and root mean square (RMS) velocity, and 95% confidence ellipse area, were computed. The average values were reported to represent postural control ability among both groups and vision conditions. The calculation methods of the COP outcomes were referenced from a previous study[26]. All data post-processing was performed on MATLAB software (MathWorks, R2021a, Natick, MA, USA).

Statistical analysis

Descriptive statistical analysis was used to compare the baseline demographic of the participants between the injured and control groups. The Shapiro–Wilk test was used to test the normality of the primary outcomes, and all data were found to follow a normal distribution. Two-way repeated measures ANOVA was used to compare the primary outcomes of the study between the groups (HSI vs. control) and eye conditions (eyes-closed vs. eyes-open) during challenging balance control in the forward and backward leans. The statistical analysis was performed in the SPSS program (Version 26, IBM Corp., Armonk, NY, USA) with the alpha level set at 0.05. The effect size, calculated from Cohen's *d*, was also reported for all outcomes.

Results

Muscle activation

The HSI group demonstrated a decrease in LH activation during the forward lean (F = 8.095, $p = 0.009$), as well as reductions in LH and MH activation during the backward lean (F = 14.295, $p = 0.001$ and F = 17.812, $p < 0.001$, respectively; Figure 2 and Tables 2 & 3).

There were no statistically significant differences in the median power frequency of the muscles between the HSI and control groups during a single-limb postural lean (Tables 2 & 3). However, significant differences in median power frequency were observed only between eyes-open and eyes-closed conditions in the GM (forward; F = 4.622, $p = 0.041$), LH (forward; F = 8.019, $p = 0.009$ and backward; F = 10.758, $p = 0.003$), and MG (forward; F = 13.128, $p = 0.001$ and backward; F = 6.057, $p = 0.021$).

Center of pressure

The HSI group exhibited greater RMS velocity and a larger 95% confidence ellipse area compared to the healthy group during the forward lean (F = 5.694, $p = 0.025$ and F = 6.057, $p = 0.021$) as well as the backward lean (F = 5.794, $p = 0.023$ and F = 7.786, $p = 0.010$). Furthermore, the results indicated that the control group had a lower ML sway range during the forward lean (F = 4.907, $p = 0.036$) and AP sway range during the backward lean (F = 5.482, $p = 0.027$; Tables 2 and 3). Additionally, significant differences were observed in the eye conditions, with the eyes-closed condition yielding higher values than the eyes-open condition for all COP outcomes ($p < 0.001$ for all outcomes).

Discussion

This study investigated the hamstrings and their association with the posterior chain coordination muscle activation during a single-limb challenging forward and backward lean in athletes with a history of HSI. The results align with our assumption and display lower hamstring activation in the HSI group compared to the control group. Reducing the hamstring activity in the injured group may contribute to degraded balance control ability presented through the COP parameters. In addition, we found that visual information influences the recruitment of the lower limb posterior chain muscles.

The hamstrings are the primary prime mover of maintaining postural control in the ankle and hip strategies in response to anticipated postural correction[27]. To the best of the authors' knowledge, this is the first study designed to observe the influence of the HSI on lower limb posterior chain muscle activity and recruitment during single-limb balance control. The novel findings from this study indicated that the previously injured athletes who returned to sports displayed lower hamstring activation during leaning in both anterior and posterior directions compared to the controls. Even though significant differences in the median power frequency were not detected, the HSI group presented a lower trend in the frequency domain. The lower activation of the injured hamstrings during single-limb control is consistent with findings from previous cohort studies conducted during isokinetic testing[24,28] and dynamic movements such as sprinting[17,19] and jumping[18]. It is widely recognized that HSI athletes may have morphological and structural changes, such as the presence of scar tissue[29] or a decrease in the physiological cross-sectional area[30]. The factors mentioned above can affect muscle properties and contractile function of the injured muscle, influencing the sensitivity or responsiveness of the fusimotor-spindle system as well as alterations in the control signals from the fusimotor neurons. Disruptions in the normal feedback loop between muscle length and tension after undergoing the fiber tears can decrease the ability to accurately sense and control muscle length and tension during postural lean. Consequently, this may lead to lower activation and poor coordination during muscle contractions[31]. Additionally, considering the findings of Ariena et al.[28], which reported poor knee proprioception among this population, it could potentially contribute to inadequate sensory input and hinder crucial feedback integration required for maintaining single-limb stability. This may impair the ability to accurately sense the position and recruitment levels. Therefore, motor skills related to single-limb control become repressed and compromise postural control and stability in athletes with a history of HSI.

Additionally, changes in muscle activation during balance

Table 3. Two-way repeated measures ANOVA of muscle activation and COP trajectory during a single-leg backward lean.

	Single-leg with eyes-open			Single-leg with eyes-closed			Interaction effect		Group effect		Eye effect	
	HSI	CON	ES	HSI	CON	ES	F	P	F	P	F	P
Normalized RMS electromyographical activity (% peak)												
GM	45.56 ± 13.72 (37.63-53.48)	47.13 ± 13.67 (39.24-55.02)	0.115	40.90 ± 14.21 (32.69-49.10)	48.84 ± 12.13 (41.83-55.84)	0.601	1.152	0.293	1.324	0.260	0.248	0.623
LH	24.05 ± 9.16 (18.76-29.35)	34.16 ± 11.65 (27.44-40.89)	0.965	23.48 ± 9.29 (18.12-28.84)	36.05 ± 5.39 (32.94-39.16)	1.655	0.513	0.480	14.295	**0.001***	0.146	0.706
MH	27.59 ± 8.76 (22.53-32.65)	42.11 ± 11.46 (35.49-48.72)	1.424	30.40 ± 8.71 (25.37-35.43)	41.58 ± 9.19 (36.27-46.88)	1.249	0.715	0.406	17.812	**<0.001***	0.331	0.570
MG	30.62 ± 12.17 (23.60-37.65)	27.14 ± 11.89 (20.27-34.00)	0.289	30.85 ± 8.37 (26.01-35.68)	30.25 ± 7.65 (25.83-34.67)	0.075	0.416	0.524	0.420	0.523	0.554	0.463
Median power frequency (Hz)												
GM	166.07 ± 44.82 (140.19-191.94)	171.87 ± 27.76 (155.84-187.90)	0.156	155.52 ± 43.84 (130.21-180.84)	158.64 ± 39.07 (136.08-181.20)	0.075	0.038	0.847	0.114	0.739	2.968	0.097
LH	158.52 ± 17.07 (148.66-168.37)	160.20 ± 12.97 (152.71-167.69)	0.111	141.32 ± 16.34 (131.88-150.76)	155.44 ± 14.33 (147.17-163.72)	0.919	3.457	0.074	2.828	0.105	10.758	**0.003***
MH	154.60 ± 22.88 (141.39-167.80)	145.60 ± 21.59 (156.84-172.95)	0.405	147.95 ± 17.26 (137.99-157.92)	161.96 ± 15.15 (153.21-170.70)	0.863	0.564	0.459	3.845	0.061	3.767	0.063
MG	145.60 ± 21.59 (133.13-158.07)	150.72 ± 15.70 (141.65-159.78)	0.271	141.30 ± 22.30 (128.42-154.18)	143.16 ± 18.82 (132.29-154.03)	0.090	0.457	0.505	0.457	0.505	6.057	**0.021***
COP parameters												
AP sway range (cm)	4.58 ± 1.58 (3.67-5.49)	4.20 ± 1.06 (3.59-4.81)	0.282	7.32 ± 1.41 (6.50-8.14)	6.02 ± 1.54 (5.13-6.91)	0.881	1.353	0.255	5.482	**0.027***	33.513	**< 0.001***
ML sway range (cm)	6.28 ± 2.62 (4.77-7.79)	4.80 ± 2.23 (3.51-6.09)	0.608	9.55 ± 3.48 (7.53-11.56)	7.46 ± 3.28 (5.56-9.35)	0.618	0.268	0.609	3.551	0.071	25.438	**< 0.001***
Mean velocity	4.58 ± 1.58 (3.67-5.49)	4.20 ± 1.06 (3.59-4.81)	0.282	3.13 ± 0.75 (2.71-3.57)	2.67 ± 0.76 (2.23-3.11)	0.609	0.022	0.882	2.170	0.153	25.610	**< 0.001***
RMS velocity	1.77 ± 0.63 (1.41-2.13)	1.38 ± 0.43 (1.14-1.63)	0.723	2.63 ± 0.62 (2.27-2.99)	2.13 ± 0.73 (1.71-2.55)	0.738	0.151	0.701	5.794	**0.023***	32.288	**< 0.001***
95% confidence ellipse area (cm^2)	19.45 ± 18.61 (8.70-30.19)	11.00 ± 6.54 (7.23-14.78)	0.606	42.07 ± 17.08 (32.21-51.93)	27.75 ± 14.95 (19.11-36.38)	0.892	0.552	0.464	7.786	**0.010***	24.743	**< 0.001***

** indicates statistically significant differences; HSI: hamstring strain injury; CON: control; ES: Cohen's d effect size; GM: gluteus maximus; LH: lateral hamstring; MH: medial hamstring; MG: medial gastrocnemius; AP: anteroposterior; ML: mediolateral; RMS: root-mean-square.*

control are most likely mediated by central inhibitory neurophysiological mechanisms since neural inhibitory mechanisms are believed to be activated particularly during single-limb control. Based on previous research, it could be assumed that a reduction in hamstring activity may be attributed to alterations in the motor control system, such as increased intracortical inhibition among athletes with HSI 3-24 months[14] and/or reduced voluntary contraction and stretch and tendon reflex excitability in athletes who had between 2-18 month since injury[13], and thus inevitably leading to a lessening myoelectrical activity and motor output of the muscle in balance control[32]. The imbalance of the injured hamstring due to the neuromuscular inhibition of the hamstrings in this present study may lead to postural stability dysfunction identified in a single or multi-segment[33]. It is reasonable to address that hamstring function might not have returned to the pre-injured level because the muscle exhibits inappropriate muscle programming and cannot recruit the active motor unit during postural control in athletes suffering from chronic HSI who return to sports activities. It may compromise sports practice and sport-specific skill training.

Literature has demonstrated that the proximal joint, particularly the hip, involves a single-limb balance control with postural lean. Since the hamstrings are the bi-articular muscle primarily responsible for maintaining hip stability, lower activation of this muscle may compromise the ability to control the hip, leading to poor hip control strategies during a challenging single-limb control. Before any HSI injury occurs, athletes independently perform advanced skills by incorporating neuromuscular control of stability and mobility[3]. Interestingly, the deficits in hamstring activation contribute to impaired balance control, as manifested by a higher COP trajectory in both forward and backward leans. Athletes at an increased risk of hamstring injuries are particularly susceptible to perturbations caused by anticipated forward or backward trunk leans during gameplay. It seems that decreased hamstring activation in the present study may contribute to a lesser ability to control hip strategy in anticipation of challenging balance control aimed at maintaining proper postural alignment[34]. This, in turn, may increase the likelihood of recurrent hamstring injuries and other lower limb injuries. Therefore, we suggested that clinicians may need to focus on targeted training strategies to enhance muscle activation, improve postural control, and minimize compensatory patterns in the early stage of clinical management for HSI.

On the other hand, this study investigated the influence of visual information on the recruitment of the posterior chain muscles. Theoretically, the lower limb activation or recruitment is expected to be higher in the eyes-closed condition compared to the eyes-open condition in a balance task[23,27]. This is because when vision is unavailable, the body needs to rely more on proprioceptive feedback and vestibular inputs, leading to increased activation of lower limb muscles to stabilize and control body movements[23,27]. However, we reversely observed higher recruitment in the eyes-open condition marked through higher RMS EMG and higher power median frequency in both leaning directions. This finding agrees with a previous study observing muscle synergies during single-limb control in young healthy participants[35]. It is possible that when we eliminate the visual input in athletes who sustain a muscle injury, the injured muscle's function may be compromised, affecting the ability to provide sufficient activation and adequate stabilization during postural control, especially in challenging situations like the eyes-closed condition where visual cues are absent. To compensate for the weakened or injured muscle, the body may rely more on visual inputs to aid in balance control. In contrast, in eyes-open conditions, the athlete can use visual information to adjust their body position and movements to some extent, thereby reducing the reliance on the injured muscle and distributing the load to other unaffected muscles. It is important to note that further research and clinical studies would be necessary to validate and understand the full extent of this phenomenon in athletes with hamstring injuries during postural control. Moreover, it is unsurprising that all the COP parameters were higher in the eyes-closed condition in both forward and backward leans. Literature has so far mentioned that reducing visual cues would increase other strategies, defined as the vestibular and somatosensory systems, to quantify and maintain postural stability in relation to a task. Hence, the results are consistent with previous studies that measure balance ability in healthy[36] and older participants[37].

The strength of this study pointed out the influence of HSI and vision on muscle activity, together with the essential role of hamstring activation in terms of postural stability demands in athletes with a history of HSI. However, some limitations should be addressed in the current study. Firstly, only male participants in track and field sports were recruited into the study. The findings may limit the generalization in terms of gender or sports differences. Next, the inclusion criteria for the HSI were based on the participants' report. Examining imaging related to specific muscle injuries may provide more profound information and explanation.

In conclusion, athletes with HSI highlighted reduced hamstring activation with no changes in other posterior chain muscles during challenging postural control compared to the healthy group. This isolated activation deficit of the hamstrings may contribute to poor hip control strategy in both forward and backward leans, leading to more significant sway in both anteroposterior and mediolateral directions. Additionally, we observed that visual information mainly influences the EMG frequency domain and COP trajectories. The findings of the current study provide evidence regarding neuromuscular inhibition after HSI during postural control. Thus, training programs aimed at improving activation profiles and postural stability should be considered in clinical rehabilitation to enhance sport-specific skills in chronic hamstring injuries.

Ethics Approval

This study was approved by the Research Ethics Committee of the National Cheng Kung University Hospital, Taiwan. The approval number is A-ER-110-075.

Consent to participate

All subjects signed a written informed consent prior to all testing.

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Authors' Contributions

AJ, YKJ, and CFL conceived the study concept and design. AJ and CFL carried out data acquisition and performed data analysis. AJ, YKJ, and CFL wrote the first draft of the manuscript. AJ, YKJ, CFL, THY, and HWW revised and edited the manuscript. All authors approved the final version of this manuscript.

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