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COMPARISONS OF HAMSTRING MUSCLE ACTIVATIONS DURING NORDIC HAMSTRING EXERCISE AND SINGLE-LEG ROMAN CHAIR HOLD EXERCISE: A RANDOMISED ELECTROMYOGRAPHY AND THERMOGRAPHY STUDY

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NORDIC HAMSTRING EGZERSİZİ VE SINGLE LEG ROMAN CHAIR HOLD EGZERSİZİ SIRASINDA HAMSTRİNG KASI AKTİVASYONLARININ KARŞILAŞTIRILMASI: RANDOMİZE ELEKTROMİYOGRAFİ VE TERMOGRAFİ ÇALIŞMASI

ÖZET

Giriş: Hamstring kas gerilme yaralanmaları (HSI), kas-iskelet sistemi yaralanmaları içerisinde en sık karşılaşılan ve spora bağlı morbiditenin en önemli nedenlerinden biri olarak kabul edilmektedir. Özellikle futbol, rugby, atletizm, Amerikan futbolu ve Avustralya futbolu gibi yüksek hız, ani yön değiştirme ve patlayıcı güç gerektiren branşlarda HSI'nin görülme sıklığı oldukça yüksektir. Literatürde, profesyonel futbolcularda meydana gelen tüm yaralanmaların yaklaşık üçte birini hamstring yaralanmalarının oluşturduğu bildirilmiş, ayrıca bu yaralanmaların tekrarlama oranlarının da %30'lara varabildiği belirtilmiştir. Bu durum, sporcuların yalnızca kısa süreli performans kayıplarına değil, aynı zamanda uzun vadede tekrarlayan sakatlıklarla birlikte kariyerin erken sonlanmasına kadar uzanan ciddi sorunlara yol açabilmektedir.

Hamstring kas grubu, uyluğun arka kısmında yer alan biceps femoris (BF), semitendinosus (ST) ve semimembranosus (SM) kaslarından oluşmaktadır. Bu kaslar diz fleksiyonu ve kalça ekstansiyonu gibi fonksiyonlarda görev almakta olup, sprintin farklı fazlarında farklı yüklenmelere maruz kalmaktadır. Özellikle biceps femoris long head kası, sprintin geç salınım fazında hem yüksek eksantrik kuvvet hem de artmış mekanik gerilime maruz kalmakta ve bu nedenle yaralanmaya en yatkın kas olarak öne çıkmaktadır. Yapılan çalışmalar, biceps femoris kasının diğer hamstring kaslarına kıyasla daha kısa fasikül uzunluğuna, daha yüksek pasif sertliğe ve farklı mimari özelliklere sahip olduğunu göstermiştir. Bu özellikler, kasın hem yaralanma riskini hem de rekürrens ihtimalini artırmaktadır.

HSI'nin yüksek görülme sıklığı ve tekrarlama oranları, araştırmacıları bu yaralanmaları önlemeye yönelik egzersiz protokolleri geliştirmeye yöneltmiştir. Bu kapsamda en çok kullanılan yöntemlerden biri Nordic Hamstring Exercise (NHE) olmuştur. Eksantrik kasılmayı temel alan NHE, kas kuvvetini artırması, fasikül uzunluğunu uzatması ve yaralanma riskini azaltıcı etkileri nedeniyle önleyici programlarda uzun yıllardır yaygın olarak kullanılmaktadır. Bununla birlikte, son yıllarda isometrik egzersizlerin hamstring yaralanmalarının önlenmesinde daha etkili

olabileceği tartışılmaya başlanmıştır. Özellikle kalça-dominant isometrik egzersizlerin, biceps femoris kasını daha yoğun şekilde aktive edebileceği düşünülmektedir. Bu noktada öne çıkan egzersizlerden biri de Single-leg Roman Chair Hold (RCH) egzersizidir.

RCH, yüksek yoğunluklu isometrik kasılma özelliği sayesinde biceps femoris kasına daha doğrudan yük bindirdiği öne sürülen bir egzersizdir. Ancak bu egzersizin NHE ile karşılaştırıldığında kas aktivasyonuna etkilerini ortaya koyan çalışmaların sayısı oldukça sınırlıdır. Literatürde her iki egzersizin etkinliğini karşılaştırmalı olarak inceleyen çalışmalar genellikle yalnızca elektromiyografi (EMG) yöntemiyle kas aktivasyonunu değerlendirmiştir. Ancak EMG tek başına kas aktivasyonu hakkında bilgi verirken, kasın metabolik yanıtlarını veya dolaşım üzerindeki etkilerini ortaya koymakta sınırlı kalmaktadır. Bu noktada infrared termografi (IRT), egzersiz sonrasında kas yüzey sıcaklığındaki değişimleri ölçerek kasın metabolik yanıtını dolaylı şekilde değerlendiren ve EMG'ye tamamlayıcı bir yöntem olarak kullanılan bir ölçüm aracıdır.

Dolayısıyla bu çalışmada hem EMG hem de termografi yöntemleri kullanılarak NHE ve RCH egzersizleri sırasında biceps femoris ve semitendinosus kaslarının aktivasyon düzeylerinin karşılaştırılması amaçlanmıştır. Böylece yalnızca kasların elektriksel aktivitesi değil, aynı zamanda egzersiz sonrasındaki fizyolojik tepkileri de değerlendirilmiş, hangi egzersizin hamstring yaralanmalarının önlenmesinde daha etkili olabileceğine dair daha kapsamlı veriler elde edilmiştir.

Metodoloji: Bu çalışma, Nordic Hamstring Exercise (NHE) ve Single-leg Roman Chair Hold (RCH) egzersizleri sırasında biceps femoris (BF) ve semitendinosus (ST) kaslarının aktivasyon düzeylerini karşılaştırmak amacıyla planlanmış ve iki farklı araştırma tasarımı birlikte kullanılmıştır. Termografi ölçümleri için paralel gruplu randomize boylamsal çalışma tasarımı, elektromiyografi (EMG) ölçümleri için ise yarı deneysel, randomize, paralel gruplu kesitsel tasarım benimsenmiştir. Bu yöntem hem kasların anlık elektriksel aktivasyonunu hem de egzersiz sonrası ortaya çıkan fizyolojik yanıtlarını değerlendirmeye olanak sağlamıştır.

Çalışmaya dahil edilme kriterleri ayrıntılı şekilde belirlenmiştir. Katılımcılar 18 ile 35 yaş aralığında, düzenli olarak fiziksel aktivite yapan ancak profesyonel düzeyde sporcu olmayan sağlıklı bireylerden seçilmiştir. Son altı ay içerisinde alt ekstremite yaralanması geçirmiş olanlar, nörolojik veya kardiyovasküler hastalığı bulunanlar ve egzersiz sırasında herhangi bir kontrendikasyonu olan bireyler çalışma dışında bırakılmıştır. Tüm katılımcılardan bilgilendirilmiş onam alınmış ve çalışma etik kurul tarafından onaylanmıştır.

Toplamda yirmi dört gönüllü birey çalışmaya katılmıştır. Katılımcılar rastgele yöntemle iki gruba ayrılmıştır. İlk grup Nordic Hamstring Exercise (NHE) egzersizini uygulamış, ikinci grup ise Single-leg Roman Chair Hold (RCH) egzersizini gerçekleştirmiştir. Gruplar arasında yaş, cinsiyet, boy ve kilo açısından istatistiksel olarak anlamlı fark bulunmamıştır, bu da egzersizlerin karşılaştırılabilirliğini güçlendirmiştir.

Egzersiz protokolleri standartlaştırılmıştır. NHE grubunda katılımcılar partner desteğiyle diz fleksiyonu pozisyonunda öne doğru kontrollü şekilde bırakılmış, konsantrik faz minimuma indirilmiş ve kasların eksantrik çalışması sağlanmıştır. Egzersiz üç set halinde uygulanmış ve her sette katılımcılar maksimum efor göstermeye teşvik edilmiştir. RCH grubunda katılımcılar glute-ham makinesi üzerinde tek bacak stabilize edilerek gövde nötr pozisyonda tutulmuş ve bu pozisyon mümkün olduğunca uzun süre korunmuştur. İkinci ve üçüncü setlerde ek olarak on ve yirmi kilogramlık ağırlıklarla egzersizler tekrarlanmıştır. Böylece hem vücut ağırlığıyla yapılan hem de yük eklenmiş versiyonlar test edilmiştir.

Elektromiyografi (EMG) ölçümleri için Delsys Trigno kablosuz EMG sistemi kullanılmıştır. Elektrotlar SENIAM protokolüne uygun olarak biceps femoris long head ve semitendinosus kaslarına yerleştirilmiştir. Elektrotların yerleştirilmesinden önce cilt temizliği alkolle yapılmış, böylece sinyal kalitesinin artırılması sağlanmıştır. EMG sinyalleri 20–450 Hz band-pass filtre ile işlenmiş ve root mean square (RMS) yöntemiyle analiz edilmiştir. Kas aktivasyonlarının karşılaştırılabilir olması amacıyla tüm veriler maksimal istemli izometrik kontraksiyon (MVIC) ile normalize edilmiştir. Her setin üçüncü tekrarında kayıt yapılmış ve kasların aktivasyon yoğunluğu değerlendirilmiştir.

Infrared termografi (IRT) ölçümleri için InfReC R300 termal kamera kullanılmıştır. Katılımcılar egzersiz öncesinde on dakika boyunca oda sıcaklığına aklimatize edilmiş, böylece cilt sıcaklığının stabil hale gelmesi sağlanmıştır. Egzersiz öncesi ve sonrası kas yüzey sıcaklıkları üç metre mesafeden kaydedilmiş, posterior uyluk bölgesi odak alınmıştır. Görseller ROI (region of interest) yöntemi ile analiz edilmiş ve sıcaklık değişimleri derece cinsinden kaydedilmiştir.

İstatistiksel analizler SPSS yazılımı kullanılarak gerçekleştirilmiştir. Gruplar arası farkların belirlenmesi için one-way ANOVA, grup içi değişimlerin değerlendirilmesi için mixed-model ANOVA tercih edilmiştir. Ayrıca sadece istatistiksel anlamlılık değil, klinik açıdan etkinin büyüklüğü de değerlendirilebilmesi için Hedges' g etki büyüklüğü hesaplanmıştır. Bu sayede anlamlı bulunmayan fakat klinik açıdan dikkate değer olabilecek sonuçlar da yorumlanabilmiştir.

Bulgular: Çalışmaya dahil edilen yirmi dört katılımcının demografik özellikleri incelendiğinde, yaş, boy, kilo ve cinsiyet dağılımı açısından NHE ve RCH grupları arasında istatistiksel olarak anlamlı fark olmadığı görülmüştür. Bu bulgu, her iki gruptaki katılımcıların benzer özelliklere sahip olduğunu ve dolayısıyla egzersizlerin etkilerinin güvenilir bir şekilde karşılaştırılabileceğini göstermiştir. Ayrıca, katılımcıların fiziksel aktivite düzeyleri de homojen bulunmuş, bu da çalışmanın geçerliliğini artırmıştır.

EMG sonuçları incelendiğinde her iki egzersiz sırasında da biceps femoris kasında semitendinosus kasına kıyasla daha yüksek aktivasyon düzeyleri gözlenmiştir. Bu farklılık grup içi analizlerde istatistiksel olarak anlamlı bulunmamış olsa da klinik açıdan önem taşımaktadır. Çünkü biceps femoris kası yaralanmalara en yatkın kas olup, bu kasın egzersiz sırasında daha fazla aktive edilmesi, yaralanma önleme stratejileri açısından dikkate değer bir bulgudur. Ayrıca, anlamlı bulunmayan bu farklılığın küçük örneklem büyüklüğünden kaynaklanabileceği de göz önünde bulundurulmalıdır.

RCH grubunda ikinci sette ek yükle yapılan egzersiz sırasında biceps femoris kasında anlamlı derecede daha yüksek ortalama EMG aktivasyonu saptanmıştır ($p = 0,038$, $g = 0,93$). Bu sonuç, ek yükle gerçekleştirilen isometrik egzersizlerin kas aktivasyonunu artırabileceğini göstermektedir. Bunun yanı sıra, genel analizler RCH grubunun NHE grubuna kıyasla biceps femoris kasında daha yüksek ortalama aktivasyon sergilediğini ortaya koymuştur ($p = 0,044$, $g = 0,87$). Bu fark hem istatistiksel olarak anlamlı bulunmuş hem de büyük etki büyüklüğüyle desteklenmiştir. Ancak RCH egzersizi sırasında semitendinosus kasında gözlenen aktivasyon, biceps femoris kadar belirgin olmamıştır ve gruplar arasında anlamlı bir fark ortaya çıkmamıştır. Bu durum, RCH'nin özellikle biceps femoris kasını hedefleme konusunda daha etkili olabileceğini düşündürmektedir.

NHE grubunda ise biceps femoris ve semitendinosus kasları arasında aktivasyon farkı gözlenmiş, ancak bu fark istatistiksel olarak anlamlı bulunmamıştır. Yine de her iki kasın da yüksek düzeyde aktive edilmesi, NHE'nin genel hamstring kuvvetlendirme programları açısından etkinliğini desteklemektedir. Anlamlılık düzeyine ulaşmayan bu farklılıkların klinik açıdan dikkate alınması gerektiği, çünkü küçük örneklem büyüklüklerinde istatistiksel anlamlılığın her zaman ortaya çıkmayabileceği unutulmamalıdır.

Termografi sonuçları değerlendirildiğinde, NHE sonrasında biceps femoris kasında anlamlı bir sıcaklık artışı gözlenmiştir ($p = 0,003$, $g = 1,01$). Bu bulgu, NHE'nin özellikle biceps femoris

kasında metabolik talep oluşturduğunu ve dolaşım ile kas yüzey sıcaklığında belirgin artışa yol açtığını göstermektedir. RCH grubunda da biceps femoris kasında sıcaklık artışı gözlenmiş, ancak bu artış istatistiksel olarak anlamlı bulunmamıştır. Buna rağmen orta düzeyde bir etki büyüklüğü hesaplanmış olması, RCH'nin de biceps femoris kasında dikkate değer bir metabolik yanıt oluşturabileceğini düşündürmektedir.

Semitendinosus kasında her iki egzersiz sonrasında da sıcaklık artışı gözlenmiştir. NHE grubunda bu artış büyük etki büyüklüğüyle desteklenmiş ($p = 0,004$, $g = 0,80$), RCH grubunda ise orta düzeyde bir artış saptanmıştır ($p = 0,012$, $g = 0,50$). Gruplar arası karşılaştırmalarda semitendinosus kasındaki sıcaklık artışları açısından anlamlı bir fark bulunmamıştır. Bu bulgu, her iki egzersizin de semitendinosus kasını benzer düzeyde uyardığını göstermektedir.

Özetle, EMG sonuçları RCH'nin özellikle biceps femoris kasında daha yoğun elektriksel aktivasyona yol açtığını ortaya koyarken, termografi sonuçları NHE'nin biceps femoris kasında daha yüksek metabolik yanıt oluşturduğunu göstermektedir. Bu durum, her iki egzersizin farklı fizyolojik mekanizmalar üzerinden kasları aktive ettiğini düşündürmektedir. Ayrıca, anlamlı bulunmayan ancak eğilim gösteren sonuçların da dikkate alınması gerektiği, çünkü bu tür bulgular ileride daha geniş örneklemlerle yapılacak çalışmalar için yol gösterici olabileceği sonucuna varılmıştır.

Sonuç: Bu çalışma, Asyalı bireylerden oluşan bir örneklemde Nordic Hamstring Exercise (NHE) ve Single-leg Roman Chair Hold (RCH) egzersizleri sırasında biceps femoris (BF) ve semitendinosus (ST) kaslarının aktivasyon örüntülerini hem elektromiyografi (EMG) hem de infrared termografi (IRT) kullanarak karşılaştırmalı biçimde incelemiştir. Elde edilen bulgular, literatürde daha önce yapılan çalışmalardan kısmen farklı sonuçlar ortaya koymuştur. Özellikle önceki araştırmaların çoğunda NHE'nin daha çok semitendinosus kasını aktive ettiği bildirilmişken, bu çalışmada hem NHE hem de RCH egzersizleri sırasında biceps femoris kasında daha yüksek aktivasyon gözlenmiştir. Bu durum, Asyalı popülasyonda kas mimarisinin ve kas içi aktivasyon stratejilerinin farklılık gösterebileceğini düşündürmektedir.

EMG sonuçları, RCH egzersizinin özellikle ek yükle uygulandığında biceps femoris kasında anlamlı derecede daha yüksek aktivasyon sağladığını ortaya koymuştur. Bu bulgu, isometrik temelli egzersizlerin, özellikle kalça-dominant olanların, biceps femoris kasını etkin şekilde hedefleyebileceğini göstermektedir. Buna karşın, semitendinosus kası açısından NHE ve RCH egzersizleri arasında anlamlı bir fark bulunmamıştır. Dolayısıyla, RCH'nin özellikle biceps

femoris odaklı bir aktivasyon sağladığı, NHE'nin ise her iki kası da dengeli bir şekilde uyardığı söylenebilir.

Termografi sonuçları, NHE'nin biceps femoris kasında belirgin metabolik yanıt oluşturduğunu göstermiştir. NHE sonrasında kaydedilen anlamlı sıcaklık artışı, bu egzersizin kas üzerinde daha yüksek metabolik talep oluşturduğunu ve dolaşım artışı sağladığını düşündürmektedir. RCH sonrasında da sıcaklık artışı gözlenmiş, ancak bu artış istatistiksel olarak anlamlı bulunmamıştır. Yine de orta düzeyde etki büyüklüğüne ulaşılması, RCH'nin de metabolik açıdan dikkate değer bir yanıt oluşturabileceğini göstermektedir. Semitendinosus kası açısından her iki egzersiz de sıcaklık artışına yol açmış, ancak gruplar arasında anlamlı bir fark bulunmamıştır.

Bu çalışmanın bulguları literatürdeki bazı sonuçlarla uyumlu olmakla birlikte, bazı farklılıklar da içermektedir. Özellikle önceki çalışmaların çoğu NHE'nin semitendinosus kasını daha fazla aktive ettiğini rapor ederken, bu çalışmada biceps femoris kasında daha yüksek aktivasyon gözlenmiştir. Bu farklılık, etnik ve anatomik faktörlerle açıklanabilir. Asyalı bireylerde kas mimarisi, tendon yapısı, fasikül uzunluğu ve kas lifi tip dağılımı farklılık gösterebilir. Bu farklılıklar, egzersiz sırasında kasların aktivasyon stratejilerini değiştirebilir. Ayrıca, bireylerin antrenman geçmişleri, fiziksel aktivite düzeyleri ve biyomekanik özellikleri de bu sonuçların ortaya çıkmasında rol oynamış olabilir.

Klinik açıdan değerlendirildiğinde, bu çalışma hem NHE hem de RCH egzersizlerinin hamstring kaslarının kuvvetlendirilmesinde ve yaralanmaların önlenmesinde kullanılabileceğini göstermektedir. NHE, kolay uygulanabilirliği, literatürde kanıtlanmış etkinliği ve biceps femoris kasında güçlü metabolik yanıt oluşturması nedeniyle önleyici programlarda öncelikli olarak tercih edilebilir. RCH ise özellikle ek yüklerle uygulandığında biceps femoris kasını yüksek düzeyde aktive etmesi sebebiyle değerli bir alternatif egzersizdir. Bu nedenle, hamstring yaralanmalarını önleme programlarında her iki egzersizin birlikte kullanılması, kas gruplarının farklı özelliklerini hedeflemek açısından faydalı olabilir.

Bu çalışmanın sonuçları aynı zamanda etnik farklılıkların kas aktivasyon paternleri üzerinde etkili olabileceğini göstermiştir. Literatürde çoğu çalışma Batılı popülasyonlar üzerinde yapılmışken, bu araştırmanın Asyalı bireyler üzerinde gerçekleştirilmesi, kas mimarisi ve aktivasyon stratejilerindeki varyasyonları ortaya koyması açısından önemlidir. Bu durum, gelecekte farklı popülasyonlarda yapılacak araştırmaların gerekliliğini ortaya koymaktadır. Daha

büyük örneklem büyüklükleriyle ve farklı etnik grupları kapsayan çalışmalar, elde edilen bulguların genellenebilirliğini artıracaktır.

Sonuç olarak, bu çalışma NHE ve RCH egzersizlerinin hamstring kas aktivasyonları üzerindeki etkilerini karşılaştırmalı biçimde incelemiş, her iki egzersizin de farklı fizyolojik mekanizmalarla kasları uyardığını ortaya koymuştur. NHE, özellikle metabolik yanıtı artırması nedeniyle, RCH ise ek yükle uygulandığında biceps femoris kasında sağladığı güçlü aktivasyon nedeniyle önleyici programlara dahil edilmelidir. Elde edilen bulgular hem sporcu sağlığının korunması hem de performansın artırılması açısından önemli katkılar sunmaktadır.

Anahtar Kelimeler: Biceps femoris, eksantrik egzersiz, elektromiyografi, hamstring zorlanma yaralanmaları, yaralanma önleme, Nordic hamstring egzersizi, Roman Chair-hold egzersizi, semitendinosus.

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ABSTRACT

Introduction: Hamstring strain injuries (HSI) are frequent in sprinting sports and often result in high recurrence rates and considerable time loss. The biceps femoris (BF) is the most commonly injured hamstring muscle, usually strained during the late swing phase of running. While eccentric training, such as the Nordic hamstring exercise, is widely used for prevention, recent evidence indicates that hip-dominant isometric exercises might target the vulnerable muscle more effectively. However, comparative data on muscle activation during these exercises are still limited.

Methodology: This study employed a parallel-group randomised longitudinal trial design for thermography measurements and a quasi-experimental, randomised, parallel-group, cross-sectional design for electromyography (EMG) assessments. Twenty-four physically active participants aged 18 - 35 were recruited and randomly assigned to perform either the Nordic Hamstring Exercise (NHE) or the Single-leg Roman Chair Hold (RCH). The medial (semitendinosus (ST)) and lateral (BF) hamstrings' muscle activations during three sets of exercises were measured using EMG and infrared thermography under controlled laboratory conditions. EMG data were normalised via maximal voluntary isometric contractions (MVIC), and thermographic imaging was conducted before and after exercise sessions to assess muscle temperature changes. Statistical analyses included mixed-model and one-way ANOVA to compare muscle activation between groups. Additionally, Hedges' (adjusted) *g* effect sizes were calculated for each intervention.

Results: There were no significant differences in participants' physical characteristics between the Nordic Hamstring Exercise (NHE) and single-leg Roman Chair-Hold (RCH) groups. Both exercises elicited higher EMG activations in the biceps femoris (BF) than in the semitendinosus (ST), though these differences were not statistically significant within groups. The

RCH group demonstrated significantly greater mean EMG activation in the BF during the second set with added load ($p = 0.038$, $g = 0.93$), and overall higher mean BF EMG activation compared to the NHE group ($p = 0.044$, $g = 0.87$). Thermographic analysis showed a significant temperature increase in the BF following NHE ($p = 0.003$, $g = 1.01$), which was greater than the nonsignificant thermal change observed after RCH ($p = 0.234$, $g = 0.26$). Both exercises produced significant thermographic increases in the ST, with a large effect size for NHE ($p = 0.004$, $g = 0.80$) and a moderate effect size for RCH ($p = 0.012$, $g = 0.50$), without significant between-group differences.

Conclusions: This study reveals distinct activation patterns of the medial (ST) and lateral (BF) hamstrings during the Nordic Hamstring Exercise (NHE) and the single-leg Roman Chair Hold (RCH) in an Asian population sample compared to previous studies. Contrary to previous research, both exercises elicited greater biceps femoris activation, especially in the NHE, which also exhibited a significantly higher thermographic response in this muscle. The findings suggest ethnic differences in muscle recruitment strategies, possibly influenced by anatomical and genetic factors unique to this group. A future study is warranted to determine whether there are differences in muscle recruitment patterns during the exercises between different ethnicities. From a practical perspective, both NHE and RCH should be incorporated into hamstring conditioning and injury prevention programmes, with the NHE particularly recommended due to its feasibility and its strong activation of the biceps femoris.

Keywords: Biceps femoris, eccentric exercise, electromyography, hamstring strain injuries, injury prevention, Nordic hamstring exercise, Roman Chair-hold exercise, semitendinosus.

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SYMBOLS AND ABBREVIATIONS

ACL: Anterior Cruciate Ligament

ACTN3: Alpha-actinin-3

ANOVA: Analysis of Variance

BF: Biceps Femoris

BFlh: Biceps Femoris Long Head

EMG: Electromyography

GHR: Glute-ham Raise

HSI: Hamstring Strain Injury

IBM SPSS: IBM Statistical Package fort he Social Sciences

IPAQ-sf: International Physical Activity Questionnaire – Short Form

IMT: Intramuscular Tendon

IRT: Infrared thermography

LSET: Lengthened State Eccentric Training

MVIC: Maximal Voluntary Isometric Contraction

NHC: Nordic Hamstring Curl

NHE: Nordic Hamstring Exercise

PAR-Q: Physical Activity Readiness Questionnaire

PCSA: Physiological Cross-Sectional Area

RCH: Roman Chair Hold

RB: Roman Bench

RDL: Romanian Deadlift

ROI: Region of Interest

RMS: Root Mean Square

SENIAM: Surface Electromyography for Non-Invasive Assessment of Muscles

SLHB: Single-leg Hamstring Bridge

SM: Semimembranosus

SPSS: Statistical Package for the Social Sciences

ST: Semitendinosus

%: Percent

°C: Degree Celsius

n: Number of subjects in the sample

p: Statistical significance level

Δ: Change

1. INTRODUCTION

Hamstring strain injuries (HSI) are endemic in sprinting, involving sports ranging from amateur to professional levels (1) such as American football, Australian Rules football, track and field disciplines, rugby union and soccer. (2-6). The HSI rates are calculated as 24% in soccer (3), 26% in track and field (7), 13.7% in Australian football (8), 12% of all American football injuries (4) and 6-15% of all injuries in rugby (9). Additionally, the injury rates have shown an incremental trend in sports, e.g. soccer, Australian Rules football, and rugby (10). For instance, the HSI rate in soccer had annually risen by 4% between 2001 and 2014, (11) and it had also risen annually by 3.9 - 6.7 % (match and training, respectively) between 2014-2022 (3). Consequently, the HSI has constituted 24 per cent of all injuries in soccer (3). Furthermore, the HSI recurrence rates are also high among athletes, such as 32% in American football (12), 21% in rugby (9), 27% in Australian football (13), and 16% in soccer (14). Importantly, these repeated HSIs are more severe and cause more time loss than the initial HSI (9). Beyond the mentioned reinjury rates, recurrent HSI may lead to enthesopathy, problems in meniscuses of the knee, adhesion in the popliteal nerve, motor dysfunction of the ischiatic nerve, abnormal quadriceps power and the end of athletic career (15-17). Therefore, scientists have focused on providing an optimal prevention technique for HSI before their initial occurrences over the past twenty years (18).

Medical and sports specialists have been focusing on identifying risk profiles, which involve complex and phenomenal interactions between risk factors, to identify risk patterns of sports injuries (19). Accordingly, prospective studies have identified a variety of risk factors for HSI, including, but not limited to, injury history (e.g. calf strains (20-25), HSI (20, 21, 25-27), knee injuries (28, 29), and anterior cruciate ligament injuries (20, 21, 25), ankle injuries (30), older age (23, 26, 29, 31, 32), ethnicity (29, 32, 33), strength imbalances (24, 31, 34-43), fatigue (39, 40, 44-46), lower eccentric strength (28, 47-49), lower isometric strength (47, 48), lower single-leg hamstring bridge (SLHB) performance (28), the lesser single-leg hop distance (48), insufficient warm-up (50), increased anterior pelvic tilt (32, 51), altered intermuscular coordination (49, 52, 53), hamstring muscle architecture, structure, and morphology

(shorter fascicle length, higher passive muscle stiffness and fast muscle fibre typology) (25, 54-56), higher differences between countermovement jumps and non-countermovement jumps (57), increased electromyographic (EMG) activity of the gluteus medius muscle (58), elevated high-speed running exposure (59, 60), lesser EMG activity of the trunk muscles (61), thoracic bending at the front-swing phase of sprinting (62), increment in anterior pelvic tilt at the backswing phase of sprinting (62).

Amongst hamstring muscles, the most frequently injured muscle is stated as the biceps femoris long head (BFlh) (63). In detail, HSI was estimated to be more than 60% in soccer (32), 80% in Australian rules football (64), 80% in Australian rules football (64), and 100% in sprinters (15). The late swing phase of high-speed running was pointed out as the most vulnerable time for hamstring injuries (65-67). At the late swing phase of running, hamstring muscles generate eccentric contraction and force to decelerate the tibia and control the quadriceps femoris, which is an antagonist to the hamstrings (68). Among the hamstrings, the biceps femoris (BF) reaches 109.5% of its length, which is greater than the semitendinosus (ST) (107.4%) and semimembranosus (SM) (108.1%) muscles due to the elongation at the late swing phase of running (69). At this moment, HSI generally occurs when the muscle fibres cannot resist excessive force (70). In this way, deficient eccentric hamstring muscle contraction during the late swing phase of running was considered the leading cause of HSI (67, 71). Subsequently, scientists, medical and sports professionals have focused on improving possible deficiencies in the hamstring and proposed eccentric training modalities, including the popular Nordic hamstring exercise (NHE), to prevent future HSI (72-75). However, recent research conducted via electromyography (EMG) (76) and magnetic resonance imaging (77-80) found that NHE primarily targets the semitendinosus muscle (ST) rather than the biceps femoris, which is the most frequently injured muscle among the hamstrings, due to its knee dominance; and they suggested that hip-dominant exercises may lead more activation in the biceps femoris compared to knee-dominant exercises.

On the other hand, Van Hooren and Bosch (81, 82) have recently initiated a discussion about the contraction type of hamstrings during the late swing phase of running and suggested that hamstrings contract isometrically at this moment. As a result, Van Hooren and Bosch (81, 82) suggested that high-intensity isometric

exercises, e.g. Single-leg Roman chair hold exercise (RCH), are a more efficient alternative to eccentric exercises, including the NHE. Following this, McDonald et al. (83) The NHE and RCH were compared in terms of their effectiveness in improving strength endurance, which was measured by the single-leg hamstring bridge test, which was previously defined as a risk factor for HSI. As a consequence, McDonald et al. (83) stated that the RCH was more effective in improving the outcome parameter than the NHE. In summary, there is a debate ongoing in the literature regarding the supremacy of eccentric training and isometric training for providing optimal injury prevention for HSI, considering the mechanism of injury (81-86).

It has been previously stated by recent research conducted via electromyography (EMG) (76) and magnetic resonance imaging (77-80) that NHE primarily targets the ST rather than the BF is the most frequently injured muscle among the hamstrings. Despite the ongoing debate, comparing muscle activation during the NHE and RCH exercises is limited by electromyography studies (EMG) and ultrasound-measured fascicle behaviours (87). Therefore, a new study comparing muscle activations during the NHE and RCH using other techniques, including recently introduced thermography measurements and EMG, is warranted for strengthening the relevant evidence in the literature. Therefore, this study aimed to compare hamstring muscle activations during the NHE and RCH training protocols (88) via thermography, and EMG to detect the exercise that targets the most frequently injured muscle. The hypotheses of this study are as follows:

1) NHE would generate higher activation in the ST than in the BF muscle.
2) RCH would lead to greater activation in BF muscle than ST muscle due to its hip-dominant movements.
3) RCH would lead to activated BF muscle than NHE at the second and third sets due to the external weight-bearing at the hip-dominant movement (88).
4) NHE would produce more activation in the ST muscle compared to RCH exercise at the first set (RCH would be applied without external weight according to the protocol (88).
5) RCH would generate more activations in both BF and ST at the second and third sets (according to the protocol, RCH was applied with an external weight holding).

2. GENERAL INFORMATION

2.1. OVERVIEW OF HAMSTRING STRAIN INJURIES

Hamstring strain injuries (HSI) are prevalent in sports characterized by high-speed movements and are associated with elevated recurrence rates (89, 90). These injuries can lead result in extended absences from sports and could potentially lead to severe consequences, including injuries that terminate professional careers (90). HSI constitute one of the most prevalent non-contact musculoskeletal injuries in sports characterized by high-speed running, kicking, and rapid directional changes. In field-based team sports, HSIs account for about 10% of all injuries, with an incidence rate of around 0.81 per 1,000 athlete exposure, based on prospective meta-analyses covering over seven million hours of recorded exposure (91). Risk factors for HSIs are multifaceted, necessitating comprehensive intervention strategies (89). Rehabilitation programs should target these risk factors and follow evidence-based training guidelines to lower injury rates and severity (89, 92). However, insufficient criteria for returning to sport could lead to premature returns and higher re-injury rates (92). Ongoing research is vital for discovering more effective methods to prevent and treatment strategies for HSIs (90, 93).

2.2. EPIDEMIOLOGY OF HAMSTRİNG INJURIES ACROSS SPORTS DISCIPLINES

Hamstring strain injuries have been extensively examined across various sports, and recent epidemiological data provide significant insights into their incidence and distribution (94, 95). Systematic reviews and large prospective studies show that HSIs remain among the most prevalent non-contact injuries in field-based team sports (94, 96). For instance, a 2021 meta-analysis encompassing over 3,800 male soccer players and two million hours of exposure reported that acute hamstring injuries occur at an incidence rate of 0.3 to 1.9 injuries per 1,000 hours of play, accounting for approximately 5% to 15% of all soccer-related injuries (96, 97). A recent systematic review among female field-sport athletes, a recent systematic review reported an incidence of about 0.6 injuries per 1,000 hours of exposure (95% CI 0.4–0.8), highlighting that HSIs remain a notable injury concern in female populations (98).

In professional rugby union, hamstring injuries make up about 15% of all injuries players face. The frequency of these injuries can vary quite a bit, ranging from roughly 0.27 per 1,000 hours of training to as many as 5.6 cases per 1,000 match hours (33, 99). Notably, approximately 68% of these injuries occur during running actions, and recurrent hamstring injuries typically result in more extended time-loss periods compared to initial injuries (99). In an analysis of European professional football leagues, a significant and troubling trend has been observed: hamstring injuries are becoming a far more common problem. The percentage of all injuries that are hamstring-related has jumped from about 12% in 2001 to roughly 24% by the 2021-22 season. This alarming increase has raised concerns throughout the sport and is connected to a higher overall injury rate, which, in turn, means players are spending more time on the sidelines (94).

In conclusion, these findings highlight the critical importance of addressing hamstring injuries in sports that involve a lot of high-speed running and explosive movements (95). Because the frequency and impact of hamstring injuries vary based on the type of sport, the athlete's sex, and the level of competition, it's essential to use customized prevention and rehabilitation plans to reduce their occurrence and severity effectively (98).

2.3. CLINICAL CONSEQUENCES OF RECURRENT HSIS

Recurrent hamstring strain injuries (HSIs) considerably elevate the risk of long-term functional impairment among athletes. These recurrent injuries are often linked to more severe clinical symptoms and extended recovery periods, and they predominantly occur at the same anatomical site as the initial injury (95). When compared to non-intramuscular cases, elite athletes with intramuscular tendon involvement have been shown to have longer time to return to play (TTRTP) and re-injury rates as high as 60% (95, 100, 101).

Impaired neuromuscular function, long-term strength deficiencies, and tissue pathology like enthesopathy and scar tissue formation at the musculotendinous junction are among the persistent issues linked to recurrent HSIs (102). Unless rehabilitation protocols are specifically tailored to address tendon healing dynamics,

these structural changes, particularly within intramuscular tendon (IMT) injuries, may predispose athletes to longer recovery periods and further recurrence (102-105).

A 2023 systematic review of proximal hamstring tendon repairs found that the overall postoperative complication rate was 15.3%, with significant risks of sciatic nerve injury (1.7%) and persistent myopathy (up to 2.4%) in cases that underwent surgery (105). In contrast to stabilization-focused rehab, which has a significantly lower recurrence rate (e.g., ≤7.7%), incomplete rehabilitation, especially without functional criteria and structured progression, has been linked to reinjury rates as high as 70%, even in conservative management pathways (103-105).

Additionally, there is evidence that athletes returning to sports with unresolved pain, weakness, or flexibility problems are at a significantly higher risk of reinjury, especially when injury protocols are not properly tailored or when loading progression is inadequate (95).

2.4. FUNCTIONAL ANATOMY AND BIOMECHANICS OF THE HAMSTRINGS

2.4.1. Muscle Anatomy and Regional Structure

The hamstring muscle complex consists of the biceps femoris (long and short heads), semitendinosus, and semimembranosus located within the posterior compartment of the thigh (106). These muscles mainly originate from the ischial tuberosity, except for the short head of the biceps femoris, as it originates from the linea aspera of the femur, and they insert on the proximal tibia and fibula, facilitating coordinated movements such as hip extension and knee flexion (107).

The hamstrings not only help with primary movements but also assist in secondary actions like rotating the tibia and stabilizing the pelvis during active movements such as sprinting and jumping (108). Each hamstring muscle has a unique fiber arrangement and tendon length, which play a crucial role in how our body handles the mechanical stresses during rapid movements (109).

2.4.2. Muscle Architecture and Fiber Characteristics

The architecture of the hamstring muscles, characterized by fascicle length, pennation angle, physiological cross-sectional area (PCSA), and tendon compliance, constitutes a critical factor in determining their function and vulnerability to injury (108).

Fascicle length reflects the number of sarcomeres aligned in series; longer fascicles allow for a greater range of contraction and are associated with a reduced risk of injury. In contrast, shorter fascicles (often seen in BFlh) are linked to higher vulnerability during eccentric loading (110). Training such as the NHE has been documented to increase fascicle length by 10–30%, thereby enhancing muscle resilience (111).

Pennation angle is the angle between fibers and the tendon; smaller angles enhance force transmission efficiency and contraction velocity (112).

Physiological Cross-Sectional Area (PCSA) reflects the total cross-sectional area of fibers perpendicular to their orientation and is proportional to maximum force output. The PCSA, an indicator of force-generating capacity, is generally greater in the semimembranosus muscle than BFlh, explaining its capacity for sustained force production despite experiencing less strain (108).

Tendon compliance indicates the elastic capacity of tendinous structures, allowing energy storage and recoil during sprinting (107).

Research on architectural adaptation indicates that a 9 week NHE intervention resulted in a 19% increase in BFlh fascicle length centrally and a 33% increase distally, accompanied by approximately 40% improvements in eccentric strength, although these effects were partially reversed following a detraining period (111). Furthermore, architectural heterogeneity exists along the length of the muscle; fascicle length, thickness, and orientation may differ regionally, thereby impacting localized injury and the recovery process (108).

2.4.3. Regional Variations and Gender-Based Differences

Research shows that the hamstring muscles exhibit notable differences across various regions. In particular, the lengths of fascicles tend to vary between the proximal and distal regions, tendon stiffness is not uniform along the muscle, and neural activation patterns also change along the length of the muscle belly (108). Such heterogeneity may play a role in the development of localized injury hotspots, especially in the long head of the biceps femoris, which is frequently prone to proximal tears (113).

Studies on elite athletes have shown that there are generally no significant differences in fascicle length or pennation angles between males and females; however, it is noted that males tend to have greater muscle thickness and overall muscle volume, factors which can affect their strength and force output (114). These distinctions are essential considerations in the formulation of customized strength training and rehabilitation programs within sports medicine, ensuring that interventions are properly adapted to each gender (108).

2.4.4. Force-Length Relationship and Moment Arms

The hamstrings function according to distinct segments of their force-length curves, affecting torque generation at the hip and knee joints (109).

The semitendinosus muscle displays a more flattened force-length relationship and plays a greater role in quick, rapid contractions rather than maintaining prolonged force generation. The long head of the biceps femoris features shorter fascicles and smaller moment arms, which may increase its vulnerability to overstrain during eccentric deceleration (106).

The semimembranosus muscle features the largest PCSA and the most extended moment arm, allowing it to withstand higher sustained loads during hip extension, highlighting its vital role in supporting hip joint stability and function (108).

2.4.5. Biomechanics During Sprinting

Hamstring strain injuries frequently happen during sprinting activities, particularly during the terminal swing phase, when the risk of injury is at its highest (107, 115). During this phase, the hamstring muscles experience peak strain, generate the greatest force, and perform negative work, with biceps femoris exhibits the highest level of strain (107). The injury probably results from an eccentric contraction occurring just before the foot-strike (116). During high-speed running, the hamstring muscles endure significant eccentric forces, which can reach up to eight times the body's weight especially in the final phase of the swing (107). Following an injury, hamstring muscles tend to exhibit a diminished capacity for eccentric contractions, with decreased peak length and decreased negative work during the terminal swing phase (115). Nevertheless, there is also a possibility of injury occurring during the late stance phase (117). The differences in biomechanics between the legs can play a role in the risk of injury risk, with the injured leg tends to exhibit greater knee extension and longer hamstrings during terminal swing, and increased torque from the hip extensor during the initial stance (116). Faulty sprint mechanics, including over-striding, excessive anterior pelvic tilt, or incorrect trunk alignment, can increase the risk of hamstring strain and may lead to injuries in athletes to injury prevention (118).

2.4.6. Neuromuscular Coordination and Kinesiology

The hamstring muscles are essential for effective neuromuscular coordination and athletic performance. Their functioning is shaped by neural, architectural, and morphological elements, and achieving high activation levels is vital for reaching maximum running speeds (119). Torque-sharing torque among the different heads of the hamstring muscles vary between individuals and are linked to endurance performance, with greater imbalance in torque sharing is associated with decreased endurance (120). Following anterior cruciate ligament reconstruction, individuals tend to exhibit increased hamstring activation and co-activation during gait and ambulation, as well as longer electromechanical delay, which may influence the risk of re-injury and overall joint health (121). The coordination of two-joint muscles, such as the hamstrings, is a complex; their effect is never limited to one joint, and their activity closely coordinating with other muscles during movements that involve only one joint.

In the case of movements involving two joints simultaneously, the activity of the hamstrings is typically inhibited when they act as antagonists, especially during knee motions (122).

The hamstring muscles work collaboratively with the gluteus maximus to facilitate hip extension, while the gastrocnemius muscle contributes to knee flexion during activities such as running and jumping (106). Electromyographic analyses indicate that athletes who have previously suffered from hamstring injuries often exhibit changes in the timing and intensity of muscle activation. These alterations can result in imbalances between the medial muscles (SM, ST) and the lateral muscle (BF) of the hamstring group (108). Such neuromuscular deficits can interfere with effective load sharing and may elevate the risk of reinjury during high-intensity activities (123).

2.4.7. Exercise-Specific Biomechanics and Adaptations

The Nordic Hamstring Exercise (NHE) enhances sprint and lower-limb swing phase mechanics, effectively builds eccentric hamstring strength, and aids in sustaining strength gains even following detraining (124). Targeting the biceps femoris muscle specifically, NHE promotes hypertrophy and an increase in fascicle length, both of which are advantageous because they may lower the risk of injury (119, 125).

By using isoinertial weight-stack resistance, Lengthened State Eccentric Training (LSET) primarily increases the size of muscles and aponeuroses, which are crucial for strengthening the knee flexors, in addition to encouraging muscle hypertrophy (125).

As a hip-dominant exercise, the Romanian Deadlift (RDL) may be just as beneficial as or even more so than the Nordic Hamstring Exercise (NHE) in reducing the risk of hamstring strain injuries and improving sprint performance. It also targets different facets of hamstring morphology, including fascicle length and pennation angle (126). When compared to other exercises, the Nordic Hamstring Curl (NHC) is particularly good at producing the greatest peak eccentric forces in the hamstrings and causing fascicle stretch. The semitendinosus and biceps femoris short head are its main targets (127). According to longitudinal studies, ten weeks of NHC training results in

a fascicle lengthening of about 20 millimeters, which lowers the risk of hamstring strain injuries (128).

The Single-Leg Roman Chair Hold (RCH) is a hip-focused exercise that specifically activates the semimembranosus and long head of the biceps femoris muscles (129). While the SLRCH targets back muscles, it also engages hip extensors, potentially limiting its specificity (130).

Compared to exercises like lying leg curls and good mornings, the glute-ham raise (GHR) exercise frequently results in higher activation because it efficiently engages both the concentric and eccentric muscles of the activation. The semitendinosus and biceps femoris muscles are efficiently used during forward trunk flexion and controlled extension in the morning exercise, which mostly consists of hip-focused movements (131).

Leg curls are exercises that target the semitendinosus and the short head of the biceps femoris muscles, mainly involving the knee joint (132). These exercises are often included in advanced stages of rehabilitation because they are beneficial for strengthening the hamstrings when the muscles are at shorter lengths, even though they cause less fascicle lengthening than NHC or RDL (128).

During both the isometric and concentric phases, the hip bridge exercise focuses on activating the hamstrings and gluteal muscles, especially the semitendinosus and semimembranosus muscles (131). Single-leg variations are essential for correcting limb asymmetries and improve neuromuscular engagement (133).

2.5. MECHANISMS OF HAMSTRING STRAIN INJURIES

Hamstring strain injuries frequently occur in various sports, especially during activities that involve high intensity running activities. The primary mechanisms involve excessive muscle strain during the late swing phase of sprinting, which involves trunk flexion and knee extension (106, 134). However, HSIs in rugby can also happen during situations such as deceleration, kicking, tackling, and rucking (135).

2.5.1. Sprint (Late Swing Phase)

A systematic analysis of real-world cases and biomechanical models indicates that most hamstring injuries related to sprinting tend to happen during the final (late) swing phase, when the hamstring muscles eccentrically act to decelerate knee extension under significant strain, approximately 10% elongation (106, 136). The BFlh undergoes greater maximal strain compared to the semitendinosus or semimembranosus during this phase, which aligns with its higher rate of injury incidence (134, 136). The real-time kinematic analysis suggests that the initial injury stimulus may occur prior to foot-strike, as evidenced by deviations in the trunk and pelvis observed during the mid-swing phase (116).

2.5.2. Stretch-type Injuries

Stretch-related hamstring injuries often occur during activities involving extreme hip flexion with an extended knee such as maximal kicking, forward trunk swings, or reaching during sprinting and tend to primarily affect the semimembranosus tendon, presenting initially with mild pain but typically necessitating a longer recovery period (106).

2.5.3. Stance-phase Strain Considerations

Emerging research indicates that early stance phase mechanics such as elevated ground reaction forces combined with hip flexion torque can also create tensile overload in the biceps femoris, particularly significant when trunk lean is modified, potentially increasing the risk of acute injury (136).

2.5.4. Fatigue and Strength Deficits

Fatigue can diminish eccentric strength and cause persistent neuromuscular inhibition, especially in athletes with prior hamstring injuries, thereby potentially compromising their ability to control deceleration and increasing the risk of future injury risk (137, 138).

2.5.5. Neuromuscular Coordination and Trunk Mechanics

Impaired control of the lumbo-pelvic region, particularly in muscles such as the gluteus maximus, gluteus medius, internal and external obliques, and erector spinae, has been significantly associated with a higher risk of hamstring strain during dynamic movements. Prospective studies indicate that delayed activation of these muscles in individuals who later experience hamstring injuries suggests that neuromuscular coordination issues may contribute to increased injury susceptibility (106, 139).

Excessive forward trunk lean or lateral trunk rotation during sprinting or in response to disturbances can increase the strain by altering the kinematic relationship between the pelvis and muscle attachments, particularly due to the iliopsoas muscle inducing an anterior pelvic tilt lengthens the biceps femoris long head (BFlh) and subsequently elevates its tensile load (106, 107).

In unanticipated trunk perturbation tests, athletes with a history of HSI showed delayed activation of the erector spinae and gluteus maximus muscles compared to controls, suggesting impaired stabilization of the lumbopelvic region may further reduce the protection of the hamstrings during high-demand activities (140).

2.6. INTRINSIC AND EXTRINSIC RISK FACTORS

2.6.1. Intrinsic Factors

Intrinsic factors encompass previous injuries, age, muscle imbalances, and limited flexibility (141, 142). A history of having sustained a HSI is the likelihood of experiencing future injuries, with previous injury being the most influential factor in predicting recurrence (143, 144). Reduced eccentric hamstring strength and poor endurance are consistently recognized as modifiable risk factors for both initial and recurrent hamstring injuries (143, 145). Imbalances between the quadriceps and hamstrings (Q/H) muscles, as well as disparities between the left and right limbs, can elevate the risk of injury, particularly when hamstring coordination is insufficient (144, 145). Although decreased hamstring flexibility's role in predicting injury remains uncertain, reduced fascicle length and increased tendon stiffness are believed to be

associated with a higher risk of strain (143, 146). Older age and anatomical differences, such as shorter fascicles or accessory bellies, are non-modifiable risk factors that can be partially mitigated through customized training interventions (146).

2.6.2. Extrinsic Factors

Extrinsic factors include insufficient warm-up routines, unsuitable training activities, and the quality of playing surfaces (147). Frequent matches, such as two to three times per week, along with tightly packed competition schedules and inadequate load management, can significantly increase the risk of hamstring injuries, particularly among elite football players (143, 145). Insufficient training in eccentric and high-speed running, as well as a lack of adequate exposure to proper sprinting mechanics, can elevate the risk of hamstring injuries (148). There have been reports from medical officers at elite clubs indicating that poor coordination between coaching and medical staff, along with controlling leadership styles, have been linked to injury clusters, as reported by elite club medical officers (145). Limited recovery during the season, combined with inadequate training programs in the off-season and insufficient buildup of load before the season begins, can hinder proper tissue adaptation and increase the risk of injury (149). Athletes who exhibit obsessive passion, have limited health literacy, or tend to train through pain and hide symptoms are at a higher risk of developing HSI, particularly in high-stress training environments (150).

2.7. ETHNIC AND ANATOMICAL VARIATIONS IN HAMSTRING FUNCTION

Variations in the anatomy and physiology of hamstring muscles can influence the likelihood of injury risk (146). The long head of the biceps femoris features shorter, more pennated fibers closer to the origin, whereas the semitendinosus includes a tendinous inscription known as the raphe (151, 152). Variations in muscle anatomy such as muscle bellies, tendon length, aponeurosis width, and fiber types among individuals and within the same person influence hamstring performance and injury risk, highlighting the importance of these differences (146). These innate structural characteristics are partly inherited or developed and may increase the likelihood of strain due to concentrated stress at the point where muscle and tendon meet (153).

Verrall et al. (154), who found that Australian Rules football players of Aboriginal descent are more likely than their teammates to experience a primary hamstring injury. According to Woods et al. (32), individuals of Black ethnic background tend to exhibit a greater anterior pelvic tilt, which overstretches the hamstring complex, potentially increasing their risk of injury. According to other researchers (154), individuals of Aboriginal heritage may have an increased likelihood of experiencing hamstring injuries, potentially due to a higher proportion of type-II muscle fibers in their hamstrings (155).

2.8. STRATEGIES FOR INJURY PREVENTION

Eccentric-focused training programs, especially those that incorporate the NHE, have been consistently demonstrated to significantly decrease the incidence of hamstring strain injury incidence by approximately 57 to 70%, while also improving fascicle length, muscle strength, the hamstrings to quadriceps strength ratio, and help reduce limb asymmetries (156). Furthermore, meta-analysis suggests that engaging in training sessions twice a week over a period of 21 to 30 weeks can significantly decrease hamstring injury rates by as much as 46% and general lower limb injuries by approximately 28% (157).

2.8.1. Progressive Muscle Strengthening

Eccentric hamstring strength training, especially through the NHE, has been shown to be highly effective in minimizing the risk of injury risk, with studies showing a significant decrease in injury incidence by up to 70% (156, 158). Eccentric training enhances hamstring strength, increases fascicle length, and improves the hamstring/quadriceps ratio, all of which are essential components in preventing injuries (156).

2.8.2. Optimal Workload Management

Effective management of training loads involves gradually increasing training intensity and volume, tailored to the athlete's current condition, to prevent overuse injuries and fatigue (157). Monitoring systems that monitor player load, schedule

recovery sessions, and align training intensity with each athlete's readiness are linked to a reduction in injury clusters (159).

2.8.3. Neuromuscular and Core Stabilization Training

Programs that incorporate core and lumbopelvic stabilization exercises, such as those targeting the gluteal muscles, transverse abdominis, and erector spinae, play a vital role in reducing injury resistance by enhancing neuromuscular coordination and strengthening the connection between trunk and lower limb control (156, 159).

2.8.4. Multidimensional, Tailored Prevention Programs

Individualized prevention strategies that incorporate aspects such as eccentric training, flexibility, neuromuscular control, biomechanical correction, and athlete education have been shown to be more effective than programs focusing on a single component (156, 160).

2.9. ELECTROMYOGRAPHY

2.9.1. Definition and Principles

Electromyography, commonly known as EMG, is a diagnostic procedure employed to evaluate neuromuscular disorders by measuring the electrical activity in accurate diagnosis and effective treatment planning (161). It involves the use of specialized electrodes, amplifiers, and display systems designed to capture and analyze muscle potentials also EMG can distinguish between neuropathies and myopathies by examining the characteristics of motor unit potentials and interference patterns (162). In infants and children, the use of EMG along with nerve conduction studies serves as a valuable tool in diagnosing various disorders affecting nerves, neuromuscular junctions, and muscles (163). This technique is widely used in areas such as biofeedback, gait analysis, and clinical diagnosis, reflecting its significance in medical and research settings (164). EMG signals represent the combined activity of individual motor units and this technology offers important insights into muscle activation timing, amplitude, fatigue levels, and neuromuscular coordination during a variety of athletic movements (139).

2.9.2 Types of Electromyography

Electromyography is a versatile and non-invasive technique used to record the electrical activity of muscles, with surface and high-density surface EMG suited for large and superficial muscles, while intramuscular methods like fine-wire and needle electrodes are more appropriate for examining deep or small muscles (165, 166). Needle EMG is particularly useful for identifying spontaneous potentials and analyzing changes in motor units, which are essential in the diagnosis of neuromuscular disorders (167). The selection of an appropriate EMG technique should be made considering the particular research goals and the specific characteristics of the muscles involved (166). Proper selection and strategic placement of electrodes are essential for ensuring high-quality signals and accurate interpretation, with each technique offers unique advantages and limitations that should be carefully considered (165, 166).

2.9.3 Signal Processing and Normalization

Various techniques are employed to extract meaningful information from EMG signals, including filtering, spectral analysis, wavelet transform, and modeling (168, 169). These techniques are designed to effectively handle challenges like eliminating noise and accurately interpreting signals, ensuring clearer and more reliable results (168, 170). EMG signal analysis can be viewed from two perspectives: a comprehensive, overall examination of interference signal properties, and a more detailed analysis focusing on individual motor units, achieved Advanced processing methods, including higher-order statistics and spatio-temporal analysis, offer valuable insights into muscle activation patterns, fatigue levels, and motor unit characteristics higher-order statistics and spatio-temporal processing provide insights into muscle activation dynamics, fatigue, and motor unit characteristics (171).

2.9.4 Crosstalk in Electromyography

Surface EMG crosstalk, which involves detecting signals from muscles that are not actively contracting, mainly results from non-propagating components generated at the muscle-tendon junctions (172). This phenomenon may result in

misinterpretation of EMG data and can lead to an overestimation of the correlation between different muscles (173). Crosstalk signals vary in shape and frequency content from those produced by active muscles, making common quantification methods such as cross-correlation and high-pass filtering less reliable for their quantification (172, 174). Spatial filtering techniques, including single and double differential recordings, have demonstrated their effectiveness in reducing crosstalk (173, 174).

2.10. INFRARED THERMOGRAPHY

2.10.1. Definition and Principles

Infrared thermography (IRT) is a non-invasive, non-contact imaging method that detects the infrared radiation naturally emitted by the skin, providing valuable insights into underlying tissue conditions (175).

Thermography detects potential abnormalities by measuring skin temperature changes caused by blood flow variations, providing a precise, non-invasive assessment of physiological conditions (176). The non-contact aspect of thermography makes it an important diagnostic tool in various fields, offering reliable and precise evaluations of temperature-related concerns (176, 177).

2.10.2. Applications of Infrared Thermography in Hamstring Injury Screening

Infrared thermography (IRT) has become an increasingly valuable tool in the field of sports medicine, aiding in the early detection of soft tissue injuries and assisting healthcare professionals in monitoring the recovery process (176). This non-invasive, safe, and cost-effective method enables quick detection of changes in skin temperature, which can potentially signal underlying musculoskeletal issues (178). The technology's capability to identify thermal irregularities enhances its usefulness in both preventing injuries and monitoring recovery processes (179). IRT can detect temperature differences greater than 0.4°C, indicating potential muscle strain, allowing for early intervention protocols (180). Additionally, IRT plays a valuable role in evaluating treatment effectiveness by monitoring temperature variations during rehabilitation, providing insight into the healing process (181).

2.10.3. Measurement Protocols and Standardization

Standardized protocols are essential to ensure accurate and consistent measurements, including controlled environmental conditions with temperatures between 18-25°C, allowing a 15-minute period for acclimatization, and positioning the patient positioning (182). The Thermographic Imaging in Sports and Exercise Medicine consensus emphasizes the importance of conducting image capture in a controlled laboratory setting. It is recommended to maintain a comfortable ambient temperature ranging from 18 to 23 °C, with relative humidity levels between 40 and 60%, and avoidance of air drafts, direct sunlight, or nearby heat sources during the imaging process to ensure accurate results (183).

Thermography effectively identifies temperature differences associated with muscle imbalances, tension, and activation levels, typically measuring mean temperatures between 32.97°C and 34.90°C in the muscles of the head and neck muscles (184). For imaging of the hamstring imaging specifically, ROI in accordance with the anatomical boundaries of the posterior thigh muscles, typically using circular or polygonal shapes to accurately measure both mean and maximum skin temperature values for the identification of potential injury-related asymmetries (185).

3. METHODOLOGY

3.1. DESIGN, TIMING AND LOCATION OF RESEARCH

This research used two main designs for each outcome: A parallel group randomised longitudinal trial for thermography measurements and a quasi-experimental, randomised, parallel-group, cross-sectional study for EMG measurements. Although crossover designs are common in electromyography (EMG) research comparing muscle activation after exercise, this study deliberately avoided such a design. This choice was made to prevent the influence of previous exercise on subsequent muscle activations, ensuring participants did not perform one exercise right after another.

Recruitment of the participants and data collection for this study were performed at Tokyo Metropolitan University facilities and laboratories in

Tokyo/Japan. This study received ethics approval from the Research Ethics Committee of Tokyo Metropolitan University Arakawa Campus (Approval No. 24088) on February 2, 2025, and data collection was completed by June 29, 2025. All participants read and signed a written informed consent form before participating in the study according to the Declaration of Helsinki Ethical Principles for Medical Research Involving Human Subjects (186).

3.2. PARTICIPANTS

Physically active participants, regardless of gender, were recruited via e-mail, electronic and hard-copy posters, advertisements and verbal announcements. The physical activity levels of the participants were classified via the Physical Activity Questionnaire short form (IPAQ-sf) (187).

The inclusion criteria for the participants were as follows: Being apparently healthy without a known chronic disease; performing 150 minutes of moderate-intensity or 75 minutes of high-intensity exercise within a week before applying to participate in this study (188) according to the IPAQ-sf (187); not having any acute lower extremity injury; not having a known hamstring injury and traumatic knee injury history, such as anterior cruciate ligament injury (77); being between 18-35 years old. The exclusion criteria for the study were as follows: a recent history of lower extremity injury; previous hamstring or traumatic knee injury; a history of cardiovascular disease; having an implanted pacemaker; and being younger than 18 or older than 35 years old.

Additionally, participants' health status was screened via the Physical Activity Readiness Questionnaire (PAR-Q) before participating in the study (189). Participants' height, weight, age, training and injury history were recorded prior to the measurements. Participants were advised not to perform any vigorous-intensity training or unaccustomed exercise one day before the measurements (190).

3.3. SAMPLE SIZE AND RANDOMISATION

Sample size calculation was performed via G*Power software (version 3.1.9.7) (191) for the F test, one-way analysis of variance (ANOVA) within-between interaction, 0.8 effect size (according to the study of Van Hooren et al., (87) (the effect size for peak EMG activations differences of the biceps femoris long head between the NHE and RCH was 1.99 (87) (both Cohen's d and Hedges' g; However, this study chose a smaller effect size (0.8) to ensure an adequate and higher sample size), 95% power, 0.05 alpha level, a nonsphericity correction value (1 for a study containing fewer than three groups), and 0.5 correlations among measurements (a lower amount than the fail-safe value of 0.7 (192-194), were chosen to ensure higher and adequate sample size), two groups and two measurements. As a result, the total required sample size was calculated as sixteen for the two groups. However, this study recruited twenty-four participants to ensure an adequate sample size (twelve participants for the NHE and twelve for the RCH groups). Randomisation of the twenty participants into the groups was performed using a 1:1 allocation ratio, with the randomisation tool feature of GraphPad QuickCalcs, considering gender stratification (the numbers of males and females were equal in the groups). A researcher (G.Y.) with no contact or knowledge about the participants performed the randomisation. In this manner, random allocation concealment was achieved (195).

3.4. EXERCISE PROTOCOLS

Both groups performed three sets of allocated exercises, NHE or RCH, by following a training protocol of McDonald et al. (83). Participants performed five repetitions per set in each group (Table 1). RCH group trained with an external weight bearing at the second and third sets corresponding to the third-fourth weeks and last week in the protocol of McDonald et al. (83). There was a 10-second break between repetitions, and the third repetition of each set was recorded for an EMG assessment. The concentric parts of the NHE movements were not performed (196). Additionally, only the single-leg hold and barbell lowering part of the RCH were recorded (87). The relevant instructions shown by Van Hooren et al. were followed during the exercises (87). There were three-minute breaks between each set (196).

Table 1. NHE and SLRCHE sets and repetitions.

	NHE	RCH
1st set	Five repetitions, 10 seconds each repetition	Five repetitions, 10 seconds of waiting at each rep
2nd set	Five repetitions, 10 seconds each repetition	Five repetitions, 10 kg plate rows
3rd set	Five repetitions, 10 seconds each repetition	Five repetitions, 20 kg plate rows

Abbreviations. NHE, Nordic hamstring exercise; RCH, single-leg Roman chair hold exercise.

3.5. NORDIC HAMSTRING EXERCISE

The traditional method, which has been defined as preventative for HSI, was used by the NHE group (74). A partner held the participant's leg and applied vertical pressure to the ankles to ensure the participant's ankle and lower legs contact the floor during the NHE (74). Participants started the NHE when their knees were at 90 degrees of flexion and hip and spine neutral (74). Afterwards, participants started to fall forward slowly by allowing the hamstrings' eccentric actions to control and resist the falling motion (74). Participants were expected to continue the falling motion as long as they could (74). This study encouraged the participants to keep this forward-falling motion for about ten seconds for more comparable results with the RCH. Participants caught the floor with their hands and arms together, with the chest touching the floor at the end of the NHE movements to minimise the concentric phase of the movement (197). To maintain the angular velocity, instructions were given to the participants by counting from ten seconds to one second (196). There was a 10-second break between the repetitions and a 3-minute break between the sets (196).



Figure 1. A photo illustrating the Nordic hamstring exercise.

3.6. SINGLE-LEG ROMAN CHAIR HOLD EXERCISE

A glute-hamstring machine was used to perform the RCH exercise, which generates predominantly isometric contraction (82). RCH exercise was completed in light of the work published by McDonald and colleagues (83). Participants took a prone position on the machine, and their knees were at a slight extension (83). The right ankle of the participants was stabilised under the glute-ham machine's pad (83). Then, participants raised their trunks until reaching a neutral hip-lumbar position. The other leg (left) was above the pad of the glute-hamstring machine for establishing the single-leg condition of the exercise (83). The reps and sets were performed as described in Table 1. This exercise was performed on the participants' right legs for comparable results with NHE, the effects of which were also measured on the right legs.

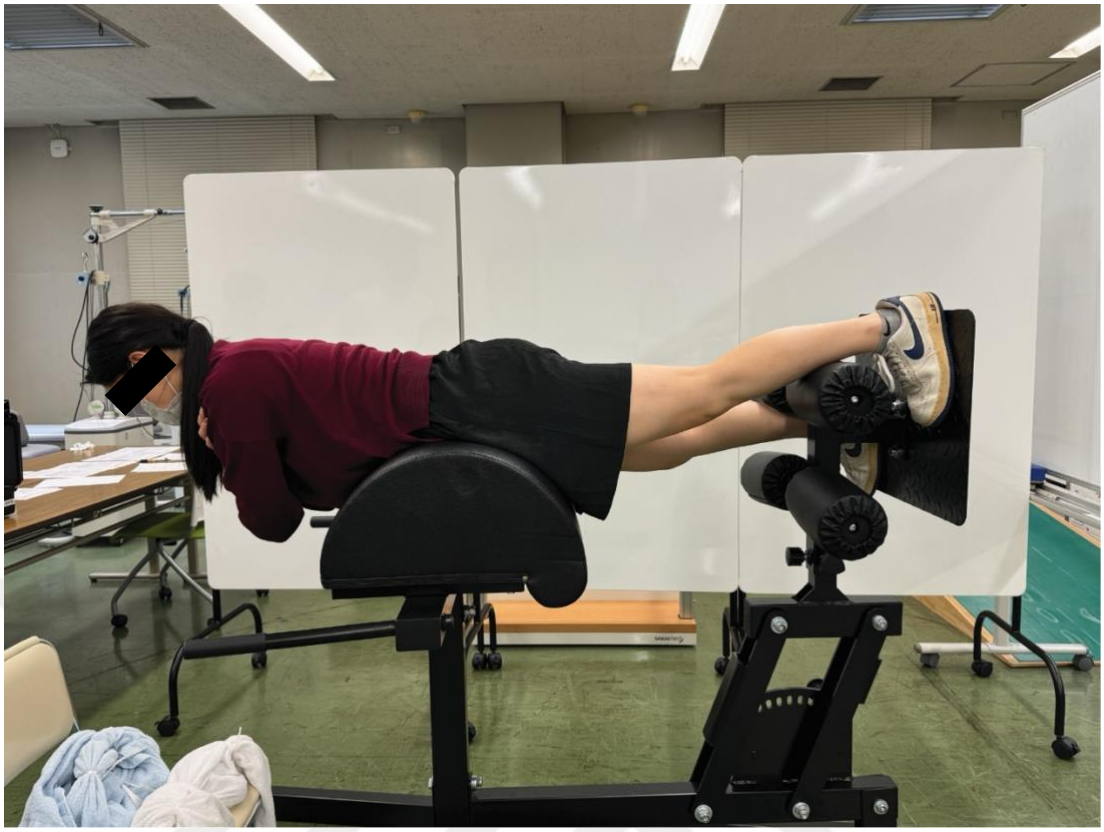


Figure 2. An illustration of the single-leg Roman chair hold exercise was depicted during the first set.

3.7. EMG MEASUREMENTS PROCEDURES

During the EMG measurements, the room was cleaned of other devices as much as possible, including cell phones, to eliminate external electronic interference from the measurements. Surface Electromyography for Non-invasive Assessment of Muscles (SENIAM) guideline (198), was followed during the measurements and electrode placements. Proximal and distal electrode pairs were placed at approximately 35% and 75% of the distance between the ischial tuberosity and the head of the fibula (87) on the right legs of the participants (199). The sensor placement locations were shaved before warm-up and will be cleansed with isopropyl alcohol wipes to reduce possible skin impedance (200).

A wireless EMG system (Delsys Trigno, Delsys Japan) was used during the measurements. This system had a sampling rate of 1926 Hz, a voltage range of 11 mV, and a common-mode rejection ratio of greater than 80 dB. The distance between electrodes was 10 mm, and the diameter of the self-adhesive EMG electrodes was 10

mm. Possible artefacts were visually monitored during data collection. Raw EMG data were stored digitally using EMGworks Acquisition software (Delsys Inc.). EMG signals were filtered with a 20-450 Hz ± 10% band-pass filter. The EMG data were smoothed with a moving root mean square (RMS) using a 100-ms time window. To normalise the EMG data, MVICs were performed prior to the intervention.

3.8. EMG DATA NORMALISATION VIA MVIC

After the warm-up protocol, participants performed MVICs in a prone position with a 45º-knee flexion of the right leg. A hand-held dynamometer (Mobie Project, SAKAImed, Japan) measured the MVICs, and during the measurements, EMG signals of the BF and ST muscles of the right leg were recorded. Participants performed an MVIC for 5 seconds for the right leg (196). The measurements' mean peak RMS of surface EMG were estimated and used to normalise the EMG data as a percentage of MVIC, which was obtained during the exercise interventions. (196).

3.9. INFRARED THERMOGRAPHY MEASUREMENTS

The infrared Thermography measurements for the hamstring muscle were taken using descriptions of Côrte et al. (201). Participants were advised not to consume alcohol or caffeine-containing beverages for at least four hours prior to the analysis (201). Additionally, they were advised not to use anti-inflammatory or cosmetic products that could alter skin temperature on the measurement day (201). The environmental conditions of the laboratory were at 23.0°C (±1.0%) and 40%–60% of relative humidity for each participant (201). The participants stayed at least 15 minutes to acclimate to the room before the study (202). Thermographic measurements from the posterior thigh of each participant were collected in the standing upright rest position (202). Thermographic images were digitally recorded with an InfReC R300 infrared thermographic camera (Nippon Avionics Co., Ltd., Tokyo, Japan). The camera was positioned 3 metres away from the participants and perpendicular to the ROI (201) (posterior thigh). The light and temperature were controlled and kept the same in the measurement room for each participant (201) (Figure 3). The InfReC Analyser software (Nippon Avionics Co., Ltd., Tokyo, Japan) was used to analyse the thermal images, and temperatures were calculated for the

highest point on the ROI. A 0.98 emissivity factor was used while processing the images to obtain human skin temperatures (201). Colour mapping (the rainbow palette) was used with a fixed scale ranging from 27°C to 35°C (201). Measurements were performed immediately before and after completing the three sets of programs. Attention was given to choosing the same ROIs before and after the exercises for each muscle. ROIs were determined based on the hamstrings' anatomical locations. The participants' right legs were examined for compatible results with EMG measurements.

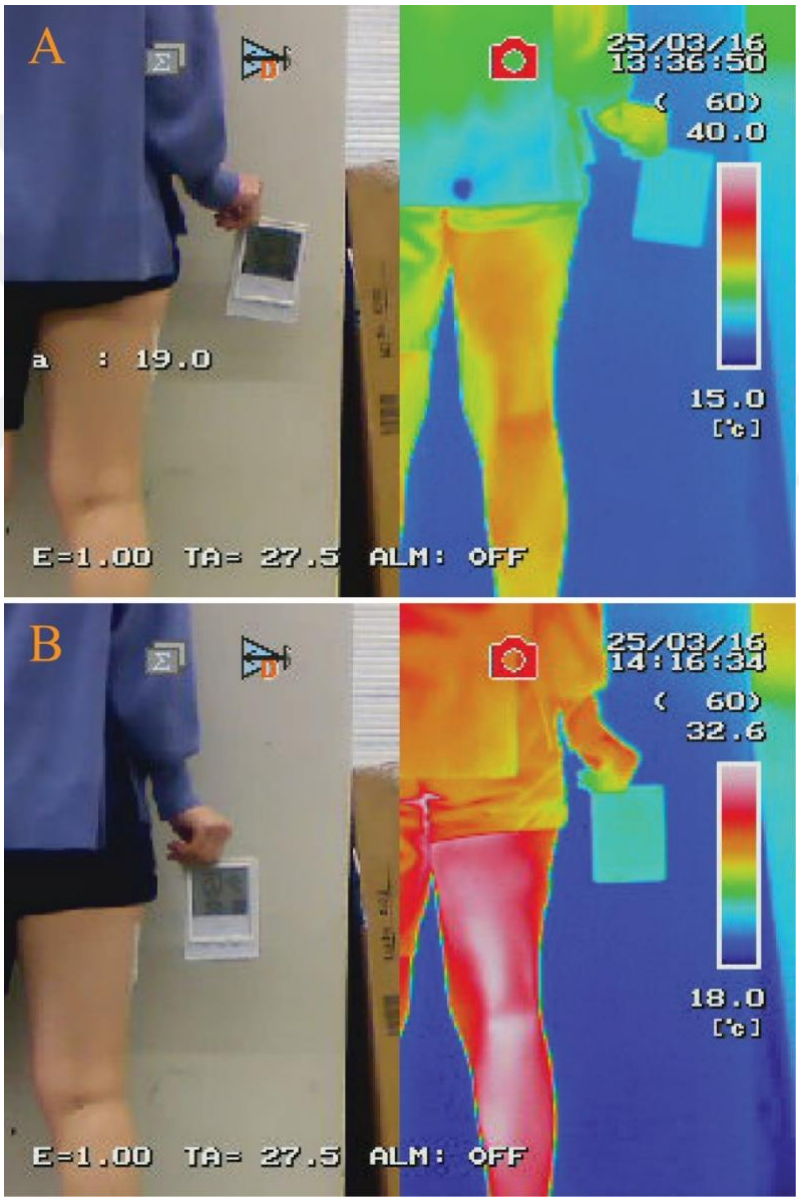


Figure 3. An example of infrared thermography measurements before (A) and after (B) an exercise intervention.

3.10. STATISTICAL ANALYSES

Statistical analyses were performed using mixed-model Analysis of Variance (ANOVA) and one-way ANOVA to compare the outcome measures between groups and muscles using the IBM SPSS 29.0 software (IBM Corp, Armonk, NY). Additionally, Hedges' adjusted g effect size (203), which corrects potentially biased small sample sizes ($n < 20$), differing from Cohen's d effect size (204) were also calculated. The effect size of the intervention was classified as follows: small (0.2), medium (0.5), or large (0.8), which are commonly employed for Cohen's d (205) and Hedges' g (206) effect size classifications (207).

4. RESULTS

Based on the results, there were no significant differences observed between the participants' physical characteristics between the NHE and RCH groups (Table 2).

Table 2. Physical characteristics of the participants.

	NHE (n=12)	**RCH (n=12)**	**P-value**
Age	25.92 ± 4.56	25.67 ± 3.82	0.886
Height	166.52 ± 11.20	168.47 ± 7.50	0.623
Body Mass	66.59 ± 16.30	61.50 ± 11.70	0.389

Abbreviations: NHE, Nordic Hamstring exercise; RCH, single-leg **R**oman **C**hair-**H**old exercise

Despite the NHE-led higher EMG activations in the BF compared to the ST during all sets, the difference was not statistically significant (Table 3). The RCH also led to statistically insignificant higher activations in the BF compared to the ST during all the sets (Table 4). There were also no significant differences observed between the thermographic increases between the medial and lateral hamstrings for both exercise groups (Tables 3 and 4).

Table 3. Thermographic (Celsius) and electromyographic (MVIC%) changes based on the muscles in the NHE group

	BF (n=12)	**ST (n=12)**	**P-value**	**Effect Size** (Hedges' *g*)
Thermography	0.93 ± 0.70	0.84 ± 0.62	0.736	0.14
Mean EMG for 1st set	60.62 ± 38.64	57.44 ± 28.80	0.821	0.09
Mean EMG for 2nd set	74.31 ± 44.26 (n=11)	65.09 ± 43.29 (n=11)	0.627	0.21
Mean EMG for 3rd set	78.33 ± 50.56	66.82 ± 36.23	0.528	0.26
Mean average EMG	70.89 ± 39.77	62.38 ± 34.13	0.580	0.23
Max EMG for 1st set	87.52 ± 45.87	79.54 ± 33.81	0.632	0.20
Max EMG for 2nd set	111.52 ± 55.93	90.59 ± 58.04	0.388	0.37
Max EMG for 3rd set	121.38 ± 90.31	91.46 ± 46.82	0.319	0.42
Max average EMG	106.81 ± 55.31	86.30 ± 41.38	0.315	0.42

Abbreviations: BF, biceps femoris; EMG, electromyography; max, maximum; ST, semitendinosus.

Table 4. Thermographic and electromyographic changes based on the muscles in the RCH group

	BF (n=12)	**ST (n=12)**	**P-value**	**Effect Size**
Thermography	0.34 ± 1.19	0.70 ± 1.10	0.450	0.31
Mean EMG for 1st set	129.23 ± 106.02	89.26 ± 85.47	0.320	0.42
Mean EMG for 2nd set	207.08 ± 174.71 (n=11)	126.53 ± 119.62 (n=11)	0.222	0.54
Mean EMG for 3rd set	193.80 ± 201.50 (n=10)	137.99 ± 166.22	0.484	0.30
Mean average EMG	181.02 ± 150.48	116.36 ± 120.85	0.258	0.47
Max EMG for 1st set	152.58 ± 133.01	129.80 ± 119.06	0.63	0.18
Max EMG for 2nd set	235.74 ± 219.98 (n=11)	189.60 ± 183.87 (n=11)	0.599	0.23
Max EMG for 3rd set	230.60 ± 239.82 (n=11)	175.90 ± 201.55 (n=11)	0.569	0.24
Max average EMG	208.59 ± 188.77	169.68 ± 163.86	0.595	0.22

Abbreviations: BF, biceps femoris; EMG, electromyography; max, maximum; ST, semitendinosus.

The RCH group exhibited higher EMG muscle activations, both with and without additional load, compared to the NHE groups in both BF and ST muscles. However, these higher activations only reached statistically significant levels in the second set when the RCH group held an additional 10 kg weights for the BF. As a result, the overall mean EMG activations in the BF were significantly higher with a large effect size in the RCH group compared to the NHE group (p = 0.44, g = 0.87) (Table 5).

Table 5. Thermographic (Celsius) and electromyographic (MVIC%) changes based on the groups.

	NHE (n=12)	RCH (n=12)	P-value	Effect Size
Thermography for BF	0.93 ± 0.69	0.34 ± 1.19	0.153	0.61
Thermography for ST	0.84 ± 0.62	0.70 ± 1.10	0.715	0.16
Mean EMG for 1st set for BF	60.62 ± 38.64	114.51 ± 100.97	0.098	0.70
Mean EMG for 1st set for ST	57.44 ± 28.80	100.49 ± 96.32	0.152	0.61
Mean EMG for 2nd set for BF	73.71 ± 42.25	**180.16 ± 160.48*** (n=11)	**0.038**	0.93
Mean EMG for 2nd set for ST	65.09 ± 43.29 (n=11)	149.55 ± 149.29 (n=11)	0.087	0.77
Mean EMG for 3rd set for BF	78.33 ± 50.55	189.50 ± 191.69 (n=11)	0.066	0.81
Mean EMG for 3rd set for ST	66.82 ± 36.24	135.90 ± 174.17 (n=11)	0.193	0.56
Mean average EMG for BF	70.89 ± 39.77	**162.73 ± 143.58***	**0.044**	0.87
Mean average EMG for ST	62.38 ± 34.13	131.89 ± 136.04	0.100	0.70
Max EMG for 1st set for BF	87.53 ± 45.87	152.58 ± 133.01	0.123	0.65
Max EMG for 1st set for ST	79.54 ± 33.81	129.80 ± 119.06	0.173	0.57
Max EMG for 2nd set for BF	111.52 ± 55.93	235.74 ± 219.98 (n=11)	0.072	0.80
Max EMG for 2nd set for ST	90.59 ± 58.04 (n=11)	189.60 ± 183.87 (n=11)	0.104	0.73
Max EMG for 3rd set for BF	121.37 ± 90.31	230.60 ± 239.82 (n=11)	0.156	0.61
Max EMG for 3rd set for ST	91.46 ± 46.82	175.90 ± 201.55 (n=11)	0.172	0.59
Max average EMG for BF	106.81 ± 55.31	208.59 ± 188.77	0.087	0.73
Max average EMG for ST	86.30 ± 41.38	169.68 ± 163.86	0.102	0.70

Abbreviations: BF, biceps femoris; EMG, electromyography; max, maximum; NHE, Nordic Hamstring exercise; RCH, single-leg **R**oman **C**hair-**H**old exercise; ST, semitendinosus; * significantly higher.

Regarding the thermographic changes in the medial and lateral hamstrings due to the exercises, the NHE group showed a significant increase in the BF with a large effect size (p = 0.003, g = 1.01) while the RCH leading increments in the BF was not significant and small (p = 0.234, g = 0.26) (Table 6). Despite only NHE showing a significant increase in the BF, the increase could not reach the significance level compared to the RCH, leading to the increase in the BF (p = 0.153) (Table 6). Concerning the same outcome for the ST muscle, both exercises led to significant thermographic increases in the ST, while the NHE was having a large and RCH was having moderate magnitudes of effects (NHE: p = 0.004, g = 0.8; RCH: p = 0.012, g

= 0.5) (Table 7). Similarly, between-group differences did not lead to a significant level for the thermographic increases in the ST (p = 0.715)

Table 6. Thermographic changes in BF across the groups.

	Pre-Test	Post-Test	Δ Changes	P-value (pre-test vs post-test)	Effect Size
NHE (n=12)	31.93 ± 1.03	**32.87 ± 0.81***	0.93 ± 0.69	**0.003**	1.01
RCH (n=12)	32.27 ± 1.14	32.61 ± 1.49	0.34 ± 1.19	0.234	0.26
P-value (NHE vs RCH)	0.462	0.609	0.153		

Abbreviations: NHE, Nordic Hamstring exercise; RCH, single-leg **R**oman **C**hair-**H**old exercise; Δ, post-test – pre-test; *significantly higher.

Table 7. Thermographic changes in ST across the groups.

	Pre-Test	Post-Test	Δ Changes	P-value (pre-test vs post-test)	Effect Size
NHE (n=12)	32.10 ± 0.99	**32.93 ± 1.06***	0.84 ± 0.62	**0.004**	0.80
RCH (n=12)	32.24 ± 1.24	**32.94 ± 1.55***	0.70 ± 1.10	**0.012**	0.50
P-value (NHE vs RCH)	0.760	0.990	0.715		

Abbreviations: NHE, Nordic Hamstring exercise; RCH, single-leg **R**oman **C**hair-**H**old exercise; Δ, post-test – pre-test; *significantly higher.

5. DISCUSSION

This study aimed to explore and compare the activation profiles of the medial (9ST) and lateral (BF) hamstrings during the single-leg Roman Chair Hold and Nordic Hamstring Exercises using surface EMG and infrared thermography in a sample consisting of an Asian population. Contrary to the majority of previous studies (76-80, 208), which report higher ST activations than the BF during the NHE and RCH, EMG results of this study revealed significantly greater BF activity in both the RCH and NHE groups. Meanwhile, the NHE is also showing a greater increase in the BF (g = 1.01) compared to the ST (g = 0.8) in the infrared thermography; the RCH led to a higher thermographic increase in the ST (g = 0.50) than the BF (g = 0.26). This divergence between electrical and thermal indicators indicates a complex interaction of physiological, methodological, and population-specific factors affecting muscle function.

Ethnic differences in the alignment of the lower limbs and musculoskeletal structure may have influenced how muscles are recruited. Asian populations are characterised by more pronounced tibial bowing and a higher prevalence of genu

varum, attributed to reduced femoral anteversion and distinctive tibial morphology (209-211). Genetic variations in muscle fibre composition might also play a role. For example, the ACTN3 R577X polymorphism is less common in Asian populations, which tend to have a dominance of type I fibres and aerobic metabolic profiles (212, 213). These characteristics may affect neuromuscular adaptation and recruitment strategies during isometric or eccentric loading, as evidenced by Knox et al. (214), who noted ethnic-specific responses to compound resistance training. Additionally, Walhain et al. (215) and Wakahara et al. (216) identified significant ethnic differences in fascicle length, tendon structure, and pennation angles, which may contribute to the altered recruitment patterns observed in our participants compared to the literature. Considering all the above, there may be ethnic differences in muscle recruitment strategies based on ethnic background. Supportively, another study conducted in Thailand (217) suggested that unilateral isometric NHE, rather than bilateral isometric NHE, may lead to higher BF activations than the ST muscle. During unilateral isometric NHE on an inclined platform, BFlh showed significantly greater EMG activation than ST (217). However, a future study is still needed to compare muscle activation patterns based on ethnicity during the NHE and RCH.

For the NHE group, thermography showed higher increases in BF compared to the ST group, similar to its EMG results. Interestingly, thermography showed greater thermal responses in the ST muscle compared to the BF in the RCH group, as opposed to the EMG findings. Infrared thermography is sensitive to changes in local blood flow, metabolic activity, and inflammation (218, 219), which may not directly correlate with immediate electrical activation measured by EMG. Instead, infrared thermography may reflect cumulative workload or post-exercise muscle stress. Furthermore, infrared thermography is capable of recording delayed physiological responses, such as augmented perfusion and thermogenesis in tissues subjected to injury or overuse, whereas electromyography (EMG) supplies real-time data on neural activation (220, 221). This may be a limitation for infrared thermography measurements of this study and warrants future research to explain possible physiological factors influencing the difference between the EMG and thermography measurements during the RCH.

This study may have limitations affecting its interpretation and broad applicability. Surface electromyography (EMG) offers an indirect estimate of muscle

force and tension, but EMG amplitude does not always reliably correspond with muscle force across different contraction types or movement speeds (222). For example, eccentric contractions can generate significant muscle force even with low EMG amplitude, making it harder to interpret activation data as a reflection of mechanical loading (222). Additionally, higher movement speeds or complex joint movements can affect how motor units are recruited, complicating the relationship between EMG amplitude and actual muscle output (222). This methodological limitation is particularly significant in dynamic, multi-joint tasks, such as the NHE and RB exercises, where joint angles, contraction speeds, and neuromuscular coordination change throughout the movement. Consequently, while the EMG data in this study provides useful comparative insights into muscle activity, it should not be considered a definitive measure of exercise intensity or tissue load across different exercises.

Additionally, surface EMG presents practical challenges. Crosstalk from surrounding muscles and skin impedance fluctuations can introduce noise, even though measures like shaving and cleaning the skin help minimise these effects. However, the study did not measure skin resistance quantitatively, which limited its ability to account for signal variation fully. Future research could improve accuracy by incorporating intramuscular (needle) EMG, allowing for more precise, localised muscle activity recordings, especially in smaller or deeper muscles. Another issue is electrode placement, which followed SENIAM guidelines but was not confirmed with ultrasound imaging. This could lead to misalignment between the sensor and muscle fascicles, particularly in participants with anatomical differences. Using ultrasound guidance for electrode placement would ensure better accuracy and reduce variability in EMG signals.

This study did not consider individual biomechanical factors that may affect hamstring activation, such as foot posture- pronation or supination- or the use of standardised footwear, both of which can influence lower-limb kinematics and potentially alter hamstring recruitment during movements like RB and NHE. While the cross-sectional approach offers a snapshot of muscle activity during each exercise, it does not provide information on long-term training effects or injury prevention. Future longitudinal research is necessary to determine whether differences in EMG

activation lead to meaningful physiological or functional outcomes related to hamstring strain injuries (HSIs).

From a rehabilitation and performance standpoint, the findings support the inclusion of both RCH and NHE in hamstring training protocols. RCH may be especially beneficial for athletes with a history of hamstring injuries, considering the previous research and current findings pointing out higher VF activations (83). On the other hand, the NHE has a proven ability to prevent HSIs (72-75), and the findings of this study show that the NHE results in higher activation in the BF. Given its feasibility on sports pitches, the NHE should be included in injury prevention programmes.

6. CONCLUSIONS

This study highlights distinct activation patterns of the medial (ST) and lateral (BF) hamstrings during the Nordic Hamstring Exercise (NHE) and the single-leg Roman Chair Hold (RCH) in an Asian population sample, compared to earlier research. Unlike past findings, both exercises resulted in greater activation of the biceps femoris, especially during the NHE, which also showed a significantly increased thermographic response in this muscle. These results suggest possible ethnic differences in muscle recruitment strategies, potentially influenced by unique anatomical and genetic factors in this group. Further research is needed to explore whether muscle recruitment patterns during these exercises vary across different ethnicities. Practically, incorporating both NHE and RCH into hamstring conditioning and injury prevention programmes is advisable, with particular emphasis on the NHE due to its ease of implementation and robust activation of the biceps femoris.

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APPENDICES

Appendix 1: Ethics Committee Approval

別記第２号様式（第6条関係）

6都立大荒管第755号
２０２５年２月４日

信太 奈美　様

東京都立大学大学院人間健康科学研究科
研究科長　西村　一

研究倫理審査結果通知書

審査依頼のあった件について、下記のとおり荒川キャンパス研究倫理委員会における審査結果を通知いたします。なお、委員会での承認確定後、通知書発行日をもって研究科長の研究実施許可日とします。

記

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4 研究課題名	ノルディックハムストリングスエクササイズと片足ローマンチェアホールドエクササイズ中のハムストリングスの筋活動の比較：磁気共鳴画像、サーモグラフィー、筋電図検査による研究		
5 研究期間	通知書発行日　から　2025年3月31日　まで		
6 審査結果	承　認	委員会開催日	2025年1月27日
		承認確定日	2025年1月27日
7 理由又は勧告等			

※委員会の審査結果に対して異議がある場合は、この通知を受けた日の翌日から起算して2週間以内に再審査を請求することができます。

2025(R7)年1月　審査

T.C.
ANKARA 17. NOTERLİĞİ
Güzeltepe Mah. Simon Bolivar Cad.
Sedat Simavi Sk. No:34 Kat:1 Çankaya/ANKARA
Tel: 0 312 442 78 77 Faks: 0312 442 06 77

TERCÜME

anadil tercüme

NO 19537
18 AĞUSTOS 2025

Ek-12 (Madde 6 ile ilgili)

Tokyo 6. Metropoliten Ökō Yönetimi 755 numaralı belge
04.08.2025

Sayın Shida Nami

Tokyo Metropoliten Üniversitesi İnsan Sağlığı Bilimleri Lisansüstü Programı
Enstitü Başkanı Nishimura Yumi

Araştırma Etik Değerlendirme Sonuç Belgesi

Değerlendirme talebinde bulunulan konu hakkında, aşağıda belirtildiği şekilde Arakawa Kampüsü Araştırma Etik Kurulu'nun değerlendirme sonucunu bildiriyoruz. Komite tarafından onay kesinleştikten sonra, bildirim belgesinin düzenlenme tarihi itibarıyla Enstitü Başkanı'nın araştırmanın yürütülmesine izin verdiği tarih olarak kabul edilir.

AÇIKLAMALAR

Onay Numarası	24088		
Sınıflandırma	Bağlı bulunduğu birim	Adı Soyadı	
1 Başvuru sahibi	Fizyoterapi Bilimleri Alanı	Doçent Dr. Shida Nami	
2 Araştırma sorumlusu	Fizyoterapi Bilimleri Alanı	Doçent Dr. Shida Nami	
3 Danışman öğretim üyesi			
4 Araştırma Projesi Başlığı	Nordic Hamstring Egzersizi ile Tek Ayaklı Roman Chair Hold Egzersizi Sırasında Hamstring Kas Aktivitesinin Karşılaştırılması: Manyetik Rezonans Görüntüleme, Termografi ve Elektromiyografi Yöntemleriyle Bir Araştırma		
5 Araştırma Süresi	Bildirim belgesinin düzenlenme tarihinden 31 Mart 2025 tarihine kadar		
6 Değerlendirme Sonucu	Onay	Komite Toplantı Tarihi	27.01.2025
		Onay Kesinleşme Tarihi	27.01.2025
7 Gerekçe veya Tavsiyeler vb.			

※ Komitenin değerlendirme sonucuna itiraziniz varsa, bu bildirimi aldığınız tarihten itibaren başlayarak 2 hafta içinde yeniden değerlendirme talebinde bulunabilirsiniz.
Ocak 2025 (Reiwa 7) yılı, – Değerlendirme

Soğuk Damga Vardır

別記第７号様式(第16条関係)

6都立大荒管第990号
２０２５年3月３１日

信太 奈美　　様

東京都立大学大学院人間健康科学研究科
研究科長　西村　ユミ
(公印省略)

研究計画変更に関する倫理審査結果通知書

研究計画変更に係る標記の件について、下記のとおり荒川キャンパス研究倫理委員会における審査結果を通知いたします。

記

1　承認番号：２４０８８

2　研究課題名：ノルディックハムストリングスエクササイズと片足ローマンチェアホールドエクササイズ中のハムストリングスの筋活動の比較：磁気共鳴画像、サーモグラフィー、筋電図検査による研究
Comparisons of Hamstring Muscle Activations during Nordic Hamstring Exercise and Single-leg Roman Chair Hold Exercise: A Magnetic Resonance Imaging, Thermography, and Electromyography Study

3　審査結果：承　認

4　承認された変更内容
(1) 研究実施期間の変更
変更前：2025年3月31日まで
変更後：2025年6月30日まで

T.C.
ANKARA 77. NOTERLİĞİ
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Tel: 0 312 442 78 77 Faks: 0312 442 06 77

TERCÜME

No 19538

anadil tercüme

18 AĞUSTOS 2025

Ek 7 No'lu Form (Madde 16 ile İlgili)

Tokyo Metropolitan Üniversitesi Arakawa Kampüsü Yönetimi 6. Bölüm No: 990

31.03.2025

Sayın Shida Nami

Tokyo Metropolitan Üniversitesi Lisansüstü İnsan
Sağlığı Bilimleri Enstitüsü
Enstitü Müdürü: Yumi Nishimura
(Resmi mührün basılması atlanmıştır)

Araştırma Planı Değişikliği ile İlgili Etik Değerlendirme Sonuç Bildirimi

Başlıkta belirtilen araştırma planı değişikliği ile ilgili olarak, aşağıda belirtildiği üzere Arakawa Kampüsü Araştırma Etik Kurulu'nun değerlendirme sonucunu bildiririz.

AÇIKLAMALAR

1 Onay Numarası: 24088

2 Araştırma Konusu: Nordik Hamstring Egzersizi ile Tek Ayaklı Roman Chair Hold Egzersizi Sırasında Hamstring Kas Aktivitesinin Karşılaştırılması: Manyetik Rezonans Görüntüleme, Termografi ve Elektromiyografi İncelemeleriyle Bir Araştırma
Comparisons of Hamstring Muscle Activations during Nordic Hamstring Exercise and Single-leg Roman Chair Hold Exercise: A Magnetic Resonance Imaging, Thermography, and Electromyography Study

3. Değerlendirme Sonucu: Onaylandı
4. Onaylanan Değişiklikler
   (1) Araştırma Yürütme Süresinin Değişikliği
   - Değişiklik Öncesi: 31 Mart 2025'e kadar
   - Değişiklik Sonrası: 30 Haziran 2025'e kadar

Soğuk Damga Vardır

Appendix 2: Informed Consent Form

INFORMED CONSENT FORM

研究対象者（研究参加協力者）への依頼・説明書、同意書(2023年10月1日版)

研究参加同意書

東京都立大学大学院人間健康科学研究科理学療法科学域
信太　奈美　殿

私は、ノルディックハムストリングエクササイズと片足ローマンチェアホールドエクササイズ中のハムストリング筋の活動の比較：磁気共鳴画像、サーモグラフィー、筋電図検査による研究（Comparisons of Hamstring Muscle Activations during Nordic Hamstring Exercise and Single-leg Roman Chair Hold Exercise: A Magnetic Resonance Imaging, Thermography, and Electromyography Study）に関する以下の事項について十分な説明を受け、内容を理解しましたので、研究に参加することに同意いたします。

（説明を受けた事項をご自身でチェックしてください）

- ☑ 研究計画の概要
- ☑ 個人情報等の取り扱いについて
- ☑ 試料・情報の保管と廃棄の方法
- ☑ 研究への参加協力は自由意思に基づき、同意撤回はいつでも可能なこと
- ☑ 研究参加によって生じる心身への負担、不利益並びに予測されるリスク
- ☑ 研究の資金源、利益相反について
- ☑ 研究により得られた結果等の取り扱いについて
- ☑ 外国にある者へ試料・情報を提供する場合の取り扱いについて
- ☑ 研究に関する情報公開の方法
- ☑ 研究成果の公表、研究成果の還元について
- ☑ 試料・情報の知的財産権及び帰属先
- ☑ この研究で取得された試料・情報が、将来の研究のために用いられる可能性又は他の研究機関に提供する可能性
- ☑ 謝金について
- ☑ 問い合わせ先（相談窓口）
- ☑ 研究の実施体制

署名日：　　年　月　日

本人署名：＿＿＿＿＿＿＿＿＿＿＿＿

説明日：　　年　月　日

説明者署名：＿＿＿＿＿＿＿＿＿＿＿＿

Appendix 3: Assessment Form

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE (August 2002)

SHORT LAST 7 DAYS SELF-ADMINISTERED FORMAT

FOR USE WITH YOUNG AND MIDDLE-AGED ADULTS (15-69 years)

The International Physical Activity Questionnaires (IPAQ) comprises a set of 4 questionnaires. Long (5 activity domains asked independently) and short (4 generic items) versions for use by either telephone or self-administered methods are available. The purpose of the questionnaires is to provide common instruments that can be used to obtain internationally comparable data on health–related physical activity.

Background on IPAQ

The development of an international measure for physical activity commenced in Geneva in 1998 and was followed by extensive reliability and validity testing undertaken across 12 countries (14 sites) during 2000. The final results suggest that these measures have acceptable measurement properties for use in many settings and in different languages, and are suitable for national population-based prevalence studies of participation in physical activity.

Using IPAQ

Use of the IPAQ instruments for monitoring and research purposes is encouraged. It is recommended that no changes be made to the order or wording of the questions as this will affect the psychometric properties of the instruments.

Translation from English and Cultural Adaptation

Translation from English is supported to facilitate worldwide use of IPAQ. Information on the availability of IPAQ in different languages can be obtained at www.ipaq.ki.se. If a new translation is undertaken we highly recommend using the prescribed back translation methods available on the IPAQ website. If possible please consider making your translated version of IPAQ available to others by contributing it to the IPAQ website. Further details on translation and cultural adaptation can be downloaded from the website.

Further Developments of IPAQ

International collaboration on IPAQ is on-going and an ***International Physical Activity Prevalence Study*** is in progress. For further information see the IPAQ website.

More Information

More detailed information on the IPAQ process and the research methods used in the development of IPAQ instruments is available at www.ipaq.ki.se and Booth, M.L. (2000). *Assessment of Physical Activity: An International Perspective*. Research Quarterly for Exercise and Sport, 71 (2): s114-20. Other scientific publications and presentations on the use of IPAQ are summarized on the website.

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____ DATE _____

SIGNATURE OF PARENT _____ WITNESS _____
or GUARDIAN (for participants under the age of majority)

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

CSEP | SCPE

© Canadian Society for Exercise Physiology www.csep.ca/forms

Appendix 4: Originality Report



turnitin Sayfa 2 of 25 - Bütünlük Genel Bakış Gönderi Kimliği trn:oid:::1:3305263100

9% Genel Benzerlik

Her veri tabanı için çakışan kaynaklar da dâhil tüm eşleşmelerin kombine toplamı.

Eşleşme Grupları

- **60** Atıf ya da Alıntı Yapılmamış **9%**
  Ne metin içi atıf ne de tırnak işareti içeren eşleşmeler
- **2** Eksik Alıntılar **0%**
  Kaynak materyale hâlâ çok benzeyen eşleşmeler
- **0** Eksik Atıf **0%**
  Tırnak işaretleri olan ancak metin içi atıfları olmayan eşleşmeler
- **0** Atıf Yapılan ve Alıntılanan **0%**
  Metin içi atıf içeren ama tırnak işareti içermeyen eşleşmeler

Ön Sıradaki Kaynaklar

- 8% İnternet kaynakları
- 8% Yayınlar
- 0% Gönderilen çalışmalar (Öğrenci Makaleleri)

Bütünlük Bayrakları

İnceleme için 0 Bütünlük Bayrağı

Herhangi bir şüpheli metin manipülasyonu belirlenmedi.

Sistemimizin algoritmaları bir belgede, onu normal bir gönderiden ayırabilecek her türlü tutarsızlığı derinlemesine inceler. Tuhaf bir şey fark edersek incelemeniz için bayrak ekleriz.

Bir Bayrak mutlaka bir sorun olduğunu göstermez. Ancak daha fazla inceleme için dikkatinizi vermenizi öneririz.

CV AND CONTACT INFORMATION

INDIVIDUAL INFORMATION

Name- Surname	Sena ADANIR
Place and date of birth	
Nationality	
E-mail	
Phone	

EDUCATIONAL INFORMATION

Bachelor degree	University of Health Sciences (ANKARA) / Faculty of Physiotherapy and Rehabilitation
High school	Ibrahim Hakki Science High School/ ERZURUM

PUBLICATIONS

Mete O, Ipek Halatci E, Cinar S, Adanir S, Unluer OU. A Comparison of the Stomatognathic and Neck Functions between Smokers and Non-smokers. Bezmialem Science. 2025; Bezmialem Science. DOI: 10.14235/bas.galenos.2024.33600

Adanir S, Yagiz G, Shida N. The Impacts of Functional Electrical Stimulation on the Morphological Characteristics of Skeletal Muscles: A Systematic Review. DOI: 10.37766/inplasy2025.2.0067

Ekinci, Y; Okuyucu, K; Adanir, S; Yagiz, G. Impact of Physical Theraphy on Hallux Valgus: A Systematic Review. DOI: 10.37766/inplasy2025.5.0040

Cerbezer, N; Adanır, S; Algun, C; Yağız, G. Effect of Stroboscopic Glasses Usage in Training and Rehabilitation: A Systematic Review and Meta-Analysis. DOI: 10.37766/inplasy2025.7.0075

CONFERENCE PAPERS

Adanir, S., Yagiz, G., & Shida, N. (2025, May). *Impacts of Functional Electrical Stimulation on Morphological Characteristics of Skeletal Muscles: A Systematic Review.* PhysAgeNet & EGRAPA Conference, 2025 Trabzon, Türkiye

Adanir, S., Soylu, C., & Ün Yıldırım, N. (2024, May). *Anterior Cruciate Ligament's Unfair Game: Hamstring Hero, Vastus Medialis Zero?* XXXI Isokinetic Medical Group Conference, 2024 Madrid, Spain

Adanir, S., Ipek Halatci, E C., Cinar, S., & Mete, O. (2024, Feb). *A Comparison of Neck Posture, Proprioception, and Disability in Smokers and Non-Smokers.* 6th International Izmir Congress on Medicine, Nursing, Midwifery, and Health Sciences, 2024 Izmir, Türkiye

Kara, D., Adanir, S., & Yildirim Sahan, T. (2024, Oct). *Investigation of the Effect of 4-Week Orthosis and Exercise Theraphy on Balance, Foot Posture and Performance in case with Pes Planovalgus.* 3rd International Izmir Congress on Medicine, Nursing, Midwifery, and Health Sciences, 2024 Izmir, Türkiye

Korkmaz, B., Adanir, S., & Turker, D. (2023, Nov). *Comparison of Attitudes and Behaviors of Physiotheraphy and Nurses Working in NICU About Family-Centered Care.* Congress on Current Developments in Risky Babies with International Participation, 2023, Türkiye