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Are Running, Speed Change and Kicking Actions during Football Training Associated with Reductions in Hip Adductor Strength?

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Complete List of Authors:	J. Hamad, Maziar; UCAM, UCAM Research Center for High Performance Sport Alcaraz, Pedro; UCAM, UCAM Research Centre for High Performance Sport Thorborg, Kristian; Copenhagen University Hospital Hvidovre, Department of Sports, Department of Orthopedic Surgery, Orthopedic Research Center-Copenhagen (SORC-C) Barrett, Steve; Playermaker, Sports Science and Research Innovation Spyrou, Konstantinos ; UCAM, UCAM Research Center for High Performance Sport
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Abstract:	This exploratory cross-sectional study quantified the associations between running, speed change, and kicking actions on acute hip adductor strength from football training. Twelve trained youth football players (34 observations) wore foot-mounted inertial measurement units during training to track football actions. Maximal isometric hip adductor squeeze strength was performed pre- and post-training to quantify change. Linear mixed models revealed moderate to large associations for all running and speed change actions (accelerations, decelerations) (r = –0.48 to –0.69, p ≤ 0.004) while associations were small and not statistically significant for the kicking metrics: ball releases, release index, and high speed releases (r = –0.24, –0.24 ,0.16, respectively, p > 0.05). The largest strength reductions were predicted by distances of high intensity accelerations (B = –0.31% per meter, 95% CI = –0.47%;–0.15%), high intensity decelerations (B = –0.30% per meter, 95% CI = –0.50%;–0.12%), and counts of high intensity speed changes (B = –0.40% per count, 95% CI = –0.57%;–0.23%). On a per meter basis, high intensity accelerations and decelerations predicted a more than seven-times greater reduction in strength than sprint meters, while low intensity accelerations and decelerations predicted similar effect magnitudes when compared to high-speed running. In conclusion, running speed and speed change metrics (accelerations, decelerations) as opposed to kicking actions displayed significant associations with acute hip adductor strength reductions. As high intensity speed-change metrics predicted the largest effects in reducing hip adductor strength, practitioners may monitor and manipulate the

	programming of these actions within training to manage groin loading and fatigue.

Are Running, Sprinting and Kicking Actions during Football Training Associated with Reductions in Hip Adductor Strength?

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Maziar J. Hamad (corresponding author), mjabar@ucam.edu, +34 637 252 400
UCAM Research Center for High Performance Sport, Catholic University of Murcia (UCAM), Murcia, Spain

Pedro E. Alcaraz, palcaraz@ucam.edu
UCAM Research Center for High Performance Sport, Catholic University of Murcia (UCAM), Murcia, Spain; Faculty of Sport Sciences, Catholic University of Murcia (UCAM), Murcia, Spain; Strength and Conditioning Society (SCS), Murcia, Spain

Kristian Thorborg, Kristian.Thorborg@regionh.dk
Department of Sports, Department of Orthopedic Surgery, Orthopedic Research Center-Copenhagen (SORC-C), Amager-Hvidovre Hospital, Copenhagen University Hospital, Copenhagen, Denmark

Steve Barrett, steve.barrett@playermaker.co.uk; Playermaker, London, United Kingdom

Konstantinos Spyrou, kspyrou@ucam.edu
UCAM Research Center for High Performance Sport, Catholic University of Murcia (UCAM), Murcia, Spain; Faculty of Sport Sciences, Catholic University of Murcia (UCAM), Murcia, Spain; Strength and Conditioning Society (SCS), Murcia, Spain

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Are Running, Speed Change and Kicking Actions during Football Training Associated with Reductions in Hip Adductor Strength?

Maziar J. Hamad [a*], Pedro E. Alcaraz [a,b,c], Kristian Thorborg [d], Steve Barrett [e], Konstantinos Spyrou [a,b]

[a] UCAM Research Center for High Performance Sport, Catholic University of Murcia (UCAM), Murcia, Spain

[b] Faculty of Sport Sciences, Catholic University of Murcia (UCAM), Murcia, Spain

[c] Strength and Conditioning Society (SCS), Murcia, Spain

[d] Department of Sports, Department of Orthopedic Surgery, Orthopedic Research Center-Copenhagen (SORC-C), Amager-Hvidovre Hospital, Copenhagen University Hospital, Copenhagen, Denmark

[e] Playermaker, London, United Kingdom

* Corresponding author.
E-mail address: mjabar@ucam.edu

Abstract

Purpose: This exploratory cross-sectional study quantified the associations between running, speed change, and kicking actions on acute hip adductor strength from football training.

Methods: Twelve trained youth football players (34 observations) wore foot-mounted inertial measurement units during training to track football actions. Maximal isometric hip adductor squeeze strength was performed pre- and post-training to quantify change.

Results: Linear mixed models revealed *moderate* to *large* associations for all running and speed change actions (accelerations, decelerations) (r = −0.48 to −0.69, $p \leq 0.004$) while associations were *small* and not statistically significant for the kicking metrics: ball releases, release index, and high speed releases (r = −0.24, −0.24 ,0.16, respectively, $p > 0.05$). The largest strength reductions were predicted by distances of high intensity accelerations (B = −0.31% per meter, 95% CI = −0.47%;−0.15%), high intensity decelerations (B = −0.30% per meter, 95% CI = −0.50%;−0.12%), and counts of high intensity speed changes (B = −0.40% per count, 95% CI = −0.57%;−0.23%). On a per meter basis, high intensity accelerations and decelerations predicted a more than seven-times greater reduction in strength than sprint meters, while low intensity accelerations and decelerations predicted similar effect magnitudes when compared to high-speed running.

Conclusions: In conclusion, running speed and speed change metrics (accelerations, decelerations) as opposed to kicking actions displayed significant associations with acute hip adductor strength reductions. As high intensity speed change metrics predicted the largest effects in reducing hip adductor strength, practitioners may monitor and manipulate the programming of these actions within training to manage groin loading and fatigue.

Keywords: Injury, Isometric Contraction, Groin, Muscle Fatigue

Introduction

Weaker hip adductor strength is associated with elevated injury risk and higher prevalences of groin pain[1,2]. As a result, it is commonly targeted in monitoring practices through load management and training planning at both individual and group levels[3,4]. Building on this monitoring practice, appropriate training prescriptions within football are necessary to promote physical adaptations and recovery while minimizing injury risk exposure[5,6]. Within the weekly training period (football microcycle), training sessions alternate by focus (i.e. recovery, loading, and priming), requiring conscious and detailed planning of training variables[7,8]. To design optimal training prescriptions that both prepare athletes for competition and facilitate return-to-play progression, it is crucial to understand the relationship between prescribed training load (doses) and player responses[9]. Consequently, understanding how specific training factors affect hip adductor strength demands can inform programming decisions for player development and rehabilitation.

The isometric hip adductor test is a suitable monitoring tool, given its sensitivity to changes in pain[10], and injury risk profile[11,12]. For instance, football players with groin pain persisting longer than six weeks during the preceding season, had 15% lower hip adductor strength compared to players without previous pain[13], while the risk of new groin problems increased by 17.5% for every 0.5 N · m/kg reduction in preseason long-lever hip adductor relative torque[12]. This signifies the need to better understand the factors influencing these fluctuations. With respect to acute hip adductor strength, the responses seem to vary according to the type and intensity of football activities, with match play inducing greater acute reductions than training[14,15] and where subsequent loadings without full recovery seem to reduce this more than isolated bouts during the week[16]. In this regard, Wollin and colleagues observed that congested match periods resulted in most players experiencing clinically meaningful (>15%) strength reductions which were associated with cumulative match loads (sessional rating of perceived exertion, [sRPE])[16].

While this highlights the influence of intensity and suggests a potential dose-response relationship between session load and hip adductor strength, two sessions with similar sRPE may have different external demands. Notably, the same author group above emphasized that the inclusion of external load data in future studies could enhance the understanding of post-activity adductor complex changes[16]. Therefore, there is a need to better understand the external demands of football activities and specifically which actions contribute most to these reductions. As common actions like running, speed changes (i.e., accelerations (Acc) – decelerations (Decl)), and kicking are described as injury inciting mechanisms to hip adductors[17], there is a need to understand their imposed demands on the adductor complex. Specifically, a greater understanding is needed regarding which running, speed change and kicking actions and intensities during football activities, influence the greatest acute hip adductor strength changes.

Therefore, this study aimed to investigate the associations between hip adductor strength changes and inertial measurement unit (IMU)-derived external training load variables during football training. Specifically, we aimed to identify which running speed, speed change (i.e., accelerations, decelerations), or kicking variables are associated with the greatest effects.

Methods

Study design

The current study is a secondary analysis of a descriptive study (https://osf.io/tr89e/overview) which aimed to investigate and quantify the acute changes to isometric hip adductor squeeze strength during the microcycle. This article followed the STROBE statement and its accompanying checklist to guide the reporting of an observational study [18]. The original data collection duration was three weeks in total, divided into two periods: a reliability testing period and the training period consisting of pre-post measurements. Familiarization and reliability testing were done 2 weeks prior to the pre-post measurement period. To familiarize the participants with the study and testing procedures, 2 familiarization sessions were done on the same time and day, one week apart. The pre-post study period lasted two weeks and participants were tested 15 minutes before the start of their training, and immediately after the termination of the session. The data was collected from training sessions during the 2024/2025 competitive season where players were tested on training days coinciding with match day (MD) –4, MD–2, and MD–1 of the microcycle to capture the complete range of training demands. To ensure immediate post-training measurements and best capture acute neuromuscular fatigue, half of the team was tested in the first week, followed by the other half in the second week.

Participants

Nineteen youth players were recruited to participate in this study. The players regularly participated in approximately 7.5 hours of organized training per week and had ≥ 4 years of competitive football and ≥ 2 years of resistance training experience. Participants were excluded for the following reasons: two being goalkeepers, two due to significant pain during the squeeze tests, two due to a groin injury in the previous two months, and one who completed the familiarization and reliability testing but then sustained a lower-limb injury prior to the subsequent pre-post testing. Therefore, twelve healthy trained/developmental (Tier 2)[19] youth football players (age: 17.11 ± 0.52 years; body mass: 72.63 ± 5.53 kg; height: 1.78 ± 0.05 m) participated in both the reliability and pre-post testing portion of the study. All participants were informed about the procedures, details, and risks of the study and all provided their written consent. Legal guardians signed the informed consent for any participant who was a minor. The study was completed according to the Declaration of Helsinki 2013 and ethical approval was provided by the Ethics Committee of UCAM (approval number: CE042410).

Sample Size Estimation and Justification

A sensistivity power analysis was conducted [G*Power, version 3.1] to determine the effect sizes this study has sufficient power to detect with the given sample size. A linear regression (R^2 deviation from zero) with 1 predictor, at an $\alpha = 0.05$, and power of 0.80 revealed an $R^2 = 0.45$.

Procedures

Isometric hip adductor squeeze strength

To assess the strength response, maximum isometric hip adductor squeeze measurements were done on the field with participants controlled in a supine position with 0° of knee and hip flexion and the sensors placed at the medial malleoli with ankles in a neutral position. Before each test, participants performed a warm-up repetition progressively going from 50% to 80% of perceived maximal intensity for 5-s. Following the warm-up, participants performed 3 maximal, 5-s bilateral hip adductor squeezes, with 30-s of rest given in between. During each repetition, all participants were provided with strong verbal encouragement. To minimize potential variability, strength was measured by the same tester each time using a fixed dynamometer (ForceFrame, VALD Performance, Brisbane, Australia). The left and right peak forces from each repetition were averaged and the best trial was used for analysis and converted to torque ($N \cdot m$) using each participant's limb length (m). Limb length was measured from the anterior superior iliac spine to the medial malleolus (point of application). To assess the interday reliability, the fixed dynamometer was tested in-house with 11 players, under the same conditions (day and time), one week apart. The intraclass correlation corresponding to $ICC_{(3,1)}$ and its 95% CI were: 0.88 (0.63 - 0.97). The mean ± standard deviation within-participant coefficient of variation was 4.93 ± 3.26%.

External Training Demands

To determine the training demands that could impact the hip and groin region during training, running, speed change, and kicking actions were measured using foot-mounted IMU (Playermaker^{TM}, London, UK). Each IMU contains a triaxial gyroscope and accelerometer to measure the angular velocity and acceleration of each foot. The IMU's are held in a silicone strap and securely attached to the participants football boot while training. The Playermaker^{TM} devices have been previously used in assessing locomotor and technical demands and have shown good-to-excellent between unit reliability and validity[20–22]. To further minimize potential reliability issues, each participant was assigned the same IMU to wear during each training session.

A detailed description of each quantified football action is provided in **Table 1.** The running metrics assessed were total distance and zone-specific distances of, low speed running distances, high speed running distances, and sprint distances. The running thresholds used were determined from those previously reported in the literature[23,24] (**Table 1**). Speed change actions (i.e. the rate of speed change; scalar equivalents of Acc and Decl), were quantified as total cumulative and zone-specific distances (i.e. low, moderate, and high intensities) and counts of high intensity speed changes (Acc & Decls). Kicking actions were quantified by counts of ball releases, release index, and high speed releases [22]; all actions are further detailed in **Table 1**.

*** **Table 1 around here** ***

Statistical analysis

The association between each football action and hip adductor strength change was assessed using a linear mixed-effects model with fixed and random effects to account for repeated measures. The model used the pre-post change in hip adductor strength (%) as the dependent variable, each football action listed above as the fixed effects variable, and each participant as a random effects grouping factor. The models used maximum likelihood estimation using the Satterthwaite method, and the model was set as percent change ~ variable + (1 | participant). To assess absolute changes, another model using change in torque was also fitted. A separate model was also used to determine if training day (MD–X) had an interaction effect with football actions (variable) (~variable * MD–X). The model statistics are described as means and 95% confidence intervals. When potential non-linear relationships were identified via assessment of residuals vs fitted plots, second-order polynomial models were fitted (~ standardized variable + standardized variable^2 + (1 | participant)) and model statistics were compared (AIC and R^2) to assess model strength. To account for the relatively small sample size (n = 12, observations = 34) and possible violation of non-normality[25], a 95% bootstrapped CI was computed for each B-coefficient[26], using a cluster bootstrap with 1,000 simulations to account for within-participant correlations[27,28]. The goodness-of-fit of each variable was assessed using the coefficient of determination (marginal R^2, the amount of variation explained by the fixed effects). The magnitude of associations were assessed with the correlation coefficient (r) and were interpreted using the thresholds set by Hopkins[29]: trivial <0.1; small, 0.1-0.29; moderate, 0.3-0.49; large, 0.5-0.69; very large, 0.7-0.89, almost perfect, 0.9-1.0. Statistical significance was set at $\alpha \leq 0.05$ and the statistical analyses were done using the 'lmerTest', 'MuMIn' and 'boot' packages in R version 4.5.1[30].

Results

No interaction effects were observed between training day and the training variables on hip adductor strength ($p > 0.05$). The linear mixed model with n = 12 and 34 observations, showed significant relationships between hip adductor strength changes and all running and speed change metrics ($p \leq 0.004$). No significant relationship was observed for kicking actions quantified by releases, release index, and high speed releases ($p > 0.05$). Second-order polynomial coefficients (AIC and marginal R^2) didn't show evidence of greater model strength than the linear relationships (available in supplementary file). In these cases, the linear models were retained for their greater simplicity. The model statistics for each variable are listed in **Table 2.**

Scatterplots of the relationships for running and speed change metrics are presented in **Figures 1, 2**. Among running zones, the observed relationships were *large* (r = –0.57 to –0.62, $p < 0.001$), with these variables explaining 32% to 45% of the variance, while unstandardized B-coefficients ranged from –0.038% to –0.007% per meter covered. Regarding speed change zones, the relationships were *moderate* to *large* (r = –0.48 to –0.69, $p \leq 0.004$), with these variables accounting for 23% to 50% of the variance, while unstandardized B-coefficients ranged from –0.312% to –0.011% per meter covered. Lastly, releases, release index, and high speed releases showed *small* associations that were not statistically significant (r = –0.24 to 0.16, $p > 0.05$) and explained up to 6% of the variance, while unstandardized B-coefficients ranged from –0.084% to 0.234% per respective unit.

The predicted per meter effect on hip adductor torque (N · m) from each running and speed change variable is also displayed in **Figure 3**.

***** Table 2 around here *****

***** Figure 1, 2, 3 around here *****

Discussion

This exploratory cross-sectional study examined the associations between running, speed change, and kicking actions on hip adductor strength responses during football training in youth football players. The main findings of this study were that running and speed change actions showed large, negative associations with hip adductor strength changes; with these variables individually explaining between 23% to 50% of the variance. Additionally, high intensity Acc, and Decl actions had the greatest effects on hip adductor strength. However, the associations between kicking actions (releases, release index, and high-speed releases) with hip adductor strength were not statistically significant, *small* and individually explained up to 6% of the variance.

The metric demonstrating the highest goodness-of-fit was distances of moderate intensity Acc (>1.5 $m \cdot s^{-2}$) which explained 50% of the variance. Among running and speed change actions, the largest effects were associated with distances and frequencies of high intensity speed changes (Acc and Decls >3.0 $m \cdot s^{-2}$). Specifically, every meter of high intensity Acc and Decl corresponded to a decrease in hip adductor strength of −0.31%, and −0.30% respectively, while each count of high intensity speed change corresponded to a decrease of −0.40%. In a previous study, Buchheit et al., reported that elite academy players experienced the greatest reduction in hip adductor strength after sessions which emphasized speed change actions and smaller playing areas[15]. Notably in their study, the session with the greatest strength reduction contained the lowest total distance, high speed, and sprint running volumes[15], aligning with our finding that speed changes may have a greater impact on hip adductor strength than running (**Figure 3**). Importantly, sports practitioners may also consider modelling individual-level responses for each player, as there may be variability in strength reduction magnitudes between players (**Figure 2**). While the overall fixed effect provides a simple, averaged response across players, modelling and considering individual-level responses can provide additional and unique, player-specific information to guide training prescriptions.

When comparing speed change actions to running, high intensity Acc and Decls (>3.0 $m \cdot s^{-2}$) per meter, were associated with a more than seven times reduction in hip adductor strength compared to running (>5.5 $m \cdot s^{-1}$). This observation also aligns with previous reports that intense speed change actions imposed higher biomechanical loads than other match activities[31].

Importantly, while good to excellent between-unit reliability has been established for most IMU metrics[20,21], larger random between-unit variations have been detected for total Acc distances (± 12.52 m)[21]. Even though this amount of noise in the context of (larger) total Acc distances may be minimal, attempting to model strength changes to smaller Acc distances (i.e. <15 m) may be limited. Considering this, our results showed that for every 20 meters covered, running >5.5 m/s, was associated with 0.8% decreased hip adductor strength while high intensity Acc and Decls were associated with reductions of 6.2%, and 6.0%, respectively. Our results also showed that for every four high intensity speed change actions (>3.0 $m \cdot s^{-2}$), hip adductor strength was associated with an approximately 1-2% reduction (B = −0.40% per action, 95% CI= −0.57, −0.23). This finding may partly be explained by the substantial ground reaction forces, and muscle activation demands imposed on the hip and groin musculature during cutting manouevres[32,33]. Additionally, strength reductions were comparable between high speed running (>4 $m \cdot s^{-1}$) and low intensity Acc and Decl (<1.5 $m \cdot s^{-2}$) (approximately B = −0.01% per meter, **Table 2**), indicating that even low intensity speed changes may be associated with considerable demands on the groin musculature. Importantly, given the high frequency of cutting actions in football[34], our findings warrant further investigation of understand injury-inciting actions[17] to inform training dose prescriptions.

Another interesting finding from this study was that kicking actions didn't show significant relationships with strength changes ($p > 0.05$). The associations consistently remained *small* when assessing volume (total releases) and as well when considering intensity (release index, high speed releases). While the hip adductor muscles are active during kicking actions, significant contributions are also made from other hip muscles like the iliacus, gluteal, and quadricep muscles[35]. In fact, variability in muscle activity is also present between the hip adductor muscles, as the adductor longus and the gracilis are significantly active during lengthening phases of inside passes[32,36], while the adductor magnus is more active during intense instep kick actions[37]. A consequence of this variability in activation could mean that the release and release index metrics may not exclusively isolate hip adductor activity over other muscle groups. Indeed, some studies have shown that non-specific fatiguing protocols (i.e. jump tasks) couldn't reduce kicking performance and that local muscle fatigue may be necessary[38,39], therefore it's possible the relationship between kicking and fatigue is complex and that the hip-adductor demands were not reflected in the assessed metrics. To the authors' knowledge, only one other study directly measured the direct effect of kicking actions on hip-adduction strength; the study by Jensen and colleagues[40] observed post-kicking-drill and next-day increases in hip-adduction strength of the supporting and kicking leg, respectively. Since kicking is identified as an injury-inciting action for the hip-adductors[41], its relationship to hip strength can't be overlooked. However, variability in muscle activation patterns across different kicking intensities and techniques (instep, side foot, outside foot, etc.) may limit the utility of release counts, release index, and high-speed releases as individual metrics for explaining hip-adduction strength responses. Additional research is recommended to investigate the impact of different kicking actions and intensities on acute hip fatigue.

A limitation of the current study is related to the inherent nature of observational studies and the inability for this study to infer causality between action intensity and hip adductor fatigue and other cofounders that exist. However, other studies have reported similar associations between activity intensity and the magnitude of hip adductor strength loss[14–16]. Additionally, it's important to mention that absolute speed thresholds (i.e. >5.5 m · s^{-1}) instead of relative thresholds (i.e. 70% maximum sprint speed, etc.), were used in this study to classify the intensity zones. The use of absolute thresholds doesn't factor in an individual's current physical capabilities and may mean relative demands varied between individuals. The use of relative speed thresholds may therefore potentially better capture the individual demands imposed on each player.

Practical Applications

The present findings have practical implications for load-monitoring and risk-reduction strategies in youth football. Given the associations observed between running, speed change actions (accelerations, decelerations) and acute reductions in hip adductor strength, practitioners may consider monitoring these accelerometer-derived variables during football training. By monitoring these training demands, practitioners can manipulate their session design to potentially manage fatigue and align adductor loading with their desired objectives at the individual and team level.

Conclusions

Running, and speed change actions were significantly associated with acute changes in hip adductor squeeze strength changes during football training. Among all running and speed change actions, high intensity acceleration and decelerations were associated with the greatest negative effect on hip adductor strength. In contrast, the kicking metrics used to quantify frequency and intensity of kicking actions performed during training did not have significant associations with acute hip adductor strength changes. All the potential effects observed in this study need confirmation through a future study with error control.

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Disclosure statement

The fourth author was employed by the company which manufactures the foot-mounted IMU device in the current study. However, throughout the data collection and write up periods, to remove any bias, the author was not involved in any statistical analysis or data interpretation conducted within the study.

Data availability statement

The data and code supporting the findings of this study are available via the Open Science Framework (OSF) at: https://osf.io/stp6h/overview

Author contributions

Conceptualization: M.J.H. and K.S.; methodology: M.J.H., K.T. and K.S.; formal analysis: M.J.H.; investigation: M.J.H. and K.S.; resources: P.E.A. and S.B.; writing—original draft preparation: M.J.H.; writing—review & editing: P.E.A., K.T., S.B. and K.S.; visualization: M.J.H.; supervision: P.E.A. and K.S. All authors have read and agreed to the published version of the manuscript.

Ethical approval and informed consent

All participants were informed about the procedures, details, and risks of the study and provided their written informed consent. Legal guardians signed the informed consent for any participant that was a minor. The study was completed in accordance with the Declaration of Helsinki 2013 and ethical approval was provided by the Ethics Committee of UCAM (approval number: CE042410).

References

1. Engebretsen AH, Myklebust G, Holme I, et al. Intrinsic risk factors for groin injuries among male soccer players: a prospective cohort study. *Am J Sports Med* 2010; 38: 2051–2057.

2. Whittaker JL, Small C, Maffey L, et al. Risk factors for groin injury in sport: an updated systematic review. *Br J Sports Med* 2015; 49: 803–809.

3. Light N, Smith N, Delahunt E, et al. Hip and groin injury management in English youth football: a survey of 64 professional academies. *Sci Med Footb* 2018; 2: 133–140.

4. Wollin M, Thorborg K, Welvaert M, et al. In-season monitoring of hip and groin strength, health and function in elite youth soccer: Implementing an early detection and management strategy over two consecutive seasons. *J Sci Med Sport* 2018; 21: 988–993.

5. McCall A, Pruna R, Van der Horst N, et al. Exercise-based strategies to prevent muscle injury in male elite footballers: An expert-led Delphi survey of 21 practitioners belonging to 18 teams from the Big-5 European leagues. *Sports Med* 2020; 50: 1667–1681.

6. Bowen L, Gross AS, Gimpel M, et al. Accumulated workloads and the acute:chronic workload ratio relate to injury risk in elite youth football players. *Br J Sports Med* 2017; 51: 452–459.

7. Los Arcos A, Mendez-Villanueva A, Martínez-Santos R. In-season training periodization of professional soccer players. *Biol Sport* 2017; 34: 149–155.

8. Martín-García A, Gómez Díaz A, Bradley PS, et al. Quantification of a professional football team's external load using a microcycle structure. *J Strength Cond Res* 2018; 32: 3511–3518.

9. Gabbett TJ, Oetter E. From tissue to system: What constitutes an appropriate response to loading? *Sports Med* 2025; 55: 17–35.

10. DeLang MD, Garrison JC, Hannon JP, et al. Weekly screening of youth male football players: a 14-week longitudinal investigation of interactions between groin pain and long lever adductor squeeze strength. *J Sci Med Sport*.

11. Crow JF, Pearce AJ, Veale JP, et al. Hip adductor muscle strength is reduced preceding and during the onset of groin pain in elite junior Australian football players. *J Sci Med Sport* 2010; 13: 202–204.

12. Esteve E, Casals M, Saez M, et al. Past-season, pre-season and in-season risk assessment of groin problems in male football players: a prospective full-season study. *Br J Sports Med* 2022; 56: 484–489.

13. Esteve E, Rathleff MS, Vicens-Bordas J, et al. Preseason adductor squeeze strength in 303 Spanish male soccer athletes: A cross-sectional study. *Orthop J Sports Med* 2018; 6: 2325967117747275.

14. Hamad MJ, Alcaraz PE, Thorborg K, et al. Match-related acute and residual changes of hip-adduction strength in youth football: an observational study. *J Hum Kinet*; 102 [Ahead of print].

15. Buchheit M, Lacome M, Cholley Y, et al. Neuromuscular Responses to Conditioned Soccer Sessions Assessed via GPS-Embedded Accelerometers: Insights Into Tactical Periodization. *Int J Sports Physiol Perform* 2018; 13: 577–583.

16. Wollin M, Pizzari T, Spagnolo K, et al. The effects of football match congestion in an international tournament on hip adductor squeeze strength and pain in elite youth players. *J Sports Sci* 2017; 36: 1167–1172.

17. Serner A, Mosler AB, Tol JL, et al. Mechanisms of acute adductor longus injuries in male football players: a systematic visual video analysis. *Br J Sports Med* 2019; 53: 158–164.

18. von Elm E, Altman DG, Egger M, et al. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet* 2007; 370: 1453–1457.

19. McKay AKA, Stellingwerff T, Smith ES, et al. Defining training and performance caliber: A Participant Classification Framework. *Int J Sports Physiol Perform* 2022; 17: 317–331.

20. Myhill N, Weaving D, Robinson M, et al. Concurrent validity and between-unit reliability of a foot-mounted inertial measurement unit to measure velocity during team sport activity. *Sci Med Footb* 2023; 1–9.

21. Waldron M, Harding J, Barrett S, et al. A New Foot-Mounted Inertial Measurement System in Soccer: Reliability and Comparison to Global Positioning Systems for Velocity Measurements During Team Sport Actions. *J Hum Kinet* 2021; 77: 37–50.

22. Lewis G, Towlson C, Roversi P, et al. Quantifying volume and high-speed technical actions of professional soccer players using foot-mounted inertial measurement units. *PLoS One* 2022; 17: e0263518.

23. Malone S, Owen A, Mendes B, et al. High-speed running and sprinting as an injury risk factor in soccer: Can well-developed physical qualities reduce the risk? *J Sci Med Sport* 2018; 21: 257–262.

24. Buchheit M, Mendez-Villanueva A, Simpson BM, et al. Match running performance and fitness in youth soccer. *Int J Sports Med* 2010; 31: 818–825.

25. Williams S, Shaw JW, Emery C, et al. Adding confidence to our injury burden estimates: is bootstrapping the solution? *Br J Sports Med* 2024; 58: 57–58.

26. Plonsky L. *Advancing quantitative methods in second language research*. 1st Edition. Routledge. Epub ahead of print 3 July 2015. DOI: 10.4324/9781315870908.

27. Huang FL. Using cluster bootstrapping to analyze nested data with a few clusters. *Educ*

Psychol Meas 2018; 78: 297–318.

28. Fox J. Applied Regression Analysis and Generalized Linear Models. *SAGE Publications Ltd*, https://uk.sagepub.com/en-gb/eur/applied-regression-analysis-and-generalized-linear-models/book237254 (2025, accessed 16 September 2025).

29. Hopkins WG. Linear models and effect magnitudes for research, clinical and practical applications. *Sportscience* 2010; 14: 49–59.

30. R Core Team. *R: A Language and Environment for Statistical Computing*, https://www.R-project.org/ (2025).

31. Dalen T, Ingebrigtsen J, Ettema G, et al. Player load, acceleration, and deceleration during Forty-Five competitive matches of elite soccer. *J Strength Cond Res* 2016; 30: 351–359.

32. Dupré T, Tryba J, Potthast W. Muscle activity of cutting manoeuvres and soccer inside passing suggests an increased groin injury risk during these movements. *Sci Rep* 2021; 11: 7223.

33. Verheul J, Harper D, Robinson MA. Forces experienced at different levels of the musculoskeletal system during horizontal decelerations. *J Sports Sci* 2024; 42: 2242–2253.

34. Harper DJ, Carling C, Kiely J. High-intensity acceleration and deceleration demands in elite team sports competitive match play: A systematic review and meta-analysis of observational studies. *Sports Med* 2019; 49: 1923–1947.

35. Brophy RH, Backus SI, Pansy BS, et al. Lower extremity muscle activation and alignment during the soccer instep and side-foot kicks. *J Orthop Sports Phys Ther* 2007; 37: 260–268.

36. Charnock BL, Lewis CL, Garrett WE Jr, et al. Adductor longus mechanics during the maximal effort soccer kick. *Sports Biomech* 2009; 8: 223–234.

37. Watanabe K, Nunome H, Inoue K, et al. Electromyographic analysis of hip adductor muscles in soccer instep and side-foot kicking. *Sports Biomech* 2020; 19: 295–306.

38. Torreblanca-Martinez V, Otero-Saborido FM, Gonzalez-Jurado JA. Effects of muscle fatigue induced by countermovement jumps on efficacy parameters of instep ball kicking in soccer. *J Appl Biomech* 2017; 33: 105–111.

39. Apriantono T, Nunome H, Ikegami Y, et al. The effect of muscle fatigue on instep kicking kinetics and kinematics in association football. *J Sports Sci* 2006; 24: 951–960.

40. Jensen J, Bandholm T, Hölmich P, et al. Acute and sub-acute effects of repetitive kicking on hip adduction torque in injury-free elite youth soccer players. *J Sports Sci* 2014; 32: 1357–1364.

41. Aiello F, Impellizzeri FM, Brown SJ, et al. Injury-inciting activities in male and female football players: A systematic review. *Sports Med* 2023; 53: 151–176.

Variables	Description	Unit
Total Distance	Total distance covered	meters
Low Speed Running Distance	Distance covered <4 $m \cdot s^{-1}$	meters
High Speed Running Distance	Distance covered >4 $m \cdot s^{-1}$	meters
Sprint Distance	Distance covered >5.5 $m \cdot s^{-1}$	meters
Total Acc distance	Total distance covered accelerating	meters
Low Intensity Acc distance	Distance covered accelerating <1.5 $m \cdot s^{-2}$	meters
Moderate Intensity Acc distance	Distance covered accelerating 1.5 – 3.0 $m \cdot s^{-2}$	meters
High Intensity Acc distance	Distance covered accelerating >3.0 $m \cdot s^{-2}$	meters
Total Decl distance	Total distance covered decelerating	meters
Low Intensity Decl distance	Distance covered decelerating <1.5 $m \cdot s^{-2}$	meters
Moderate Intensity Decl distance	Distance covered decelerating 1.5 – 3.0 $m \cdot s^{-2}$	meters
High Intensity Decl distance	Distance covered decelerating >3.0 $m \cdot s^{-2}$	meters
Total Acc & Decl distance	Total distance covered accelerating and decelerating	meters
High Intensity Speed Changes	Accelerating and deceleration actions >3.0 $m \cdot s^{-2}$	counts
Releases	Number of ball releases	counts
Release index	$\frac{ball\ release\ count \times\ average\ ball\ release\ velocity}{100}$	unitless
High speed releases	Number of ball releases >15 $m \cdot s^{-1}$	counts

436 Acc, acceleration; Decel, deceleration.

437 **Table 1.** Description and classification criteria for locomotor actions

Variable	Unstandardized Coefficients				p	r	$marginal\ R^2$
	B	SE	t	Bootstrap 95% CI			
Total Distance (m)	–0.005	0.001	–5.981	[–0.007, –0.003]	< 0.001	–0.66	0.48
Low Speed Running Distance (m)	–0.007	0.001	–5.550	[–0.009, –0.004]	< 0.001	–0.62	0.45
High Speed Running Distance (m)	–0.014	0.003	–4.433	[–0.021, –0.008]	< 0.001	–0.59	0.36
Sprint Distance (m)	–0.038	0.010	–3.933	[–0.056, –0.018]	< 0.001	–0.57	0.32
Total Acc (m)	–0.011	0.002	–5.988	[–0.014, –0.007]	< 0.001	–0.66	0.47
Low Intensity Acc (m)	–0.012	0.002	–5.434	[–0.016, –0.008]	< 0.001	–0.62	0.43
Moderate Intensity Acc (m)	–0.074	0.012	–6.338	[–0.095, –0.052]	< 0.001	–0.69	0.50
High Intensity Acc (m)	–0.312	0.083	–3.768	[–0.472, –0.149]	0.001	–0.55	0.30
Total Decl (m)	–0.010	0.002	–5.876	[–0.013, –0.007]	< 0.001	–0.66	0.47
Low Intensity Decl (m)	–0.011	0.002	–5.505	[–0.015, –0.007]	< 0.001	–0.63	0.45
Moderate Intensity Decl (m)	–0.076	0.013	–5.672	[–0.101, –0.051]	< 0.001	–0.68	0.47
High Intensity Decl (m)	–0.302	0.095	–3.178	[–0.496, –0.122]	0.004	–0.48	0.23
Total Acc & Decl (m)	–0.005	0.001	–5.985	[–0.007, –0.003]	< 0.001	–0.66	0.48
High Intensity Speed Changes (#)	–0.403	0.089	–4.521	[–0.571, –0.228]	< 0.001	–0.62	0.38
Releases (#)	–0.069	0.050	–1.370	[–0.171, 0.033]	0.180	–0.24	0.05
Release index	–0.084	0.060	–1.401	[–0.196, 0.038]	0.171	–0.24	0.06
High speed releases (#)	0.234	0.258	0.909	[–0.248, 0.741]	0.370	0.16	0.02

Acc, acceleration; Decl, deceleration; dist, distance.

438 **Table 2**. Linear Mixed Model Statistics

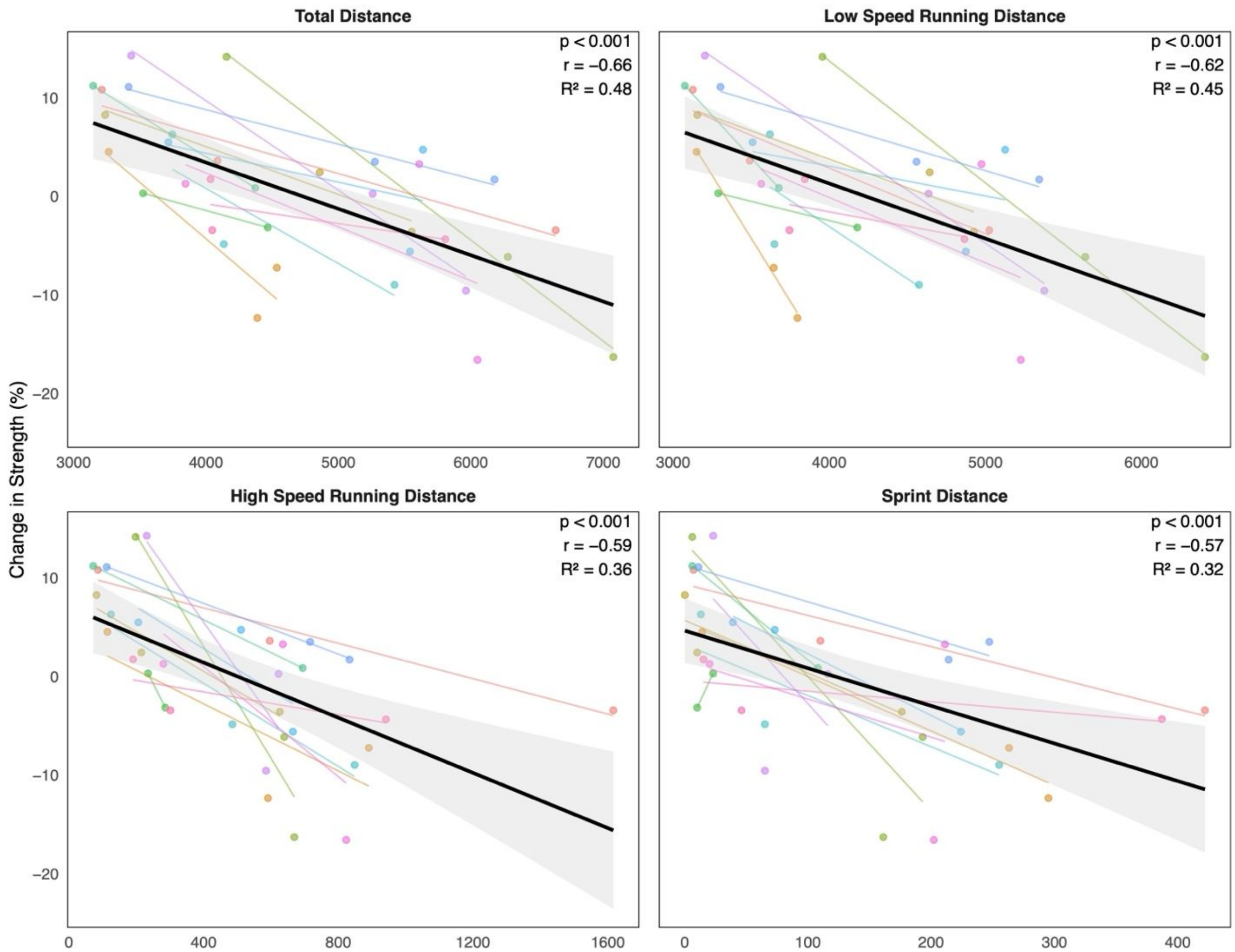

Figure 1

Scatterplots of the relationship between running actions (m) and post-training hip adductor strength change (%). Each point represents a training observation colored by participant. Black line and grey band represent the fixed effect, the average effect across all participants. (Marginal) R^2 is the variance explained by the fixed effect.

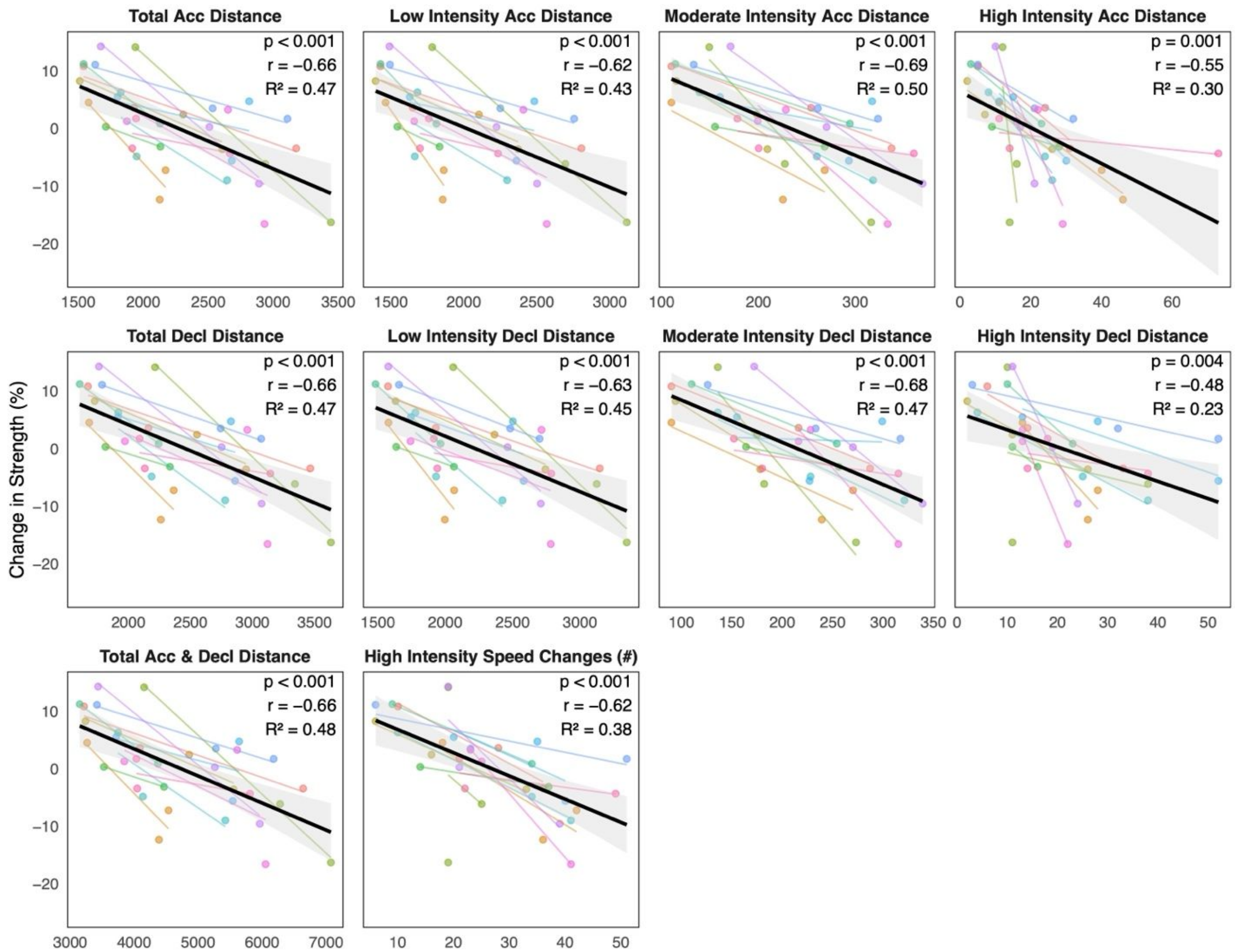

Figure 2

Scatterplots of the relationship between speed change actions and post-training hip adductor strength change (%). Each point represents a training observation colored by participant. Black line and grey band represent the fixed effect, the average effect across all participants.

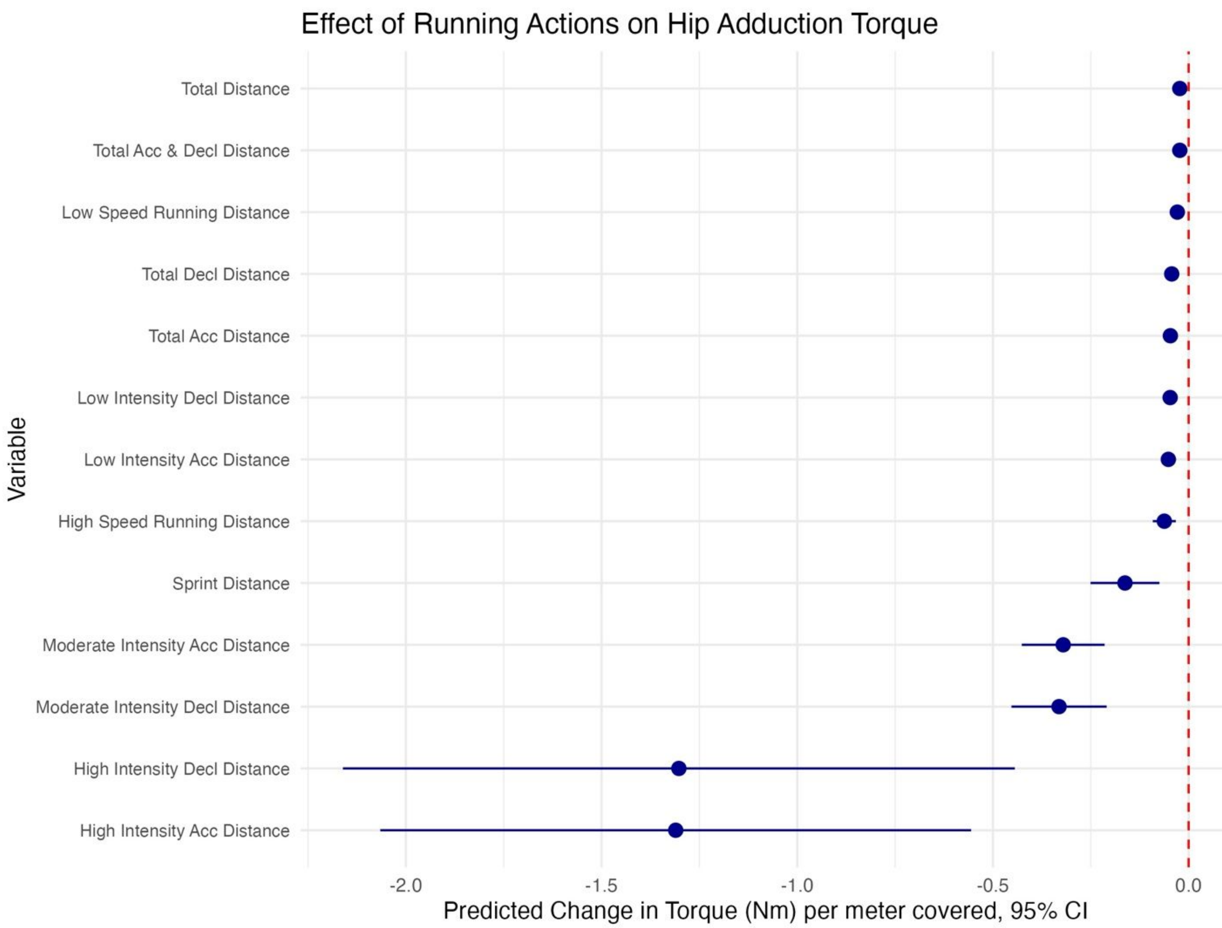

Figure 3. The predicted change in hip adductor squeeze strength for each meter covered of different running and speed change actions. Points represent the unstandardized B coefficients (per meter predicted change in torque (Nm)) and their 95% CI.