The Effects of Training Interventions on Modifiable Hamstring Strain Injury Risk Factors in Healthy Soccer Players: A Systematic Review

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ABSTRACT

Despite promising research on various soccer-specific injury prevention programs, hamstring strain injuries (HSIs) persist in being a major problem in the sport. Therefore, in an attempt to expand the current knowledge on the prevention of HSIs, this systematic review aimed to identify how modifiable risk factors for HSIs (hamstring strength, hamstring:quadriceps [H:Q] strength ratios, biceps femoris long head fascicle length, and hamstring angle of peak torque) were altered following various training interventions. The protocol was preregistered on PROSPERO (CRD42020177363). The literature search was conducted on PubMed, SportDISCUS, and Web of Science. Following the search process, 20 studies were included in the systematic review, and the methodological quality of these studies was reported. Interventions were categorized based on exercise characteristics (movement velocity and contraction type), and the effects of each intervention subgroup were analyzed separately for all proposed risk factors for HSIs. Our findings show that a broad variety of exercise types (i.e., high- and low-velocity movements, eccentric only and traditional exercises) improves all risk factors for HSIs compared with fewer exercise types. Therefore, these findings suggest that hamstring injury risk factors can best be modified using a wide variety of exercises compared with, for example, only 1 or 2 specific exercises.

INTRODUCTION

Hamstring strain injuries (HSIs) are the most common noncontact injury in soccer (28,29,37,86,87). Hamstring strain injuries have been shown to negatively impact team success (i.e., lower final league ranking and high financial costs because of player absence) (27,36) and individual performance (i.e., reduced neuromuscular function and activation deficits) (7,83,84) even long after rehabilitation and return to sport. Furthermore, HSIs have been associated with a poor healing response (15,19) and a relatively high risk of reinjury (4,87).

Researchers have shown that HSIs most commonly occur during the late swing phase of high-speed running. In this phase of the stride cycle, the hamstring muscles simultaneously reach peak levels of force and strain (16,40,41,72,88). Based on these findings, it has been suggested that poor hamstring strength, low angle of peak torque (APT), short biceps femoris long head (BFlh) fascicle length, and hamstring:quadriceps (H:Q) strength imbalances increase the risk of sustaining HSIs. It is believed that stronger hamstring muscles are more resilient to strain injury than weaker hamstring

KEY WORDS:
HSI; risk factors; injury prevention; football; hamstring; soccer

muscles (33) because they can better resist lengthening (41) and thus damage. Furthermore, muscles with longer fascicles are assumed to contain more sarcomeres in series. Therefore, each individual sarcomere undergoes less length change for a given change in muscle-tendon unit length. As a result, muscles with longer fascicle lengths might experience less damage during activities where they reach high levels of force and strain, and this may, in turn, decrease injury risk (59).

Furthermore, during high-speed running, the hamstring muscles (specifically the short head of the biceps femoris) actively control the knee extension motion (58). Accordingly, it has been suggested that the level of strain experienced by the hamstring muscles is at least partially determined by the ratio of hamstring-to-quadriceps strength, given that the quadriceps muscles are responsible for knee extension motion (41,58). Indeed, a growing body of literature now supports these suggested associations because hamstring strength (8,64,79,81), BFlh fascicle length (63,81), APT (12), and low H:Q strength imbalances (14,20,24,65) have been correlated with future HSIs. However, despite the ever-growing interest in HSIs in soccer among sport scientists, the incidence in soccer has increased over the past few years (30). These data emphasize the need to expand the current knowledge base regarding the prevention of HSIs in soccer.

Risk factors for HSIs are often modified using strength training exercises. However, muscle activation patterns, force output, and fascicle behavior do differ between various exercises (10,39,43,55,62,71,80). These acute differences may lead to different training adaptations over the long run. For example, exercises involving a predominantly eccentric muscle action typically lead to increases in fascicle length, whereas exercises involving concentric muscle actions can shorten fascicle length (11,26). Furthermore, studies have also shown regional differences in muscle activation patterns between different exercises (10,43) and between variations of the same exercise (39,71). These may lead to differences in muscle cross-sectional area and hence strength adaptations over the long run (85). Because different exercises, therefore, likely induce differential adaptations, an overview of how different individual exercises or combinations of exercises impact modifiable risk factors for HSIs might enable sport scientists and coaches alike to make more informed choices regarding program design. Additionally, a better understanding of the relationship between preventive exercises and risk factors might allow for a more individualistic approach, which, ultimately, should result in more efficient and effective injury prevention programs. Therefore, this systematic review aimed to examine the effects of different training interventions targeting the lower limbs on risk factors for HSIs among injury-free soccer players.

METHODS

SEARCH STRATEGY AND SELECTION OF STUDIES

This systematic literature search was conducted in accordance with the guidelines provided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (57). A protocol was preregistered in the International Prospective Register of Systematic Reviews (PROSPERO; ID: CRD42020177363). On May 23, 2020, an online search was performed using the following databases: PubMed, SPORTDiscus, and Web of Science. The following search strategy was used for all databases: (soccer OR football) AND (training OR program OR programme OR prevention OR protocol OR intervention OR preventative OR treatment OR exercise) AND ("biceps femoris" OR semimembranosus OR semitendinosus OR "posterior thigh" OR "posterior limb" OR "posterior leg" OR "posterior chain" OR hamstring OR injury OR "risk factor" OR ratio). Database results were limited to English research articles. Additional articles were also identified through the checking of reference lists. Following the initial search and after removing duplicates, each study was screened for the title, abstract, and full text using the inclusion and exclusion criteria described below, in this exact order.

Studies were included in the present review if they met the following inclusion criteria: (a) participants in the study were healthy (i.e., injury free upon start of intervention or participating in full training schedule): soccer players; (b) the study examined the effects of a training intervention consisting of a single lower-limb exercise (e.g., Nordic hamstring exercise) or a structured physical preparation program (i.e., combination of different exercises designed by the researchers of the study) or a commercially available injury prevention program (e.g., FIFA's "11+"); (c) the study examined the effects of a training intervention duration lasting a minimum of 4 weeks; (d) the study evaluated pre- and post-intervention measurements of at least one proposed, modifiable risk factor for HSIs (i.e., hamstring strength, APT, BFlh fascicle length and H:Q strength ratios involving the hamstrings); (e) the study included a control group (CG); (f) the study was a randomized or cluster-randomized controlled trial; and (g) the study was published in a peer-reviewed journal. Adhering to the exclusion criteria meant the removal of studies that (a) were unavailable in English; (b) were only available in abstract form; (c) did not provide a detailed description of the intervention protocol (i.e., exercise selection, number of sets and repetitions per exercise, and intervention session frequency); and (d) included athletes that were not (primarily) soccer players (e.g., futsal players).

DATA EXTRACTION AND ANALYSIS

The following information was extracted from each study: (a) author and publication year; (b) number, sex, and age of participants; (c) level of competition; (d) soccer practice frequency or volume upon start of intervention; (e) compliance to the intervention; (f) intervention program (exercise(s), sets per exercise and repetitions per set); (g) intervention session frequency and total intervention duration; (h) hamstring-specific outcome variables measured; and (i) pre- and postintervention means and standard deviations (SD) for each group. If the pre- and postintervention means and SDs were only available in figures, values were extracted using the WebPlotDigitizer (https://apps.automeris.io/wpd/). Percentage changes from pre- to postintervention and within-group Cohen's *d* effect sizes were calculated manually using a custom-made Excel sheet.

EXERCISE INTERVENTION AND PARTICIPANT TRAINING STATUS CATEGORIZATION

Exercise interventions were categorized based on contraction types (i.e., predominantly eccentric, predominantly concentric, or both) and contraction velocities (i.e., low or high velocity) to aid with the interpretation of the results. Contraction types and velocities for all exercises were categorized based on how they were classified in the original article. For example, if an article referred to the Nordic hamstring exercise as an eccentric exercise, the same classification was retained for the present systematic review. In case the classification for a given exercise differed between studies, then the predominant classification was used. For exercises not categorized in any of the studies included in this review, classifications used in other articles (see reference list) were kept for the present review. Finally, if none of the aforementioned applied, exercises were categorized as predominantly eccentric, concentric, or a combination of both based on the following: (a) exercises that resulted in significant deceleration demands with relatively long contact times (e.g., box drops), sprint or sprint-related exercises (e.g., bounding), and exercises where the eccentric portion was emphasized or performed in isolation (e.g., flywheel leg curl, eccentric-only Nordic hamstring exercise) were categorized as predominantly eccentric exercises (43,48); (b) concentric exercises were those that emphasized the concentric and/or omitted the eccentric portion of the lift (e.g., concentric leg curl on an isokinetic dynamometer); and (c) exercises that put equal emphasis on both portions of the lift were classified as targeting the hamstrings both eccentrically and concentrically (e.g., stiff-leg deadlift performed with controlled concentric and eccentric phases) (43).

In regards to contraction velocity, exercises were classified as high-velocity exercises if they were jump or sprint variations or if it was specifically mentioned in the original article that an exercise was performed at high velocity (3). Otherwise, exercises were classified as being low-velocity exercises. Finally, the participants' training status (i.e., well-trained or recreationally trained) was categorized based on McKay et al. (52). Briefly, this classification framework includes 6 tiers (sedentary to world class) and uses training volume and performance metrics to classify participants into 1 of these 6 tiers (52).

ASSESSMENT OF METHODOLOGICAL QUALITY

The methodological quality of each study was assessed separately by 2 raters (C.S. and I.J.) using the Physiotherapy Evidence Database (PEDro) scale (50). This scale consists of 11 criteria, with one point awarded for each criterion when clearly satisfied (except for criterion a, which was not part of the total score). The criteria refer to (a) reporting of eligibility criteria; (b) random assignment; (c) concealed allocation; (d) similarity of groups at baseline; (e) blinding of participants; (f) blinding of people administering the intervention; (g) blinding of assessors who measured key outcomes; (h) measures of at least one outcome were obtained from more than 85% of initial participants; (i) all participants received the intervention or control condition as allocated; (j) results of between-group statistical comparisons were reported; and (k) the study provided point measures and measures of variability for at least one key outcome. Given the nature of the studies included in this article (i.e., interventional exercise studies), it should be noted that criteria 5 and 6 (blinding of participants and administrators, respectively) were fulfilled if those concerned were unaware of the intentions of the study and the other groups' interventions/conditions. Any differences in the outcomes of the methodological quality assessments between the 2 raters were solved via discussion.

RESULTS

SEARCH RESULTS

A total of 17,483 results were found through database searching (PubMed: n = 8,660; SportDISCUS: n = 7,570; Web of Science: n = 1,253). Titles and abstracts were screened for relevance after removing duplicates (n = 4,407). During this process, 13,006 articles were excluded, leaving 70 full-text articles to be checked for eligibility. A further 50 studies were excluded for not meeting the eligibility criteria. Consequently, 20 studies (3,5,6,13,18,21–23,25,44–47,49,54,56,60,61,77,89) were included in this systematic review. No additional studies were found by checking the reference lists of the included studies. Figure 1 represents the search and selection process in a PRISMA flowchart.

DESCRIPTION OF INCLUDED STUDIES

Participant numbers across all studies ranged from 18 to 81. One study (77) was performed on female subjects, 2 studies (54,89) did not report the participants' sex, and the remaining studies (3,5,6,13,18,21–23,25,44–47,49,56,60,61) included male subjects only. Participant training status spanned from recreationally active to highly trained. A detailed overview of the participant characteristics can be found in Table 1.

From a total of 31 experimental groups, the most represented type of intervention was low-velocity eccentric hamstring training (48%) (6,21–23,25,44,46,47,49,54,60,61), followed by a combination of low- and high-velocity eccentric and high-velocity concentric training (19%) (5,21–

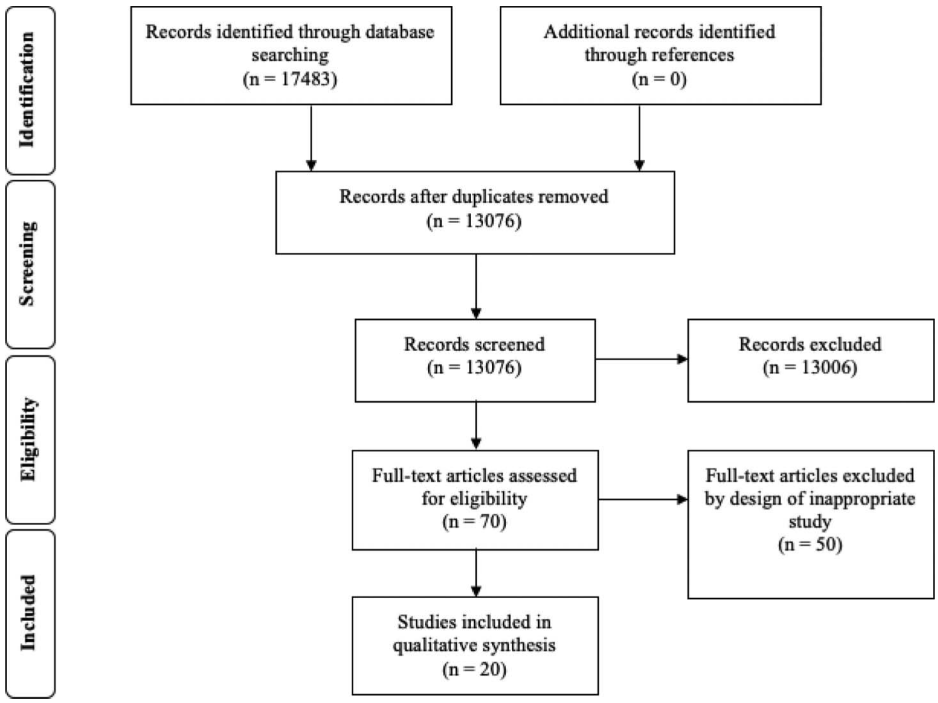

Figure 1. PRISMA flowchart.

23,45,77) and high-velocity eccentric training (13%) (3,18,47). One (3%) experimental group each performed the following: low-velocity concentric training (3); high-velocity concentric training (3); low- and high-velocity eccentric training (13); a combination of low- and high-velocity eccentric and low- and high-velocity concentric training (56); a combination of low- and high-velocity eccentric and low-velocity concentric training (89); and a combination of high-velocity eccentric and high-velocity concentric training (Table 2) (54). Risk factors for HSIs investigated across all studies were hamstring strength (*n* = 18) (3,5,6,13,18,22,23,25,44–47,49,56,60,61,77,89), H:Q strength ratios (*n* = 7) (3,5,13,18,21,56,77), hamstring APT (*n* = 2) (13,44), and BFlh fascicle length (*n* = 2) (49,54) (Table 2).

OVERVIEW OF RESULTS OF INCLUDED STUDIES

Combined low- and high-velocity eccentric and concentric training and combined low- and high-velocity eccentric and low-velocity concentric training most consistently resulted in significant hamstring strength (concentric, eccentric, and isometric combined) gains. These experimental groups improved hamstring strength in 100% of the hamstring strength tests. H:Q strength ratio improvements were most consistent following combined low-and high-velocity eccentric and concentric training interventions. BFlh fascicle length increases were the most prominent post combined high-velocity eccentric and concentric training. Combined low- and high-velocity eccentric training significantly improved hamstring APT, whereas low-velocity eccentric training did not. Both low-velocity eccentric training and combined low- and high-velocity eccentric and high-velocity concentric training resulted in negative changes in 1 and 2 H:Q strength ratio variables, respectively. Additionally, low-velocity eccentric training led to a decrement in 1 hamstring strength variable (Table 2).

OVERVIEW OF RESULTS OF METHODOLOGICAL QUALITY ASSESSMENT

The median methodological quality score was 6 of 10. Total scores ranged from 3 of 10 to 8 of 10. An overview of the methodological quality assessment of each study is provided in Table 2.

DISCUSSION

The main objective of this systematic review was to investigate the effects of lower-body–focused interventions on the proposed modifiable risk factors for HSIs in soccer players. Twenty studies met the inclusion criteria and were further analyzed. The mean methodological quality score was 6 of 10 and ranged from 3 of 10 to 8 of 10. Outcome variables reported across all studies were hamstring strength (concentric, isometric, and eccentric), H:Q strength ratios, BFlh fascicle length, and hamstring APT. The main finding of this study was that using a broad array of exercise types and modes seemed to most consistently improve hamstring strength and H:Q strength ratios. Furthermore, combined low- and high-velocity eccentric training reduced hamstring APT, whereas low-velocity eccentric training alone did not. However, low-velocity eccentric training significantly increased

Table 1
Subject characteristics

Study, y	Participants (n)	Sex	Age (y, mean ± SD)	Soccer practice frequency or volume upon start of intervention (d/wk or h/wk)	Training status	Compliance to intervention
Aagard et al., 1996	EG1 = 7 EG2 = 5 EG3 = 5 CG = 5	Male	22.8 ± 4.1	N/R	Highly trained	N/R
Askling et al., 2003	EG = 13 CG = 13	Male	EG = 24 ± 2.6 CG = 26 ± 3.6	N/R	Highly trained	100%
Steffen et al., 2008	EG = 17 CG = 14	Female	17.1 ± 0.8	13.3 h/wk	Trained	73%
Jönhagen et al., 2009	EG1 = 11 EG2 = 10 CG = 11	Male	18	3–5×/wk	Recreationally active	N/R
Brughelli et al., 2010	EG = 13 CG = 11	Male	EG = 20.7 ± 1.6 CG = 21.5 ± 1.3	EG = 10.3 h/wk CG = 10.9 h/wk	Trained	100%
Daneshjoo et al., 2012	EG1 = 12 EG2 = 12 CG = 12	Male	EG1 = 19.2 ± 0.9 EG2 = 17.7 ± 0.4 CG = 19.7 ± 1.6	Almost daily practice + 1 match/wk	Highly trained	100%
Iga et al., 2012	EG = 10 CG = 8	Male	EG = 23.4 ± 3.3 CG = 22.3 ± 3.9	N/R	Highly trained	100%
Daneshjoo et al., 2013a	EG1 = 12 EG2 = 12 CG = 12	Male	18.9 ± 1.4	Almost daily practice + 1 match/wk	Highly trained	100%
Daneshjoo et al., 2013b	EG1 = 12 EG2 = 12 CG = 12	Male	18.9 ± 1.4	N/R	Highly trained	100%
Impellizzeri et al., 2013	EG = 42 CG = 39	Male	EG = 23.7 ± 3.7 CG = 23.2 ± 3.8	×3/wk + 1 match/wk	Trained	N/R
Naclerio et al., 2013	EG = 10 CG = 10	Male	23.8 ± 3.1	×3/wk	Trained	N/R
Mendiguchia et al., 2015	EG = 27 CG = 24	Male	EG = 22.7 ± 4.8 CG = 21.8 ± 2.5	×3/wk + 1 match/wk	Trained	>70%

(continued)

Table 1
(continued)

Naclerio et al., 2015	EG1 = 11 EG2 = 11 CG = 10	Male	22.2 ± 2.6	×2/wk + 1 match/wk	Recreationally active	100%
Coratella et al., 2018	48	Male	21 ± 3	×3/wk + 1 match/wk	Trained	EG1 = 94% EG2 = 96%
Ishøi et al., 2018	EG = 11 CG = 14	Male	EG = 19.1 ± 1.8 CG = 19.4 ± 2.1	×3/wk + 1 match/wk	Trained	60%
Lovell et al., 2018	EG1 = 9 EG2 = 13 CG = 11	Male	23.6 ± 4.7	×2/wk + 1 match/wk	Recreationally active	EG1 = 34.7% EG2 = 46.8%
Arsenis et al., 2020	EG = 16 CG = 16	Male	EG = 18.8 ± 0.8 CG = 19.3 ± 0.8	N/R	Trained	N/R
Drury et al., 2020	EG1 = 8 EG2 = 16 CG1 = 11 CG2 = 13	Male	EG1 = 11.0 ± 0.9 (pre-PHV) EG2 = 14.0 ± 1.1 (mid-/post-PHV) CG1 = 10.9 ± 0.8 (pre-PHV) CG2 = 13.7 ± 1.0 (mid-/post-PHV)	×2/wk + 1 match/wk	Recreationally active	≥85%
Mendiguchia et al., 2020	EG1 = 7 EG2 = 8 CG = 8	N/R	>18	×4/wk + ≥2 matches/wk	Trained	>80%
Zarei et al., 2020	EG = 16 CG = 15	N/R	EG: 11.3 ± 0.9 CG: 11.7 ± 0.7	~4 h/wk	Recreationally active/trained	100%

CG = control group; EG = experimental group; N/R = not reported; PHV = peak height velocity.

Table 2
Study characteristics

Study, y (PEDro score)	Intervention program	Frequency (intervention sessions/wk) and duration (wks)	Hamstring-specific outcome variables	EG %-change (effect size)	CG %-change (effect size)
Aagard et al., 1996 (3/10)	EG1: Knee flexor and extensor training on hydraulic resistance machine; 4 × 8 reps at 20–50°/s EG2: Knee flexor and extensor training on hydraulic resistance machine; 4 × 24 reps at 150–200°/s EG3: Loaded kicking; 4 × 16 reps at 0–400°/s	×3/wk over 12 wks	Con PT 30°/s Con PT 120°/s Con PT 240°/s Ecc PT 30°/s Ecc PT 120°/s Ecc PT 240°/s T50° con 30°/s T50° con 120°/s T50° con 240°/s T50° ecc 30°/s T50° ecc 120°/s T50° ecc 240°/s	EG1: +14.8 (0.84)* EG2: −1.7 (0.07) EG3: +3.4 (0.15) EG1: +7.8 (0.61) EG2: −3.0 (0.21) EG3: +2.9 (0.11) EG1: +12.7 (0.75) EG2: +7.0 (0.35) EG3: −1.3 (0.06) EG1: +10.5 (0.52)* EG2: −6.1 (0.20) EG3: −1.5 (0.07) EG1: +11.2 (0.48)* EG2: −5.6 (0.24) EG3: −6.5 (0.27) EG1: +10.1 (0.65)* EG2: −10.7 (0.43) EG3: +2.1 (0.09) EG1: +11.1 (0.52)* EG2: +2.4 (0.06) EG3: +5.4 (0.22) EG1: +11.0 (0.69) EG2: −5.8 (0.34) EG3: +2.2 (0.10) EG1: +12.1 (0.66) EG2: +1.5 (0.08) EG3: −6.6 (0.28) EG1: +22.9 (1.20)* EG2: −1.8 (0.05) EG3: +6.7 (0.30) EG1: +13.7 (0.84)* EG2: −5.1 (0.21) EG3: +2.4 (0.11) EG1: +17.1 (1.15)* EG2: −9.4 (0.39) EG3: +4.1 (0.17)	+10.2 (0.44) +10.8 (0.60) +16.0 (0.72) +10.4 (0.41) +4.7 (0.18) +12.4 (0.50) +8.9 (0.35) +8.2 (0.49) +12.7 (0.69) +12.0 (0.39) +6.9 (0.28) +17.7 (0.70)

(continued)

Table 2
(continued)

Askling et al., 2003 (6/10)	Prone leg curl on flywheel; 3 × 8 reps	Every 4th or 5th d over 10 wks	Con PT 60°/s Ecc PT 60°/s	+15.3 (0.85)* +18.9 (1.22)*	+2.3 (0.14) −1.3 (0.08)
Steffen et al., 2008 (6/10)	FIFA 11	×3/wk over 10 wks	Con PT 60°/s DL Con PT 240°/s DL Ecc PT 60°/s DL Iso PT 30° DL Iso PT 60° DL Iso PT 90° DL ConH/ConQ 60°/s DL ConH/ConQ 240°/s DL EccH/EccQ 60°/s DL EccH/ConQ 60°/s DL	−1.0 (0.09) +1.5 (0.15) −1.3 (0.13) +4.3 (0.30) +5.8 (0.44) −0.7 (0.06) −3.3 (0.33) +1.4 (0.15) −2.7 (0.23) +7.1 (0.63)	−2.3 (0.29) −1.3 (0.13) −3.8 (0.43) −1.5 (0.13) +5.8 (0.41) +0.9 (0.05) −3.4 (0.40) −1.0 (0.14) −12.1 (0.95) +7.7 (0.57)
Jönhagen et al., 2009 (5/10)	EG1: walking forward lunge; 4 × 12 reps EG2: jumping forward lunge; 4 × 12 reps	×2/wk over 6 wks	Con PT 180°/s NDL	EG1: +34.5 (1.91)* EG2: +17.0 (1.18)	+9.4 (0.75)
Brughelli et al., 2010 (8/10)	1-2 of the following exercises per intervention session: Eccentric box drops, lunge pushes, forward deceleration steps, reverse Nordic hamstrings; 4–5 total sets per session	×3/wk over 4 wks	Con PT 60°/s APT 60°/s ConH/ConQ 60°/s	−2.0 (0.18) −12.4 (1.10)*§ −1.5 (0.14)	−1.0 (0.09) −7.6 (0.74)* +1.5 (0.13)

Table 2 (continued)

Daneshjoo et al., 2012 (7/10)	EG1: FIFA 11+ EG2: HarmoKnee	×3/wk over 8 wk	ConH/ConQ 60°/s DL ConH/ConQ 60°/s NDL ConH/ConQ 180°/s DL ConH/ConQ 180°/s NDL ConH/ConQ 300°/s DL ConH/ConQ 300°/s NDL EccH/ConQ 120°/s DL EccH/ConQ 120°/s NDL ConH300°/s/ConH60°/s DL ConH300°/s/ConH60°/s NDL	EG1: +7.5 (0.05) EG2: +14.6 (0.77) EG1: +14.0 (0.77)* EG2: +2.0 (0.07) EG1: +13.0 (0.11) EG2: +15.7 (0.80) EG1: +7.1 (0.42) EG2: −4.9 (0.19) EG1: +1.4 (0.05) EG2: −13.3 (0.70) EG1: −1.3 (0.05) EG2: −9.9 (0.51) EG1: −45.3 (1.08)* EG2: −16.7 (0.70) EG1: −41.5 (1.17)*§ EG2: −29.2 (0.72)§ EG1: +11.7 (0.35) EG2: −13.9 (0.70) EG1: +1.5 (0.06) EG2: −8.9 (0.44)	+4.1 (0.20) +0.0 (0.00) +6.4 (0.15) +2.0 (0.10) −10.3 (0.31) +6.0 (0.13) −7.2 (0.25) −4.3 (0.15) −13.0 (0.40) +6.9 (0.20)
Iga et al., 2012 (6/10)	NHE; 2–3 × 5–8 reps	1–3×/wk over 4 wks	Ecc PT 60°/s DL Ecc PT 60°/s NDL Ecc PT 120°/s DL Ecc PT 120°/s NDL Ecc PT 240°/s DL Ecc PT 240°/s NDL APT 60°/s DL APT 60°/s NDL APT 120°/s DL APT 120°/s NDL APT 240°/s DL APT 240°/s NDL	+14.8 (0.40)*§ +20.2 (0.59)*§ +10.7 (0.30)*§ +13.3 (0.43)*§ +7.4 (0.21)*§ +19.6 (0.61)*§ −8.8 (0.16) −23.5 (0.57) −29.0 (0.50) −23.3 (0.45) −10.7 (0.85) −3.4 (0.20)	+0.8 (0.03) +1.9 (0.06) −0.8 (0.03) +4.8 (0.15) −3.5 (0.09) +3.9 (0.13) −16.7 (0.32) −7.4 (0.13) −14.8 (0.24) +3.8 (0.07) +3.6 (0.22) +0.0 (0.00)

(continued)

Table 2
(continued)

Daneshjoo et al., 2013a (6/10)	EG1: FIFA 11+ EG2: HarmoKnee	×3/wk over 8 wks	Con PT 60°/s DL Con PT 60°/s NDL Con PT 180°/s DL Con PT 180°/s NDL Con PT 300°/s DL Con PT 300°/s NDL Ecc PT 120°/s DL Ecc PT 120°/s NDL	EG1: +19.5 (1.28)*§ EG2: +36.1 (1.19)* EG1: +20.3 (1.18)*§ EG2: +23.5 (0.78)* EG1: +27.5 (1.16)*§ EG2: +53.6 (1.28)* EG1: +19.5 (1.18)*§ EG2: +27.7 (0.67)* EG1: +32.7 (0.98)*§ EG2: +20.6 (0.56)* EG1: +20.3 (0.70)§ EG2: +14.7 (0.53) EG1: +4.7 (0.47) EG2: −0.1 (0.01) EG1: +9.0 (0.87) EG2: +0.4 (0.06)	+6.6 (0.19) −6.0 (0.18) +3.5 (0.09) +13.9 (0.32) −6.2 (0.13) +6.6 (0.13) −0.7 (0.25) −4.4 (0.50)
Daneshjoo et al., 2013b (7/10)	EG1: FIFA 11+ EG2: HarmoKnee	×3/wk over 8 wks	Iso PT 30° DL Iso PT 30° NDL Iso PT 60° DL Iso PT 60° NDL Iso PT 90° DL Iso PT 90° NDL	EG1: +17.5 (0.72)* EG2: +7.2 (0.30) EG1: +23.7 (0.90)* EG2: +13.6 (0.50) EG1: +17.4 (0.76)* EG2: +9.7 (0.44) EG1: +13.5 (0.54)* EG2: +14.9 (0.53) EG1: +11.3 (0.47) EG2: +0.9 (0.03) EG1: +5.3 (0.27) EG2: +18.7 (0.62)	−9.6 (0.45) −10.1 (0.49) −2.8 (0.13) −8.4 (0.43) −1.8 (0.07) −11.6 (0.60)
Impellizzeri et al., 2013 (7/10)	FIFA 11+	×3/wk over 9 wks	Con PT 60°/s Con PT 180°/s Ecc PT 60°/s	+6.2 (0.43)*§ +7.3 (0.41)*§ +6.0 (0.37)*§	+2.9 (0.21)* +2.6 (0.15) +2.6 (0.16)*
Naclerio et al., 2013 (6/10)	NHE, forward lunge on bosu ball, eccentric single-leg deadlift; 3 × 8 reps per exercise	×3/wk over 4 wks	Iso PT 35° DL Iso PT 45° DL Iso PT 60° DL Iso PT 80° DL Iso PT 90° DL Iso PT 100° DL	+10.8 (0.51) −2.1 (0.09) −2.1 (0.08) +14.4 (0.78)*§ −0.8 (0.03) −3.5 (0.10)	−3.4 (0.11) +0.5 (0.02) −0.7 (0.02) −1.6 (0.15) −0.9 (0.03) +2.0 (0.07)

Table 2 (continued)

Mendiguchia et al., 2015 (5/10)	Eccentric strength exercises (NHE, lunge variations, deadlift variations, glute bridge variations, box drops; 2–3 × 4–8 reps per exercise) in both sessions, plyometric exercises (horizontal jump variations, bounding, hop variations; 2–3 × 3–8 reps per exercise) in session 1 and acceleration drills (wall acceleration drills, free sprints, resisted sprints; 1–3 × 2–8 reps × 5–20 m per exercise) in session 2	×2/wk over 7 wks	Con PT 60°/s DL Con PT 60°/s NDL Ecc PT 60°/s DL Ecc PT 60°/s NDL ConH/ConQ 60°/s DL ConH/ConQ 60°/s NDL EccH/ConQ 60°/s DL EccH/ConQ 60°/s NDL	+13.1 (0.72)*§ +12.1 (0.69)* +17.2 (0.99)*§ +13.2 (0.70)* +9.8 (0.63)*§ +5.9 (0.40)§ +13.5 (1.00)*§ +6.7 (0.48)*§	+5.1 (0.25)* +5.0 (0.24)* −1.3 (0.08) +1.8 (0.09) +2.0 (0.11) +4.3 (0.25)* −4.3 (0.28)* +1.2 (0.07)
Naclerio et al., 2015 (6/10)	EG1: Band-assisted NHE, eccentric single-leg deadlift, eccentric double-leg deadlift; 3 × 8 reps EG2: Assisted single-leg squat, assisted single-leg squat on bosu ball, assisted forward lunge on bosu ball; 3 × 8 reps	×3/wk over 6 wks	Iso PT 35° DL Iso PT 45° DL Iso PT 60° DL Iso PT 80° DL Iso PT 90° DL Iso PT 100° DL	EG1: +9.2 (0.21)* EG2: −2.4 (0.05) EG1: +26.2 (0.90)* EG2: −5.2 (0.15) EG1: −3.5 (0.11) EG2: +9.4 (0.26)* EG1: −6.3 (0.20) EG2: +19.0 (0.53)* EG1: −14.0 (0.53) EG2: +29.9 (0.73)* EG1: −6.3 (0.15) EG2: +15.1 (0.32)	+5.3 (0.10) +5.8 (0.15) +0.6 (0.01) −0.5 (0.01) +2.0 (0.06) +12.2 (0.24)
Coratella et al., 2018 (5/10)	EG1: Bodymass squat jump; 5 × 10 reps EG2: Weighted squat jump; 4 × 10–11 reps	×2/wk over 8 wks	Ecc PT 60°/s EccH/ConQ 60°/s	EG1: +17.9 (0.86)* EG2: +15.8 (0.95)* EG1: +7.0 (0.46)* EG2: +0.0 (0.00)	+2.5 (0.12) +2.2 (0.15)

(continued)

Table 2
(continued)

Ishøi et al., 2018 (6/10)	NHE; 2–3 × 5–12 reps	1–3×/wk over 10 wks	Ecc PT (NordBord) Ecc fatigue resistance (NordBord) Ecc strength capacity (NordBord)	+19.2 (1.02)*§ −35.8 (0.34) +17.4 (0.93)*§	−2.4 (0.14) −75.0 (0.38) −5.3 (0.30)
Lovell et al., 2018 (4/10)	EG1: NHE before practice; 2–4 × 5–12 reps EG2: NHE after practice; 2–4 × 5–12 reps	1–2×/wk over 12 wks	BF thickness BF pennation angle BF fascicle length Ecc PT 30°/s DL Ecc AT 30°/s (0–15°) DL Ecc AT 30°/s (15–30°) DL Ecc AT 30°/s (30–45°) DL Ecc AT 30°/s (45–60°) DL Ecc AT 30°/s (60–75°) DL Ecc AT 30°/s (75–90°) DL	EG1: −3.7 (0.22) EG2: +1.5 (0.14)*§ EG1: −10.5 (1.00) EG2: +3.6 (0.20)*§ EG1: +12.8 (0.48)*§ EG2: +0.2 (0.01) EG1: +13.0 (0.68)*§ EG2: +9.2 (0.51)*§ EG1: +26.8 (0.90)*§ EG2: +3.3 (0.14)*§ EG1: +18.8 (0.80)*§ EG2: +17.1 (0.82)*§ EG1: +12.0 (0.62) EG2: +16.6 (0.75)*§ EG1: +10.7 (0.49) EG2: +13.2 (0.55)*§ EG1: +3.1 (0.13) EG2: +10.2 (0.40)*§ EG1: −3.4 (0.11)* EG2: +13.8 (0.42)§	−1.6 (0.12) −6.4 (0.26) −2.2 (0.07) −0.6 (0.04) −1.5 (0.07) +3.7 (0.27) +5.5 (0.43) +4.8 (0.36) +3.4 (0.24) +5.7 (0.31)
Arsenis et al., 2020 (7/10)	FIFA 11+	×3/wk over 8 wk	Con PT 60°/s DL Con PT 60°/s NDL Con PT 180°/s DL Con PT 180°/s NDL Ecc PT 60°/s DL Ecc PT 60°/s NDL ConH/ConQ 60°/s DL ConH/ConQ 60°/s NDL ConH/ConQ 180°/s DL ConH/ConQ 180°/s NDL EccH/ConQ 60°/s DL EccH/ConQ 60°/s NDL	+14.6 (0.70)*§ +7.6 (0.39)* +10.4 (0.33) −7.0 (0.34) +7.5 (0.36)*§ +6.2 (0.33)*§ +9.4 (0.56)* +6.7 (0.67)* +1.4 (0.06) −8.0 (0.39) +7.1 (0.40) +1.2 (0.06)	+1.6 (0.08) +1.9 (0.13) +3.5 (0.14) +7.1 (0.29) −5.0 (0.25) −1.2 (0.06) +3.4 (0.21) +3.9 (0.25) +9.7 (0.46) +7.7 (0.29) −4.7 (0.25) −3.8 (0.22)
Drury et al., 2020 (4/10)	EG1 and EG2: NHE; 2–3 × 5–8 reps	1–×2/wk over 6 wk	Ecc PT (NordBord)	EG1: +15.9 (0.83)*§ EG2: +10.2 (0.53)*§	CG1: −0.9 (0.05) CG2: −0.4 (0.03)

Table 2 (continued)

Mendiguchia et al., 2020 (4/10)	EG1: NHE; 2–3 × 5–12 reps EG2: Sprint running exercises (normal sprint accelerations, heavy resisted sprints, flying start sprints; 1–5 × 10–30 m) in session 1, loaded ankle plantar flexors exercises (gastrocnemius extensions; 2–3 × 6 reps), plyometric exercises (bounding, rebounds; 1–3 × 2–6 reps) and acceleration drills (wall acceleration drills, free sprints, weighted sled towing; 1–2 × 2–8 reps) in session 2	EG1: 1–×2/wk over 6 wk EG2: ×2/wk over 6 wk	BFlh thickness BFlh pennation angle BFlh fascicle length	EG1: +5.3 (0.58)*§ EG2: +5.4 (1.00)*§ EG1: +9.3 (0.54)*§ EG2: +0.5 (0.04)§ EG1: +7.4 (0.69)*§ EG2: +16.2 (1.05)*§	+1.4 (0.14) +1.1 (0.09) −0.3 (0.03)
Zarei et al., 2020 (6/10)	FIFA 11 + kids	×2/wk over 10 wk	Con PT 90°/s DL	+14.0 (1.35)*§	+3.2 (0.28)*

*, indicates a significant difference from pre- to post-intervention; §, indicates a significant difference between the experimental group and the control group.

APT = angle of peak torque; BF = biceps femoris; CG = control group; Con = concentric; DL = dominant leg; Ecc = eccentric; EG = experimental group; H = hamstrings; Iso = isometric; NDL = nondominant leg; NHE = nordic hamstring exercise; PT = peak torque; reps = repetitions; T50° = torque at 50° knee flexion; Q = quadriceps.

Table 3
Main findings of the systematic review

	Contraction velocity		Contraction type	
	High-velocity exercises	**Low-velocity exercises**	**Eccentrically biased exercises**	**Conventional exercises**
Hamstring strength	+++	+++	+++	+++
Unilateral strength ratios	+++	+++	+++	+++
BFlh fascicle length	+++	+	+++	++
Angle of peak torque	+++	+++	+++	+

+, small effect based on the findings from this systematic review; ++, moderate effect based on the findings from this systematic review; +++, large effect based on the findings from this systematic review.

BFlh, biceps femoris long head.

BFlh fascicle length, as did combined high-velocity eccentric and concentric training (i.e., sprinting, plyometrics, and acceleration drills).

HAMSTRING STRENGTH

The most uniform improvements across hamstring strength variables (concentric, eccentric, and isometric) were observed following combined low- and high-velocity eccentric and concentric training (56). Poor eccentric hamstring strength has been associated with increased risk for HSIs on a more frequent basis than both concentric and isometric strength (8,64,65,79,81); based on the findings of this systematic review, eccentric hamstring strength increased most after combined low- and high-velocity eccentric and concentric training (56) and low-velocity concentric training (3). The results seen in the latter subgroup are rather surprising given that concentric training is often thought to be less effective than eccentric training when it comes to improving eccentric strength (70). These findings apparently contradict the principle of specificity, which postulates that the closer a training exercise is to the requirements of the desired outcome, the better the outcome will be (38). However, a potential explanation for this finding could lie in the role of hamstrings in knee joint stabilization during the knee extension movement (3). Namely, during voluntary knee extension, the knee is stabilized by both passive and active structures through ligamentous constraints and antagonist muscle coactivation. In this regard, Aagaard et al. (2) described the potential role of the hamstring muscles in providing knee joint stabilization by expressing eccentric hamstring strength relative to concentric quadriceps strength at a given angular velocity. Furthermore, it has been demonstrated that a substantial involvement of this coactivation mechanism takes place during isokinetic knee extension (1). Thus, the

Table 4
Example exercises

Exercise name	Exercise difficulty	Muscle action
Hamstring walkout	Easy	Eccentric
Posterior sling fires	Easy	Isometric
Supine straight leg band flutters	Easy	Quasi-isometric
Kettlebell swing	Medium	Concentric-eccentric
Single-leg hip extension on 45° hip extension machine	Medium-hard	Eccentric-concentric
Single-leg stiff-legged deadlift	Medium-hard	Eccentric-concentric
Low-hurdle high-velocity run	Hard	Quasi-isometric
Nordic hamstring curl	Hard	Isometric-eccentric
Single-leg hamstring catch	Hard	Quasi-isometric

Figure 2. Pictures demonstrating the hamstring walkout exercise.

potential capacity of the hamstring muscles to provide stability to the knee joint during fast extension could have been augmented as a result of the heavy resistance strength training and could explain why low-velocity concentric training induced eccentric hamstrings strength gains (3).

The training program of the combined low- and high-velocity eccentric and concentric training subgroup consisted of an extensive mix of strength, plyometric, and acceleration exercises (56). The broad exercise selection targeted the hamstring muscles in multiple ways, explaining the consistency in hamstring strength results. For example, the hamstrings were trained: (a) at long and short muscle lengths; (b) with knee- and hip-dominant exercises; (c) through low- and high-velocity movements (i.e., strength training, acceleration drills, and plyometrics); and (d) with conventional (i.e., concentric followed by eccentric contractions or vice-versa) and eccentrically emphasized exercises. Previously, researchers have shown that exposing athletes to a wider selection of exercises leads to larger increases in muscle strength when compared with using only one exercise (32). Furthermore, a meta-analysis conducted by Roig et al. (70) found that strength gains, especially from eccentric training, tended to be specific to the contraction mode and the movement velocity (i.e., low- vs. high-velocity eccentric training), which adds further support for the inclusion of a broad exercise selection, considering that the hamstrings also function isometrically and concentrically during high-speed running (41).

A considerable amount of research has observed differential activation patterns of the hamstring muscles during various hamstring strength exercises (10,55), even when performing a similar movement pattern (e.g., activation patterns between 2 knee-dominant exercises) (10,31,39,55,66,69,71,80,82). Similarly, muscle forces, fascicle behavior, and operating lengths differ between hamstring exercises (e.g., 43). Collectively, these findings indicate that (a) a balanced stimulus across all hamstring muscles can likely only be achieved when employing a variety of exercises and (b) the homogenous results on hamstring strength following combined low- and high-velocity eccentric and concentric training (56) might at least partially be the result of the broad selection of exercises, all of which uniquely targeted the hamstring muscles.

In accordance with the abovementioned findings, the largest change in hamstring strength (measured as the average of weekly effect sizes of all hamstring strength variables, e.g., concentric, isometric, and eccentric hamstring strength) was observed following combined low- and high-velocity eccentric and concentric training (standardised mean difference: +0.110/week) (56). The same holds when looking at average effect size changes in eccentric hamstring strength only (+0.120/week). It appears that including exercises of different characteristics (that is, contraction type, contraction velocity, knee versus hip dominant, and emphasizing peak contraction force [stress] versus muscle stretch/strain) might be beneficial when aiming to optimize hamstring strength. Nevertheless, it should be kept in mind that only one experimental group had such a large exercise variety as part of their intervention. Furthermore, to the authors' knowledge, no studies to date have investigated whether combined low- and high-velocity eccentric and concentric training is capable of reducing HSIs in soccer players. Therefore, more research investigating the effects of including a broad array of exercise types in a soccer injury prevention program is warranted. From a practical standpoint of view, there are some disadvantages to prescribing more elaborate injury prevention programs. First, lack of both training equipment and time may hinder amateur clubs in implementing such programs. Especially in-season, when the match play schedule is congested and improving soccer performance and recovery are of major importance, finding the time to perform elaborate injury prevention programs may be problematic. Second, compliance may suffer as a result of such elaborate training interventions. Because compliance can significantly dampen the beneficial effects of training interventions, regardless

Figure 3. Pictures demonstrating the posterior sling fire exercise.

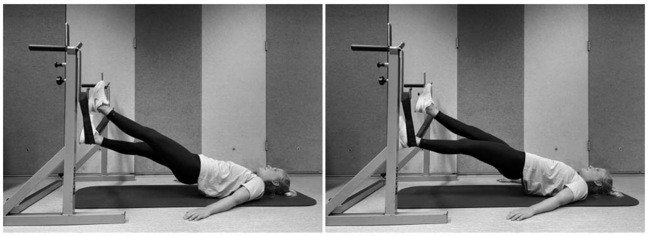

Figure 4. Pictures demonstrating the supine straight leg band flutters exercise.

of their efficacy, this is something every practitioner should take into account when designing injury prevention programs (34,76).

HAMSTRING:QUADRICEPS STRENGTH RATIOS

In congruence with the findings on hamstring strength, a large exercise variety (i.e., combined low- and high-velocity eccentric and concentric training) resulted in the largest changes across H:Q strength ratios, that is, concentric hamstring strength versus concentric quadriceps strength, eccentric hamstring strength versus eccentric quadriceps strength, and eccentric hamstring strength versus concentric quadriceps strength (56). As H:Q ratios are in part a function of hamstring strength, these outcomes are related to the previously discussed findings on hamstring strength. Although they do seem to support the use of multiple exercises targeting the hamstring muscles in various ways, it needs to be emphasized that the intervention of the combined low- and high-velocity eccentric and concentric training group was designed specifically to strengthen the hamstring muscles (56). This is likely not how injury prevention programs look in the real world because HSIs, while certainly one of the major injuries in soccer, are not the only injuries occurring in this sport (29). For example, research shows that quadriceps strains are more common than HSIs in the preseason (86). It would arguably be less than ideal not to include any knee extensor strengthening exercises in injury prevention programs. Therefore, how H:Q strength ratios would be affected by a more holistic injury prevention program in soccer players remains unknown. It could be hypothesized that including quadriceps strengthening exercises would negate some of the beneficial effects hamstring strengthening exercises have on H:Q ratios.

Contrary to the outcomes mentioned above, low-velocity eccentric training interventions (21) led to a negative average weekly effect size change (−0.029/week) when looking at H:Q strength ratios. The only experimental group belonging to this subgroup performed the HarmoKnee program (21), which included strength exercises: walking lunges in place; partner-resisted prone hamstring curls; and single-leg squat with toe raises. Given that the knee extensors are the primary targeted muscles in 2 of these exercises (walking lunges in place (68) and single-leg squat with toe raises (51)), it may be that the overload provided to the knee flexors relative to the stimulus provided to the knee extensors was insufficient to enable an average increase across all H:Q strength ratios reported in the respective studies. Thus, from these findings, it can be suggested that the ratio between quadriceps and hamstring strength training should be considered when the aim is to improve H:Q strength ratios.

BICEPS FEMORIS LONG HEAD FASCICLE LENGTH

Of the 2 studies (49,54) (2 experimental groups each, 3 groups doing low-velocity eccentric training and one group doing combined high-velocity eccentric and concentric training) that measured BFlh fascicle length, 2 low-velocity eccentric training groups

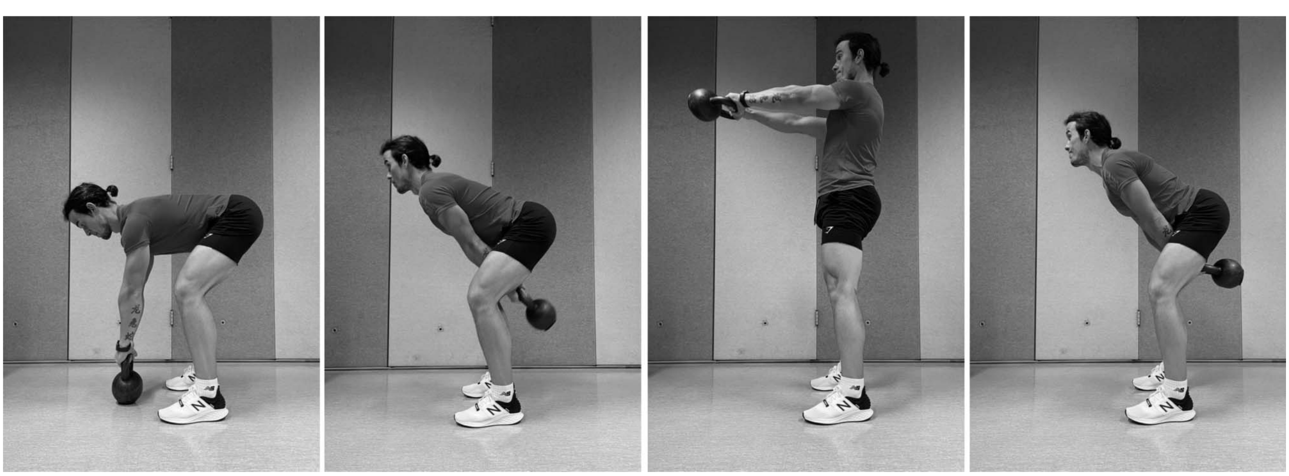

Figure 5. Pictures demonstrating the kettlebell swing exercise.

Figure 6. Pictures demonstrating the single-leg hip extension exercise.

(49,54) and the group that performed combined high-velocity eccentric and concentric training (54) significantly increased BFlh fascicle length. All experimental groups belonging to the low-velocity eccentric training subgroup performed exclusively the NHE as part of the intervention (49,54). Furthermore, 2 performed the NHE after their regular soccer practice (49,54), and the remaining experimental group completed the NHE before soccer practice (49). Interestingly, conflicting findings were reported among groups completing the NHE after soccer training, with BFlh fascicle length increasing in one experimental group and remaining similar in the other experimental group (49,54). This could be explained by the fact that the participants in the experimental group, who did not see improvements in BFlh fascicle length, were relatively weaker that is, had lower starting eccentric hamstring strength values compared with those found in other studies that measured this outcome at the same angular velocity (30°/s) and in the same population (3,35,54). As a result, the fatigue generated by the soccer practice sessions in the nonresponders might have left these participants unable to perform the NHE throughout a sufficiently large range of motion to promote fascicle length adaptations. Indeed, authors from a previous study (53) have suggested that range of motion might influence the stimulus for fascicle length adaptations. This could explain the lack of changes in BFlh fascicle length in both groups doing the NHE after soccer practice (49,54).

Of the 3 experimental groups that did notice significant effects on BFlh fascicle length (49,54), combined high-velocity eccentric and concentric training (sprinting, acceleration drills, and plyometrics) (54) led to more than twice the percentage increase in this variable compared with the other 2 experimental groups (49,54), which did low-velocity eccentric training only (NHE) (+2.70%/week versus +1.23%/week and 1.07%/week). Although the current body of evidence seems to suggest that eccentric training is a more potent stimulus for fascicle length increases than concentric training (9), it is not yet clear how movement velocity and movement pattern (i.e., knee or hip dominant) impact this adaptation.

ANGLE OF PEAK TORQUE

Hamstring muscle APT was measured in 2 studies (13,44) and improved significantly following combined low- and high-velocity eccentric training (13) but not following low-velocity eccentric training (44), even though the weekly percentage changes in the latter were higher compared with those in the former (on average −3.11%/week versus −4.12%/week, respectively). Angle of peak torque is thought to be one of the major risk factors for HSIs because of the proposed injury mechanism (peak forces combined with peak levels of strain during high-speed running) (16,40,72,88). A higher APT (with full knee extension being 180°) may allow the hamstring muscles to better handle the extremely high demands from repetitive eccentric actions that might occur while fatigued, and thus, it may play a protective role when exposed to active lengthening movements (9). The lack of improvements in APT found in the study employing low-velocity eccentric training is in opposition to findings from other studies on the effects of similar eccentrically biased, low-velocity, strength exercises (i.e., strengthening exercises that load the hamstring at short muscle lengths) on APT (11,17,74). Yet, although not quite the same as APT, the participants in the study by Lovell et al. (49) considerably improved average eccentric strength between 180–165° and 165–50° of knee flexion after doing the same intervention exercise as the athletes in the study by Iga et al. (47) (i.e., NHE). In addition, both studies conducted by Naclerio et al. (60,61) included in the present systematic review demonstrated a shift in the torque-angle relationship after low-velocity eccentric

Figure 7. Pictures demonstrating the single-leg stiff-legged deadlift.

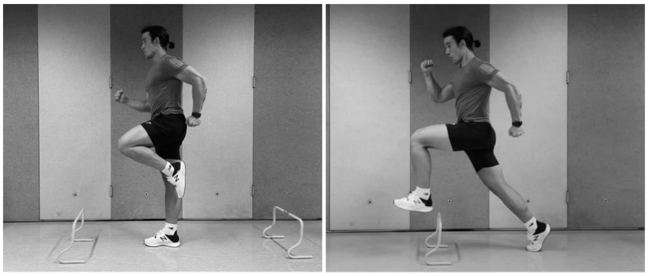

Figure 8. Pictures demonstrating the low hurdle high-velocity run exercise.

training interventions. Therefore, given the inconsistent results on the effects of low-velocity eccentric training on hamstring APT in soccer players, more research is warranted to determine the effects on this variable. Finally, future investigations could look into the effects of adding high-velocity movements (e.g., sprinting, bounding) on APT to ascertain whether this might be a suitable method.

METHODOLOGICAL QUALITY ASSESSMENT

The mean methodological quality score of the studies included in the present review was 6/10 and ranged from 3/10 to 8/10. Only one study (13) reported that the intervention administrators were blinded and were thus unable to discriminate whether participants were in the experimental group or the control group. Blinding of administrators ensures that the intervention effects (or lack thereof) are not because of the administrators' potential bias toward the intervention or control condition. Furthermore, only 5 studies (5,21,23,46,49) included in this systematic review blinded participants (i.e., participants unaware of the study's aims and the other group's condition). Similar to the blinding of intervention administrators, the blinding of participants mitigates placebo effects that may potentially arise from participants' preconceived notions and beliefs about the study conditions or the study aims. The limited number of studies that blinded intervention administrators and study participants may affect the overall findings of this systematic review that findings from individual studies may have been influenced by the placebo effect. Additionally, only 12 studies (5,6,13,21–23,25,44,60,61,77,89) explicitly stated no significant differences between groups at baseline in key prognostic indicators (e.g., eccentric hamstring strength). From the remaining 8 studies (3,18,45–47,49,54,56), 5 (18,45–47,49) used statistical procedures to mitigate potential bias arising from baseline group differences. Importantly, almost all studies (n = 17) (3,5,6,18,21–23,25,45,46,49,54,56,60,61,77,89) clearly specified participant eligibility criteria, thereby ensuring high external validity. Finally, most studies (n = 15) (3,5,6,13,21–23,44,45,47,56,60,61,77,89) ensured that all subjects, for whom outcome measures were available, received their allocated "treatment" (i.e., training intervention or control intervention), thus minimizing the effects of potential bias in the efficacy of the training intervention. Considering the above, a few methodological considerations should be taken into account while interpreting the findings of this review.

LIMITATIONS AND CONSIDERATIONS

Several aspects of this review should be considered when interpreting the findings. First, additional training outside the participants' usual soccer training schedule was not controlled in all the studies included in this review. Second, none of the included studies controlled for total training volume throughout the entirety of the study (e.g., through the use of training logs). Third, the strict eligibility criteria used for this review might have led to the exclusion of studies that could have given additional insights on the effects of hamstring injury prevention programs on proposed, modifiable risk factors for HSIs. For example, researchers have suggested that previous HSIs might alter hamstring muscle activation, architecture, and morphology (7,75,83). It is therefore plausible that previously injured athletes respond differently to training stimuli, but because studies including such athletes have been excluded, the findings from this systematic review cannot be extrapolated to this population. Fourth, we only investigated the effects of training on commonly investigated risk factors.

Figure 9. Pictures demonstrating the Nordic hamstring exercise.

Figure 10. Pictures demonstrating the single leg hamstring catch exercise.

However, other risk factors such as sprint technique (73) should also be considered in a comprehensive training program. Fifth, limitations exist pertaining to the classification of exercises. Specifically, we classified exercises according to the predominant contraction type and velocity described by other authors. However, most exercises involve a mix of different velocities and contraction types, and researchers and practitioners should keep this simplification with classifying exercises in mind when interpreting our findings. For example, the NHE has been shown to exhibit the highest peak fascicle lengthening velocity compared with other exercises (43), even though it is typically classified as low velocity. Similarly, although the NHE is typically classified as eccentric, the majority of this exercise involves quasi-isometric hamstring fascicle behavior (43), with primarily the part after the break point being eccentric. Similar discrepancies occur for other exercises. For example, although sprinting is classified in this review as a high-velocity eccentric stimulus, both animal and modeling studies show the hamstrings fascicles functioning quasi-isometrically (i.e., slow) during a part of the late swing phase (41,42). Finally, soccer playing level was not controlled. Elite players commonly employ higher training volumes in both sport-specific training and in physical preparation training (i.e., strength training, muscular endurance training, and preventive injury training). As previously shown, an athlete's training age and experience can have differential effects on the outcome of a given protocol (67,78). Therefore, the heterogeneity of the samples used in this systematic review could have led to inconsistent results in any reported variables.

CONCLUSION AND PRACTICAL APPLICATIONS

We acknowledge that 2 bodies of knowledge have been well investigated (modifiable hamstring injury risk factors and effects of individual exercises, e.g., Nordic hamstring exercise) in the literature. However, the novelty of this article is the integration of these 2 bodies of knowledge and the synthesis of the findings into exercise/exercise type suggestions that address each of these modifiable risk factors.

Understandably, exercise choice is of major importance for injury prevention. Therefore, identification of injury risk factors and exercise types that have the largest positive impact on each risk factor should theoretically result in superior exercise choice and program design. With regard to the prevention of HSIs in soccer players and based on the critique of the studies included in this systematic review, Table 3 summarizes the main findings of this review of the literature.

It seems that a broad, rather than a narrow, exercise selection is more effective at consistently modifying risk factors of HSIs in soccer players. This makes sense, as it is a holistic approach to hamstring health. Therefore, the challenge to practitioners is how to synthesize this information into a program that can be integrated into training whether it be at home, on the field, or in the gym. Toward these ends, we have suggested a program of exercises (Table 4) that address the modifiable risk factors that can be implemented relatively easily into the athlete's programming (for demonstrations on exercise execution, see Figures 2–10 throughout this article) and involve a variety of contraction modes and velocities.

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