http://dx.doi.org/10.1123/ijspp.2013-0547

Effects of a 10-Week In-Season Eccentric-Overload Training Program on Muscle-Injury Prevention and Performance in Junior Elite Soccer Players

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Purpose*:* To analyze the effect of an eccentric-overload training program (ie, half-squat and leg-curl exercises using flywheel ergometers) with individualized load on muscle-injury incidence and severity and performance in junior elite soccer players. ***Methods****:* Thirty-six young players (U-17 to U-19) were recruited and assigned to an experimental (EXP) or control group (CON). The training program consisted of 1 or 2 sessions/wk (3–6 sets with 6 repetitions) during 10 wk. The outcome measured included muscle injury (incidence per 1000 h of exposure and injury severity) and performance tests (countermovement jump [CMJ], 10-m and 20-m sprint test). ***Results****:* Between-groups results showed a *likely* (ES: 0.94) lower number of days of absence per injury and a *possible* decrement of incidence per 1000 h of match play in EXP than in CON. Regarding muscle performance, a substantial better improvement (*likely* to *very likely*) was found in 20-m sprint time (ES: 0.37), 10-m flying-sprint time (ES: 0.77), and CMJ (ES: 0.79) for EXP than for CON. Within-group analysis showed an *unclear* effect in each variable in CON. Conversely, substantial improvements were obtained in CMJ (ES: 0.58), 20-m sprint time (ES: 0.32), 10-m flying-sprint time (ES: 0.95), and injury severity (ES: 0.59) in EXP. Furthermore, a *possible* decrement in total injury incidence was also reported in EXP. ***Conclusions****:* The eccentric-based program led to a reduction in muscle-injury incidence and severity and showed improvements in common soccer tasks such as jumping ability and linear-sprinting speed.

Keywords*:* maximal power output, muscle performance

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Injuries in soccer represent the most common reason for player unavailability in training and matches.[1,2] Different authors have reported a rate of 7 to 8 injuries per 1000 hours of practice.[3,4] Muscle strains (37%) are the major type of injury and mainly occur in the lower extremity (87%).[5] Ekstrand et al[4] showed that the most common type of strain is in the thighs, representing the 17% of all injuries, with hamstring strain (12% total thigh strains) showing a higher incidence than quadriceps (5% of the total).

Soccer is a sport that requires repetitive kicking and sprinting efforts,[6] and hamstrings and quadriceps muscles are frequently injured during these actions (ie, kicking and sprinting).[6] Commonly, a quadriceps muscle injury is produced when the maximal length of the rectus femoris is reached during the early swing phase of a sprint.[7] Conversely, hamstring injuries usually appear during the second half of swing, where hamstrings are stretched and preparing for foot contact.[8,9] Note that both injuries primarily occur during the eccentric contractions.

There are many risk factors associated with muscle-strain injuries in soccer.[6,10] However, muscle-strength deficiency has been proposed as the main risk factor.[11–13] Traditionally, strengthening programs are based on resistance exercises where the stimulus is provided by gravitational loads.[14] However, the efficacy of these methods is limited to concentric actions, with lower activation in the eccentric phase.[15,16] Therefore, preventive strength-training strategies might also include exercises where muscles are activated during the eccentric phase for an adequate muscle response.[10]

It seems that eccentric strengthening exercises for the quadriceps and hamstrings reduce the thigh muscle strain-injury rate in soccer.[10,17,18] Regarding injury prevention in the quadriceps, only 1 study has assessed the chronic adaptations to eccentric training with professional soccer players.[18] During preseason, participants performed a strengthening program (3 times/wk for 4 wk) including eccentric exercises. No significant changes were observed in strength measurements. Nonetheless, eccentric training increased the optimal length of both knee extensors and flexors after the intervention. It is interesting that no injuries were reported in the intervention group, while the control group suffered 2 muscle-strain injuries. While this is not a proper eccentric-overload intervention, those authors, in the same line of recent studies such as Askling et al,[19] indicated that focusing the intervention program on lengthening-based exercises may be more effective in the rehabilitation and prevention of these injuries than traditional protocols.

On the other hand, Arnason et al[17] applied a preventive warm-up that included the Nordic hamstrings exercise (NHE) combined with stretching during 4 consecutive soccer seasons. Consequently, hamstring strains were reduced in comparison with teams that were not involved in the training program. In the same line, using an eccentric-overload training program on a flywheel inertial device for hamstring muscles (ie, leg-curl exercise), Askling et al[10] showed that the occurrence of strain injuries was lower in the training group than in the control group. Furthermore, there was an increase in both

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eccentric and concentric knee-flexor strength and in maximal sprinting speed. In this regard, it has been reported that NHE and flywheel exercises can produce greater eccentric overload[10,14] and greater muscle activation (measured by electromyography [EMG])[16] than traditional exercises. However, despite the difficulty in matching the intensities between the NHE and the YoYo leg-curl exercise, it seems that the YoYo leg curl provides a much higher eccentric overload than the NHE.[20,21] Furthermore, the eccentric–concentric transition phase is completely different in the exercises. Therefore, due to the wide spectrum of advantages, it might be recommended to include these exercises with flywheel devices.

Despite these positive results, the evidence of the preventive effects associated with these devices is scarce. Therefore, this study aimed to assess the effect of an eccentric-overload training program (half-squat and leg-curl exercises using flywheel ergometers) with individualized load on muscle-injury incidence and severity and performance in junior elite soccer players. Considering that this type of program can enhance muscle strength in a short period of time,[22] we hypothesized that it might prove effective in reducing muscle-injury incidence and severity in this population.

Methods

Subjects

Thirty-six young elite Spanish soccer players (U-17 to U-19, age 17 ± 1 y, height 178.11 ± 2.34 cm, weight 71.76 ± 4.56 kg, body-mass index 19.1 ± 2.4 kg/m^2) voluntarily accepted to participate in this study. Data collection took place during the fifth month after starting the season (Table 1). Athletes belonged to a first Spanish soccer division (ie, Liga BBVA) club academy squad. None of them had previously used flywheel devices. A physician reviewed the medical histories and assessed the suitability for the study. Participants with severe lower-limb muscle injuries (strains for more than 27 d) in the previous 2 months were excluded. The study was conducted according to the Declaration of Helsinki, and the protocol was fully approved by the local research ethics committee before recruitment. After a detailed explanation about the aims, benefits, and risks involved in this investigation, all participants gave their written informed consent.

\<<<<<<<<<<<<**TABLE 1**>>>>>>>>>>>>>>\

Study Design and Procedures

Using a controlled nonrandomized study design, players from 2 different teams were divided into an eccentric-overload training group (EXP, n = 18) and a control group (CON, n = 15). One team was assigned to EXP and another team to CON. Both teams were involved in soccer training with a similar weekly training volume and methodology (4 or 5 sessions/wk of 60–90 min and 1 match/wk). Participants in CON continued with their usual technical/tactical training, avoiding strength training during the whole season. EXP players, in addition to their usual soccer training, underwent an additional concentric–eccentric training program 1 or 2 times per week for 10 weeks (Figure 1). Furthermore, a familiarization session with the flywheel devices and exercises (half squat and leg curl) used in the study was developed in EXP. In the first week, the EXP group performed a test where the inertia used during the intervention (first 5 training wk) in the flywheel devices was selected. In these sessions, a full explanation of the experimental protocol and recommendations were given to the participants, and they were permitted to practice all the tests.

\<<<<<<<<<<<<**FIGURE 1**>>>>>>>>>>>>>>\

With these devices the “load” is given by the inertia of a rotating mass (flywheel), which in turn depends on its geometrical (diameter, thickness) and physical properties (density of the material). The flywheel provides an inertial resistance during coupled concentric and eccentric actions.[23,24] The total number of flywheels installed adjusts the overall inertia. Given their properties (material: PVC; density: 1.4 kg/cm^3, diameter: 380 mm; thickness: 20 mm), the resulting inertia of each flywheel was 0.11 kg/m^2. To determine the inertia that was used during the intervention, an assessment with inertia 2 and 4 (4 repetitions per inertia with 180-s interinertia recovery) was performed. The inertia that achieved higher power output was selected. The protocol was performed using a specific analysis feature in a performance-measurement system compatible with flywheel devices (SmartCoach Power Encoder, SmartCoach Europe AB, Stockholm, Sweden) with associated SmartCoach software (v 3.1.3.0). For each participant, the inertia corresponding to the higher concentric power output was used in the intervention. This inertia was individually readjusted after 5 training weeks.

Injury incidence and severity were registered during the whole season (10 mo, with the intervention carried out during the last 5 mo). Muscle performance was assessed through a countermovement-jump (CMJ) test and a 20-m sprint test (10-m split time). All tests were administered 1 week before and 1 week after the intervention in the following order: CMJ and 20-m sprint test.

Eccentric-Training Intervention

Two YoYo isoinertial flywheel training devices (YoYo Technology AB, Stockholm, Sweden) were used in the strengthening program (half squat in YoYo Squat and leg curl in YoYo Prone Leg Curl). During the concentric phase of the muscle action, the athlete imparts rotation to a flywheel by means of a strap connected to its shaft. At the end of the range of motion the strap is completely unwound, and the flywheel keeps spinning by virtue of its inertia and recoils the strap, demanding that the athlete decelerate it during the subsequent eccentric action. By controlling the execution technique (ie, delaying the braking action in the eccentric phase), these devices enable achievement of a given degree of eccentric overload.[10,16,21,25]

In the leg-curl exercise, participants performed a bilateral knee flexion in a prone position (Figure 2) by accelerating and decelerating the flywheel through a concentric, and subsequently eccentric, action of the hamstrings muscle group. Participants were encouraged to apply the maximum effort from the knee-extension position (0°) to a 130° to 140° flexion and then asked to resist the movement during the eccentric phase when the 90° position was reached. In the half-squat exercise, participants had to bend the knees up to 90° during the eccentric phase and then perform the concentric phase as fast as possible (Figure 3). Participants performed both exercises in 1 session during the first 2 weeks and 2 sessions per week during the other 8 weeks. The volume was increased as follows: 3 × 6 repetitions in weeks 1 to 4, 4 × 6 repetitions in weeks 5 and 6, 5 × 6 repetitions in weeks 7 and 8, and 6 × 6 repetitions in weeks 9 and 10.

\<<<<<<<<<<<<**FIGURE 2**>>>>>>>>>>>>>>\
\<<<<<<<<<<<<**FIGURE 3**>>>>>>>>>>>>>>\

Muscle-Injury Incidence and Severity

Medical staff recorded the number of training sessions and matches and registered the number of muscle injuries per 1000 hours to exposure (match and training). In addition, injury severity was determined considering the number of training or match days of absence per injury.[26] In the current study, a player was considered fully rehabilitated when the medical team allowed full participation in team training or matches.

Performance Tests

CMJ Test.

A CMJ test was assessed using an infrared-light platform built into the OptoJump system (Microgate, Bolzano, Italy). The CMJ test starts with a preparatory movement of knee extension going down to 90° knee flexion and, without pause, jumping upward as high as possible. It was performed without the use of the arms; subjects were asked to keep their hands on their hips. The subjects performed 3 jumps; the best result was used for later analyses. Participants were allowed to recover for 90 seconds between jumps.

10-m and 20-m Sprint Tests.

Acceleration and sprint tests were measured using dual-beam electronic timing gates (Race Time 2 Light Radio System; Microgate, Bolzano, Italy). All subjects' sprint times were assessed on 10-m and 20-m distance. The starting position was standardized with the left toe 1 m back from the starting line and the right toe approximately in line with the heel of the left foot. All assessments were performed on a natural grass surface, and subjects wore specific soccer shoes. All participants performed 3 sprint tests, with the best score used for subsequent analysis. A recovery time of 120 seconds between actions was allowed. The next variables were used for posterior analysis: 10-m sprint time (0–10 m), 20-m sprint time (0–20 m), and 10-m flying-sprint time (10–20 m).

Statistical Analysis

Data are presented as mean ± SD. All data were first log-transformed to reduce bias arising from nonuniformity error. The standardized difference or effect size (ES, 90% confidence limit) in the selected variables was calculated using the pooled pretraining SD. Threshold values for Cohen ES statistics were >0.2 (small), >0.6 (moderate), and >1.2 (large).[27] For within/between-groups comparisons, the chances that the differences in performance and measures of injury prevention were better/greater (ie, greater than the smallest worthwhile change [0.2 multiplied by the between-subjects SD, based on the Cohen *d* principle]), similar, or worse/smaller were calculated. Quantitative chances of beneficial/better or detrimental/poorer effect were assessed qualitatively as follows: <1%, almost certainly not; 1% to 5%, very unlikely; 5% to 25%, unlikely; 25% to 75%, possibly; 75% to 95%, likely; 95% to 99%, very likely; and >99%, almost certainly.[27] A substantial effect was set at >75%.[28] If the chances of having beneficial/better and detrimental/poorer performances were both >5%, the true difference was assessed as unclear. Otherwise, we interpreted that change as the observed chance.[27] Participants not attending 80% of training sessions (ie, due to muscle injury) were omitted from the analysis.

Results

Relative changes and qualitative outcomes resulting from the within-group analysis are shown in Tables 2A and 2B. No substantial improvements were found in any measure of injury prevention (ie, severity and incidence) in any group compared with the pretest, with the exception of severity in the EXP group, which obtained a substantial enhancement. Similarly, no substantial improvement in muscle performance (ie, CMJ and 0 to 20 m) was achieved in the CON group. Nevertheless, players in EXP showed substantial better results in CMJ and 10 to 20 m.

\<<<<<<<<<<<<**TABLE 2A**>>>>>>>>>>>>>>\
\<<<<<<<<<<<<**TABLE 2B**>>>>>>>>>>>>>>\

Results from between-groups analysis are illustrated in Figure 4. The decrement in injury severity was substantially greater (65% [90%CL: 10.1; 86.4] with chances for better/similar/lower values of 93/6/2%, respectively) in EXP than in CON. A possibly lower (23.7% [90%CL: –115.0; 72.9], 69/27/4%) incidence per 1000 hours of match play was provided in EXP compared with CON. There were no substantial between-groups differences in the rest of the injury-prevention variables. Substantially better performance was found in CMJ (9.4% [90%CL: 3.8; 15.4], 98/2/0%), 0 to 20 m (1.6% [90%CL: –0.2; 3.5], 75/23/1%), and 10 to 20 m (3.1% [90%CL: 0.9; 5.2], 96/4/0%) in EXP than in CON at posttest.

\<<<<<<<<<<<<**FIGURE 4**>>>>>>>>>>>>>>\

Discussion

This study aimed to assess the effect of a10-week eccentric-overload training on lower-limb muscle-injury prevention and performance in young elite soccer players. Our results showed a greater incidence per 1000 hours of match time in CON but also a lower injury severity in EXP after the intervention.

Previous studies have suggested that hamstrings and quadriceps strains are the most common injuries in soccer players.[4,29] The incidence of muscle strains in soccer players was low during the preseason period but 2 or 3 times higher during the competitive season.[29] This is in agreement with the results observed in our study for the CON group, although a decrement was observed during the competitive season (during and after the intervention) in the EXP group. In addition, the injury severity (days of absence) was substantially lower (ES: 0.59) in this group. Thus, it may also be attributed to an effect of the intervention.

In this line, Arnason et al[17] studied the effects of different muscle-injury-prevention programs consisting of warm-up stretching, flexibility, and/or eccentric strength training on hamstring strains in elite soccer players from Iceland and Norway. Results revealed that the incorporation of eccentric strength training of hamstrings during the warm-ups before training sessions significantly reduced the incidence of hamstring strains during training, in comparison with baseline data and other types of intervention. However, the training program was not effective at reducing match-play injury risk. These results are in contrast with the findings reported in our study, which suggest a lower injury rate during match play in comparison with CON (ES: 0.35). Differences in the training devices, eccentric overload imposed in the exercises, or volume of training (ie, sessions and repetitions) might explain these between-studies differences.

Training paradigms comparable to the ones used in the current study reached similar conclusions. After 10 weeks of eccentric strength training using flywheel devices (1 or 2 times a week), Askling et al[10] aimed to determine whether preseason training affected the occurrence and severity of hamstring injuries during the subsequent competition season in elite Swedish soccer players. The intervention was effective to reduce the injury incidence in the training group. These results are in agreement with the results found in our study. Regarding the effects of eccentric-overload training for quadriceps muscles in soccer players, only 1 previous study assessed a 4-week program (3 times/wk) together with habitual soccer training.[18] The authors found that players in the control group suffered more quadriceps injuries than those in the eccentric-based intervention group. It may be possible that the improvements in strength and mainly in the eccentric component could explain these results.[10]

In the current study, improvements in strength can be observed in the results of CMJ and sprint tests. Thus, EXP participants showed an increase in jumping ability and 0- to 20-m and 10- to 20-m sprint tests. Numerous studies have shown an improvement in muscle performance after power training.[30–32] Most of these programs lack a decelerating phase during exercise. In our study, we analyzed the combined effect of power training in both concentric and eccentric phases on muscle performance. Our improvements in CMJ (ES: 0.58) are not in agreement with other studies[14,33] that used eccentric training programs. These differences could be due to the exercises performed or training subjects (ie, soccer players vs patellar tendinopathy). Therefore, in addition to the aforementioned benefits (injury incidence and severity), this program can obtain benefits not just in CMJ but also in acceleration tasks. Authors such as Askling et al[10] observed an improvement (ES: 0.80) in a 30-m sprint test after hamstrings eccentric-overload training. These results are in line with those found in our study in 10 to 20 m (ES: 0.95). Nonetheless, in spite of enhancing 0 to 20 m, the effect reported (ES: 0.32) is lower than that found in 30-m sprint time in Askling et al.[10] It may be possible that the hamstrings are more involved in longer than shorter linear-sprinting distances, and, in consequence, it may explain these between-studies differences and the lack of improvement in 0 to 10 m (ES: 0.15). Several limitations of the study include assessing the effect of eccentric-overload training by means of strength measurements (ie, 1-repetition maximum, maximum power output at different inertias, force impulse). Furthermore, it would be of interest to analyze the effect of this intervention on the most representative performance tests in soccer, such as hop tests and change-of-direction tests, and to include more functional training exercises. Further studies are needed to analyze the effect of eccentric-overload training in subjects of different ages, genders, sports, and training backgrounds and to compare this protocol with a well-designed conventional strength-training program in both reducing injuries and improving performance.

Conclusions

In conclusion, a 10-week exercise program based on maximal-power concentric load and eccentric overload is effective in reducing muscle-injury incidence and severity in junior elite soccer players. In addition, improvements in jumping and sprinting abilities were obtained. These finding may have implications for future injury-prevention programs aiming to reduce the risk of hamstrings and quadriceps strain injury, as they are the main cause of absence from matches in soccer players. Moreover, it seems that training at the inertia that optimizes individual maximal power for these particular exercises was effective for improving sprinting and jumping ability, which are explosive strength-related tasks usually associated with performance in soccer.

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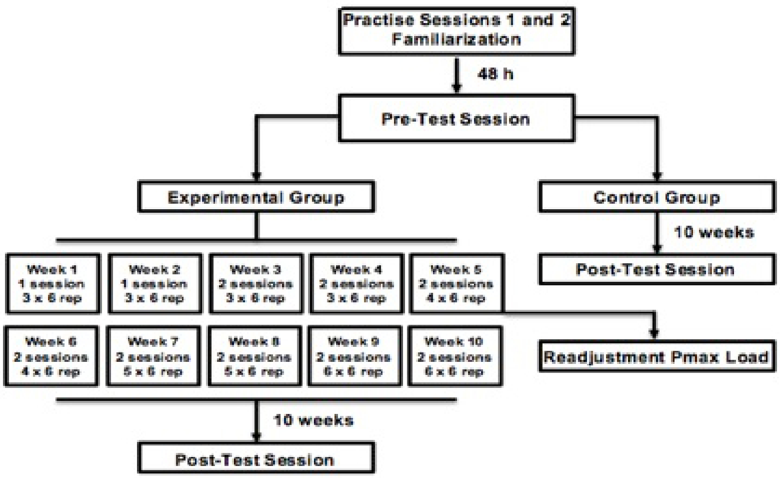

Figure 1 — Project-design timeline.

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Figure 2 — Leg-curl exercise performed in the study.

Figure 3 — Half-squat exercise performed in the study.

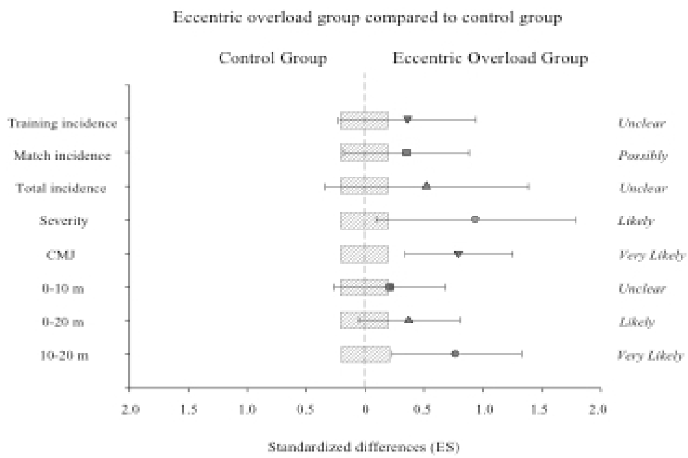

Figure 4 — Efficiency of the eccentric-overload training group in comparison with control group to improve incidence per 1000 h of training (training incidence), incidence per 1000 h of match time (match incidence), incidence per 1000 h of training and matches (total incidence), days of absence per lower-limb muscle injury (severity), countermovement-jump performance (CMJ), 10-m sprint time (0–10 m), 20-m sprint time (0–20 m), and 10-m flying-sprint time (10–20 m). Bars indicate uncertainty in the true mean changes with 90% confidence intervals. Trivial areas were calculated from the smallest worthwhile change (see the Methods section).

Table 1 Descriptive Data of the Participants, Mean ± SD

	Age (y)	Height (cm)	Weight (kg)	Body-mass index (kg/m^2)
Experimental group	18 ± 1	177.86 ± 3.12	70.87 ± 3.87	18.8 ± 2.2
Control group	17 ± 1	178.24 ± 1.25	73.12 ± 2.56	19.3 ± 2.5

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Table 2A Changes in Injury-Prevention Markers and Performance After Eccentric-Overload Training, Mean ± SD

			Difference			
Variable	Pretest	Posttest	% (90% CL)	Standardized (90% CL)[a]	Chances[b]	QA
Training incidence (n)[c]	4.4 ± 5.7	2.6 ± 3.9	2.1 (–23.6; 36.3)	0.03 (–0.35; 0.41)	21/65/15%	Unclear
Match incidence (n)[c]	7.0 ± 14.9	7.0 ± 10.6	13.3 (–31.5; 87.3)	0.08 (–0.25; 0.41)	25/68/7%	Unclear
Total incidence (n)[c]	4.7 ± 5.8	3.4 ± 4.1	14.2 (–2.3; 28.0)	0.18 (–0.03; 0.39)	43/56/1%	Possibly
Severity (d)[d]	5.9 ± 8.2	1.9 ± 1.8	47.7 (23.4; 64.3)	0.59 (0.24; 0.94)	97/3/0%	Very likely
CMJ (cm)	35.7 ± 4.1	38.3 ± 4.2	7.6 (4.1; 11.2)	0.58 (0.32; 0.85)	99/1/0%	Very likely
10-m sprint (s)	1.73 ± 0.12	1.71 ± 0.08	1.0 (–1.5; 3.4)	0.15 (–0.21; 0.50)	40/55/5%	Possibly
20-m sprint (s)	3.03 ± 0.14	2.99 ± 0.12	1.5 (0.1; 3.0)	0.32 (0.02; 0.61)	75/25/0%	Possibly
10-m flying sprint (s)	1.30 ± 0.04	1.26 ± 0.05	3.3 (2.1; 4.5)	0.95 (0.60; 1.30)	100/0/0%	Almost certainly

Abbreviations: CL, confidence limits; QA, qualitative assessment; CMJ, countermovement jump.

Note: For clarity, all differences are presented as improvements (positive), so that negative and positive differences are in the same direction.

[a] Effect size. [b] Percentage chance of having better/similar/poorer values. [c] Per 1000 h. [d] Days of absence per injury.

Table 2B Changes in Injury-Prevention Markers and Performance After Training for the Control Group, Mean ± SD

			Difference			
Variable	Pretest	Posttest	% (90% CL)	Standardized (90% CL)[a]	Chances[b]	QA
Training incidence (n)[c]	3.7 ± 3.4	3.7 ± 3.9	–9.8 (41.9; –40.0)	–0.25 (1.32; –0.82)	22/24/53%	Unclear
Match incidence (n)[c]	8.3 ± 13.4	12.5 ± 14.0	–48.4 (43.2; –287.8)	–0.32 (0.45; –1.08)	12/27/61%	Unclear
Total incidence (n)[c]	4.3 ± 4.0	5.9 ± 6.6	–22.0 (31.4; 116.7)	–0.38 (0.72; –1.48)	18/21/62%	Unclear
Severity (d)[d]	7.1 ± 6.9	8.5 ± 12.1	–49.3 (–260.5; 38.1)	–0.34 (–1.09; 0.41)	11/26/63%	Unclear
CMJ (cm)	36.8 ± 3.4	36.2 ± 3.2	–1.7 (–5.9; 2.6)	–0.18 (–0.61; 0.26)	8/46/46%	Unclear
10-m sprint (s)	1.71 ± 0.08	1.71 ± 0.08	–0.3 (–1.3; 1.8)	–0.05 (–0.38; 0.28)	10/68/22%	Unclear
20-m sprint (s)	2.99 ± 0.11	3.00 ± 0.13	–0.1 (–1.4; 1.2)	–0.03 (–0.38; 0.32)	13/66/21%	Unclear
10-m flying sprint (s)	1.27 ± 0.05	1.26 ± 0.06	0.2 (–1.7; 2.1)	0.05 (–0.40; 0.50)	28/55/17%	Unclear

Abbreviations: CL, confidence limits; QA, qualitative assessment; CMJ, countermovement jump.

Note: For clarity, all differences are presented as improvements (positive), so that negative and positive differences are in the same direction.

[a] Effect size. [b] Percentage chance of having better/similar/poorer values. [c] Per 1000 h. [d] Days of absence per injury.