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A Very Low Volume of Nordic Hamstring Exercise Increases Maximal Eccentric Strength and Reduces Hamstring Injury Rate in Professional Soccer Players

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The aim of this study was to determine whether the inclusion of a very low volume (1 set of 3 maximal repetitions) of eccentric-biased Nordic hamstring program of 21 weeks induced an increase in maximal eccentric strength and whether its magnitude was influenced by the compliance rate. The secondary aim of this study was to determine whether this eccentric-biased Nordic hamstring program was effective at reducing hamstring injury rate. Twenty-three professional soccer players formed the experimental group and undertook regular in-season hamstring strength training and monitoring for 21 weeks. Data from 23 players in the immediately preceding cohort (previous year) were included as a control group. The subdivision of the experimental group revealed that the high compliance subgroup (~13 d between sessions) exhibited higher changes in maximal eccentric strength compared with the low compliance group (~24 d between sessions; +26.5%; 95% confidence interval, 7.1%–45.9%; $P < .001$; $g = 1.2$). Five hamstring injuries (22%) were recorded in the experimental group and 9 (39%) in the control group, corresponding to a nonsignificant 2.7-fold lower risk ($P = .12$) of suffering hamstring injury in the experimental group. The current study demonstrates that the inclusion of a very low volume of eccentric-biased Nordic hamstring program for 21 weeks induced an increase in maximal eccentric strength (~15%) in professional soccer players, the magnitude of which depended on the players' compliance. We also found that this program was efficient (2.7-fold lower risk), although nonsignificant, at reducing hamstring injury rate in professional soccer players.

Keywords: eccentric exercise, prevention, maximal strength, strain injury

It is now well established that maximal eccentric strength training influences hamstring injury rate.¹ For instance, it has been shown that the inclusion of a Nordic hamstring exercise program halved the rate of hamstring injuries in 8459 athletes.² Importantly, the efficiency of such a program seems to depend on the compliance of the athletes.^{3,4} Using a meta-analysis, it has been shown that a *moderate* compliance (ie, above ~50%) to prevention program, corresponding to an application with <3 weeks per session, is needed to have a positive effect on hamstring strain injury occurrence.⁴ However, the aforementioned meta-analysis included only one study performed on elite soccer players. The major barrier that likely limits the compliance of professional soccer players is the presence of delayed onset muscle soreness associated with repeated intense eccentric contractions.^{5–7} Manipulation of eccentric training volume and frequency has been proposed as an efficient strategy to overcome this barrier.⁶ Indeed, reducing twice the number of eccentric contractions reduces the magnitude of delayed onset muscle soreness,⁸ whereas a weekly volume between ~20 and ~70 repetitions does not affect the magnitude of the adaptations in eccentric strength and muscle architecture⁹. Nonetheless, this finding should be interpreted with caution. First, the influence of training volume on the aforementioned adaptations remains poorly understood in professional soccer players. Indeed, the training status of an individual is an important feature to consider because it may affect the training response.^{10,12} This is because participants without training experience might exhibit strength gains due to “learning” effect,¹²

whereas a “ceiling effect” makes it more difficult for trained lifters.¹¹ In addition, the combination of maximal strength combined with endurance training (ie, concurrent training) in experienced athletes is known to generate the “interference” effect that attenuates muscle hypertrophy/strength.¹³ Therefore, it is unclear whether a very low volume of eccentric contractions is sufficient to induce adaptations that protect against muscle injuries in professional soccer players. Second, professional soccer players face a high training load when playing matches every 2 or 3 days. The implementation of an eccentric-biased training program, even with 20 repetitions in a week, is challenging, and even risky, because of the potential strength loss induced by muscle damage¹⁴. Nonetheless, the quick adaptations to muscle damage that limit the alterations affected by subsequent damaging exercise (ie, repeated bout effect¹⁵; reinforce the relevance of eccentric-biased training program over the season). There is, therefore, an overall need to identify a minimum dosage of this exercise that elicits adaptations and provides hamstring injury prevention in professional soccer players.

The aim of this study was to determine whether the inclusion of a very low volume (1 set of 3 maximal repetitions) eccentric-biased Nordic hamstring program of 21 weeks induced an increase in maximal eccentric strength and whether its magnitude was related to players' compliance. Although the staff encouraged the soccer players to take part in the program, they were free to not participate at each training session. This was a unique opportunity to assess the influence of compliance rate on the magnitude of increase in maximal strength. The secondary aim of this study was to determine whether this eccentric-biased Nordic hamstring program was effective at reducing hamstring injury rate.

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Methods

Participants

The sample in this cohort study consisted of 30 male professional players from a first division French soccer club. Twenty-three players (age: 25.6 [3.5] y; body mass: 79.3 [6.2] kg; height: 183 [6.0] cm) formed the experimental group and undertook regular in-season hamstring strength training and monitoring (see details following) from October 2020 to March 2021. Data from 23 players (age: 24.7 [3.7] y; body mass: 79.1 [7.3] kg; height: 183 [7] cm) in the immediately preceding cohort (2019–2020) were included as a control group. It is important to note that ~70% of the players (16/23) were common between the experimental and control groups.

Study Design

We conducted the experiment during the in-season period when players trained/played ~7 hours per week. The overall locomotor load (training + matches) was monitored using a global positioning system. Figure 1 shows the total weekly covered distance (in meters), the weekly covered distance while sprinting over 25 km·h⁻¹ (in meters), and the number of these sprints. Importantly, there were very large differences between the experimental group and control group for this locomotor load.¹⁶ As previous studies showed that running exposure influences the risk of hamstring strain injury,¹⁷ we adjusted the results on the influence of Nordic hamstring exercise on the risk of injury according to the weekly sprint distance covered by the players (see “Results” section).

Procedures

The experimental group performed a weekly training session consisting of 3 maximal repetitions of the Nordic hamstring exercise, whereas the control group did not. Nordic hamstring exercise was conducted over 21 weeks after the soccer training at 3 days post-match. A minimum resting period of ~20 minutes was considered

between soccer training and the Nordic hamstring exercise to limit fatigue. The Nordic hamstring exercise was performed using the NordBord (Vald Performance). Players were instructed to kneel on the device while the investigator secured the ankle braces superior to the lateral malleolus. In this kneeling position, players then either crossed their arms over their chest or held a weight centered over the xiphoid process, keeping their hips in a position of full extension throughout the movement. Only the eccentric phase of the Nordic hamstring exercise was completed. Two to three trials were needed to determine the maximal resistance allowing the participants to perform 3 repetitions (ie, 3 maximal repetitions). More precisely, players observed to have sufficient strength to control the descent of their bodyweight were required to perform the repetitions with added weight.¹⁸ In this case, the players were asked whether they agreed to add additional weight (increment of 5 kg). This procedure was used through the 21 weeks of intervention. Data reported for eccentric strength were the peak force value over the 3 repetitions (in Newtons) recorded during each testing session.

A hamstring injury was defined as an acute (sudden onset injury) pain in the posterior thigh that occurred during training or match play and resulted in immediate termination of play and inability to participate in the next training session or match. These injuries were confirmed through clinical examination and ultrasonography performed by a medical doctor.

Statistical Analysis

Data were analyzed using R statistical software. The compliance of the players was calculated over the 21 sessions. Then, the players were subdivided into 2 groups according to their compliance rate: “low” and “high” corresponding to a participation <50% or >50% of the total training sessions, respectively. This compliance threshold was used to ensure an application with <3 weeks per session in the high compliance subgroup, which has shown a positive effect upon hamstring strain injury occurrence.⁴ To determine whether the experimental group had a lower risk of hamstring strain injury than the control group, we calculated the association between the experimental

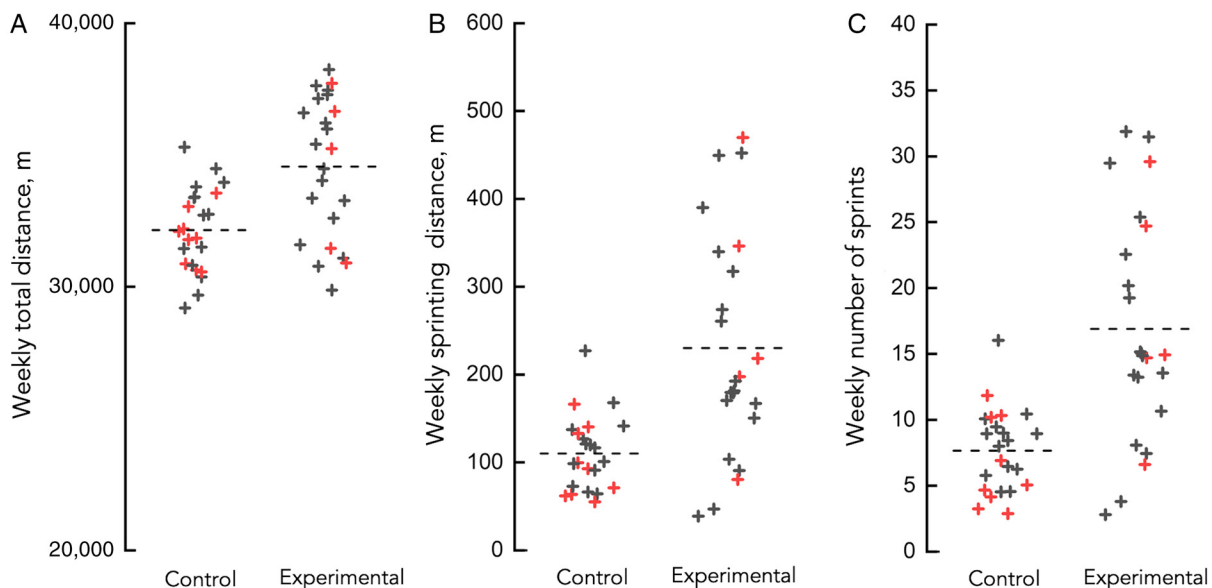


Figure 1 — Overall locomotor load for control and experimental groups. (a) Total weekly covered distance (in meters), (b) the weekly covered distance while sprinting over 25 km·h⁻¹ (in meters), and (c) the number of these sprints. Each player is represented by a gray cross and a red cross for the noninjured and injured players over the 21 weeks of the strengthening program. Mean value is represented by the horizontal dashed line. Grey and red crosses appear in dark and light, respectively, in black & white version.

group and “having at least one hamstring injury” using odds ratio (OR) and 95% confidence intervals (CI). Rates of injury between groups were compared using an independent chi-squared test. Considering the differences in locomotor load between the 2 groups and its influence on the risk of injury,¹⁷ logistic regression was used to determine the association between group and injury adjusted according to the weekly sprint distance performed with the adjusted OR.

Using the mean strength of both legs, a paired *t* test was performed to determine whether maximal eccentric strength measured during the Nordic hamstring exercise changed over the training protocol (pre vs post). To consider the small ($n = 23$) and uneven groups (ie, low [$n = 11$] and high [$n = 12$] compliance rate), the size of the effects on maximal eccentric strength comparison between pre and post was calculated using Hedge *g*.¹⁹ We used the benchmarks developed by Cohen¹⁶ wherein effect sizes about < 0.2 , 0.20 to 0.49, 0.50 to 0.79, and > 0.8 were considered as *negligible*, *small*, *medium*, and *large*, respectively. We also ran an independent *t* test to determine whether changes in strength induced by the Nordic hamstring training protocol were similar between the low compliance and high compliance subgroups (Figure 2). To consider a putative difference in initial level of strength between the 2 subgroups, a linear regression was used to determine the association between level of compliance and changes in strength adjusted on the initial strength. Also, a Pearson correlation coefficient was used to determine whether the changes in maximal eccentric strength were correlated with the compliance rate. Coefficients of correlation were considered as *negligible*, *small*, *moderate*, or *large* at $< .10$, $.10$ to $.29$, $.30$ to $.49$, and $> .50$, respectively.¹⁶ The level of significance was set at $P < .05$.

Results

Figure 2 depicts strength values measured during the Nordic hamstring exercise before and 21 weeks after the training program for the experimental group. Overall, we found a *small* increase (+15.5%

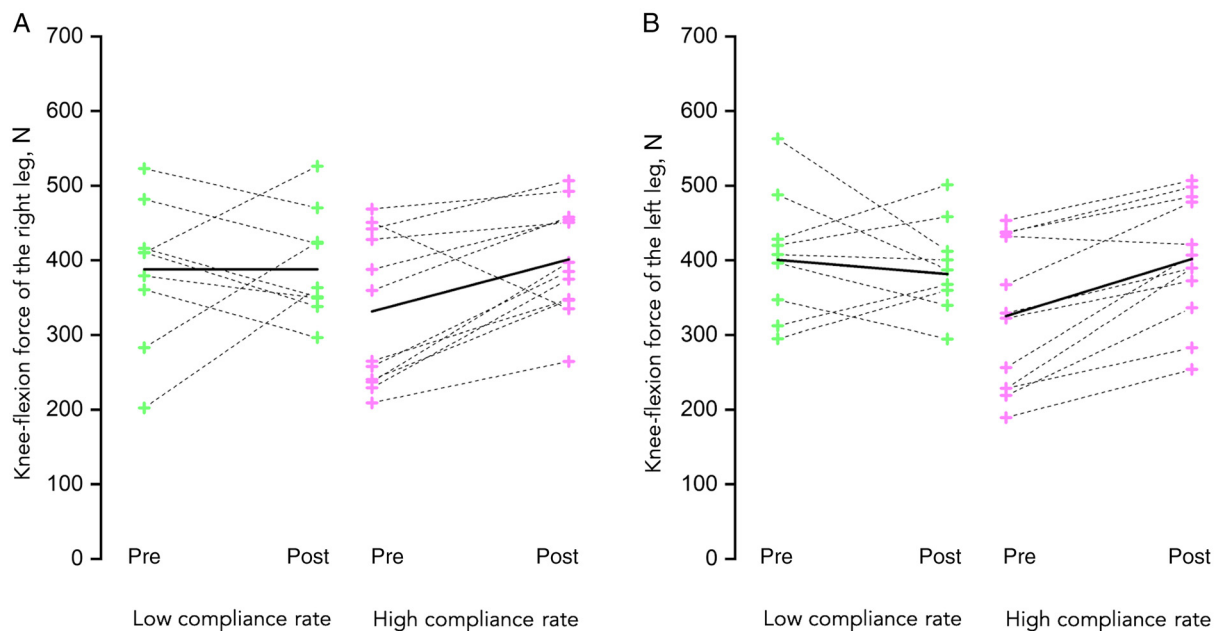


Figure 2 — Changes in knee-flexion force induced by the eccentric-biased Nordic hamstring program. Maximal eccentric knee flexion measured during Nordic hamstring exercise before (pre) and 21 weeks (post) after the strengthening program for the right leg (A) and left leg (B). The players were subdivided into 2 groups according to their compliance rate: “low” (green cross) and “high” (purple cross). Continuous black line represents the mean changes in knee-flexion force. Green and purple crosses appear in light and dark, respectively, in black & white version.

[25.5%]; 95% CI, 0.00–0.85; $P = .049$; $g = 0.42$) in maximal eccentric strength after the training program (pre = 357.3 [95.0] N and post = 390.7 [72.2] N). Importantly, the players from the experimental group participated in 9.9 (3.2) Nordic hamstring training sessions, which was close to a *moderate* compliance rate (ie, 47.2% [15.2%]). They were subdivided into 2 groups according to their compliance rate: “low” (7.2 [2.1] sessions; $n = 11$) and “high” (12.4 [1.6] sessions; $n = 12$). The mean delay between 2 training sessions is reported Figure 3. As expected, the high compliance subgroup exhibited higher changes in maximal eccentric strength compared with the low compliance group (+26.5%; 95% CI, 7.1%–45.9%; $P < .001$; $g = 1.2$; Figure 2). Note that the difference between groups was reduced, but still significant, when the analysis was adjusted on the initial level of strength (+15.5%; 95% CI, 1.2%–29.8%; $P < .001$). Finally, we have found a significant *moderate* correlation between the changes in maximal eccentric strength and the compliance rate ($r = .47$; $P = .024$; Figure 4).

We recorded 5 hamstring injuries (22%) in the experimental group and 9 (39%) in the control group. Although nonsignificant, this means that there was a 2.7-fold lower risk of suffering hamstring injury in the experimental group than in the control group (OR = 0.37; 95% CI, 0.079–1.54; $P = .12$). Similar results were found after adjustment for the weekly sprint distance covered by the players (adjusted OR = 0.30; 95% CI, 0.052–1.39; $P = .15$).

Discussion

The current study demonstrates that the inclusion of a very low volume (one set of 3 maximal repetitions) of eccentric-biased Nordic hamstring program for 21 weeks was sufficient to increase maximal eccentric strength (~15%), the magnitude of which depended on the players’ compliance. Although nonsignificant, we found that this program induced a 2.7-fold lower hamstring injury rate in professional soccer players.

A previous study composed of 10 weeks of 700 repetitions of Nordic hamstring exercise performed on 50 Union European Football Association (UEFA) Champions League clubs has presented a compliance rate as low as 16.7%.⁵ Similarly, for the International Federation of Association Football (FIFA) 11+ that include Nordic hamstring exercise, less than 15% of the football teams completed the entire recommended volume.²⁰ The time duration of the prevention program and the presence of delayed onset muscle soreness are considered as major burdens that limit the compliance of professional soccer players.⁶ The compliance of the players is crucial to improve the effectiveness of the prevention program.⁴ In the current study, we found a *moderate* compliance rate (ie, 47%), which was close to the 50.1% recommended to ensure positive effects on hamstring injury incidence.⁴ This represents an application of eccentric contractions every ~13 days and ~25 days for high and low compliance groups, respectively (Figure 3). In accordance with

the recent meta-analysis of Ripley et al.,⁴ it represents a minimal effective dose of prevention programs for improving/maintaining maximal eccentric strength that seems to protect against hamstring strain injury. A recent survey reported that negative perception and muscle soreness were identified as barriers to implementing Nordic hamstring prevention program in top-division soccer players (Ripley et al., 2021)⁴. Further studies should determine whether this low dose of eccentric training limits the aforementioned barriers and favors compliance of professional soccer players.

A recent meta-analysis performed on the effect of injury prevention programs, including the Nordic Hamstring exercise, reported a reduction of about 50% in hamstring injury rates.² Over the 8459 athletes from the 15 studies included in this work, only 2 studies were performed with first-division or professional soccer players. These studies included 2 training sessions per week composed of ~20 repetitions of the Nordic hamstring exercise. Although the current intervention was based on a very low volume of Nordic Hamstring exercise, the nonsignificant reduction in hamstring injury rate was close to that reported in the aforementioned studies (~43%). This finding was accompanied by a large decrease in the number of days absent from competition and/or training (101 d and 185 d in the experimental and control groups, respectively). Other factors may have influenced the risk of injury between the 2 seasons. According to the recent review of Green et al.,¹ high-speed running exposure has a major influence on the hamstring injury risk. Therefore, this factor was considered in the current study. Interestingly, the adjustment for the weekly sprint distance covered by the players did not change, and even reinforced, the role of Nordic hamstring program in injury rate (ie, OR = 0.37 and adjusted OR = 0.30). Some underpinning mechanisms involved in the putative protective effect associated with Nordic hamstring program have been reported (for review, see Bourne et al.³). First, the increase in maximal strength, particularly at long length, reduces the risk of injury as long as compliance is high.^{21–23} Although it is a long-held belief that stronger muscles are more resistant to injury, *in vitro* and *in vivo* studies have provided some evidence. An *in vitro* study performed in rabbit muscles demonstrated that the level of muscle activation, which is related to muscle force in this work, influenced the amount of energy absorbed by the muscle before failure.²⁴ *In vivo*, it has been shown that the increase in muscle activation during eccentric contractions was 2.6 larger after 6 weeks of eccentric compared with concentric

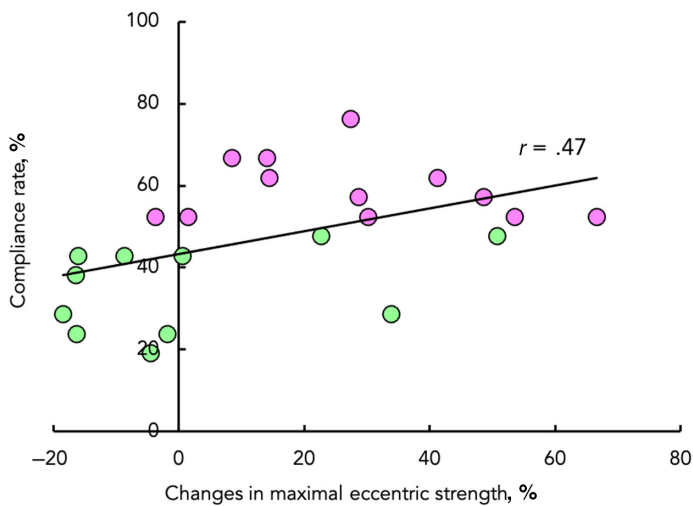


Figure 3 — A moderate correlation was found between the increase in maximal eccentric strength after 21 weeks of training and the compliance rate of the professional soccer players. The players were subdivided into 2 groups according to their compliance rate: “low” (green circles) and “high” (purple circles) corresponding to a participation <50% or >50% of the total training sessions, respectively. Green and purple circles appear in light and dark, respectively, in black & white version.

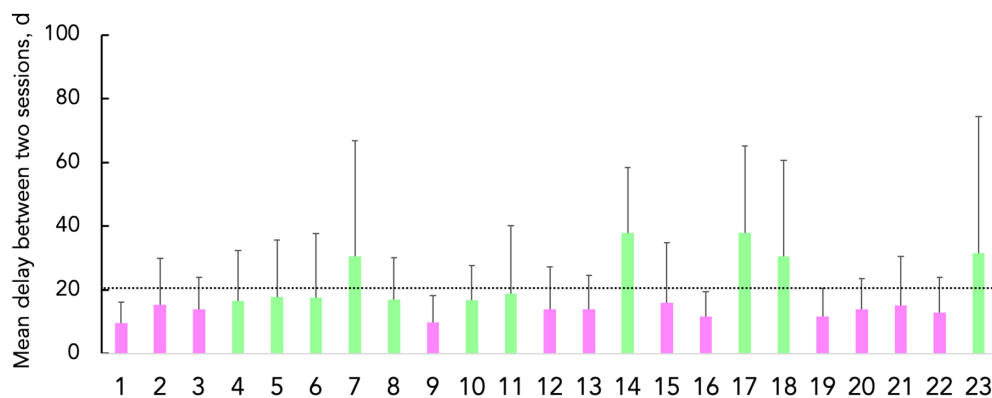


Figure 4 — Mean delay between 2 sessions during the 21 weeks of prevention program for each soccer player (player number 1–23). “Low” (green histograms) and “high” (purple histograms) compliance subgroups, corresponding to a participation <50% or >50% of the total training sessions, respectively. The horizontal dotted line corresponds to the minimal threshold (ie, 21 d) provided by Ripley et al.⁴ to have a positive effect on hamstring injury occurrence. Green and purple histograms appear in light and dark, respectively, in black & white version.

training.²⁵ Second, biceps femoris fascicle length has been shown to increase after eccentric training biased resistance training.^{26,27} This architectural adaptation favors the force production over long length ranges and at high shortening speeds,²⁸ which represent the mechanical constraints of the sprint for hamstring muscles. Although the current study reported only an increase in maximal muscle strength, we can speculate that additional neural (ie, increase in muscle activation during eccentric contractions) and structural adaptations (ie, increase in fascicle length) were involved in the decrease in hamstring injury rate reported here.

The training volume used in the current study was sufficient to induce an increase in maximal eccentric strength, especially in compliant players (+28%). The interpretation of the results is limited as duration and volume were different from previous studies (eg, Medeiros et al [2020])²⁹. Nonetheless, it has been shown that a weekly strengthening session performed during 6 to 8 weeks is sufficient to induce strength and architectural adaptations in soccer players. Indeed, Lacombe (2020)⁹ have shown that a 6-week in-season training program composed of 6 repetitions of stiff-leg deadlift and 4 repetitions of Nordic hamstring exercise induced an increase in maximal eccentric strength of about ~11% combined with an increase in fascicle length of about ~5%. Importantly, it has been shown that training volume had no effect on the magnitude of strength and architectural adaptations (Lacombe, 2020⁹; Presland, 2020²⁷). For instance, Schoenfeld et al. (2019)¹¹ found that strength gains did not differ between low (one set per exercise), moderate (3 sets per exercise), and high (5 sets per exercise) training volume performed during 8 weeks. It would be interesting to determine whether this absence of training volume effect persists when the program is carried out over a 1-year soccer season.

There are 2 main limitations that require consideration. First, the current study did not assess the changes in maximal eccentric strength in the control group. Some evidence from the current study and from the literature makes us confident that it is unlikely that the control group exhibited substantial changes in maximal eccentric strength. First, we have shown that the low compliance subgroup (n = 11) of the experimental group did not exhibit substantial changes in maximal eccentric strength (-2.8%) despite the 7.2 training sessions. Second, Mendiguchia et al³⁰ reported no changes in structural properties, sprint acceleration, and mechanical output during the first 6 preseason weeks in soccer players playing in Elite Division. Overall, it is reasonable to assume that the consistent application of a very low volume of eccentric contractions (approximately every 2 wk; Figure 3) was an efficient strategy to induce strength gains in professional soccer players. Second, Nordic hamstring exercise was performed in bilateral condition where between limbs compensations may occur. However, the level of assistance needed and the time required to perform Nordic hamstring in unilateral condition limit its relevance in professional soccer settings. Regarding the maximal eccentric strength assessment, a recent work has reported a moderate to substantial agreement between session for interlimb asymmetry identification in bilateral condition (Cuthbert et al., 2020)³¹. It confirms that maximal eccentric strength during bilateral Nordic hamstring exercise should be considered as a relevant evaluation and training method that fits with professional soccer constraints.

Conclusion

The current study reported a nonsignificant 2.7-fold lower risk of hamstring injury in professional soccer players who performed a low volume of 3 maximal repetitions per week of the Nordic hamstring exercise during 21 weeks. Importantly, we found that the

compliance of players has a pivotal role in the magnitude of the changes in maximal eccentric strength. During the in-season period, a minimum dose of 3 maximal repetitions per week of the Nordic hamstring exercise seems to represent a minimal dose that may favor the compliance of the professional soccer players and induce protective adaptations.

Acknowledgments

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