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RESEARCH ARTICLE

Changes in Isokinetic Muscle Strength in Adolescent Soccer Players after 10 Weeks of Pre-Season Training

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Abstract:

Background:

During soccer-specific movements, the strength of knee extensors and flexors is of great importance and achieving certain strength ratios between the two has been identified as an important parameter for reducing the risk of soft tissue injuries around the knee.

Objective:

The aim of the study was to evaluate changes in isokinetic strength of the knee flexors and extensors and their strength ratios in elite adolescent soccer players.

Methods:

Before and after 10 weeks of standard pre-season soccer training with progressive eccentric hamstring exercises, the players (n=18; age 17.1±0.4 years) participated in isokinetic testing to assess concentric and eccentric peak torque at $60°\cdot s^{-1}$.

Results:

After 10 weeks of training, the peak eccentric torque of the non-dominant quadriceps increased (p=0.018; ω=0.24). Additionally, the average eccentric work increased in the dominant hamstrings (p=0.007; ω=0.23), dominant quadriceps (p=0.02; ω=0.31), non-dominant hamstrings (p=0.003; ω=0.25 and non-dominant quadriceps (p=0.01; ω=0.37). Lastly, the isokinetic functional ratio (eccentric hamstrings-to-concentric quadriceps) increased in favor of eccentric hamstring strength in the non-dominant limb (p=0.04; ω=0.31).

Conclusion:

The results of the study indicate that pre-season training induced suboptimal changes in the isokinetic strength of the knee flexors and extensors in elite adolescent soccer players. However, the lack of injuries combined with an apparent lack of preparedness explained by slow velocity isokinetic testing indicates that future research should investigate other forms of strength testing to determine soccer-specific preparedness such as isokinetic dynamometry at higher speeds (*i.e.* $180°.s^{-1}$ or $240°.s^{-1}$) and traditional weight-room testing such as 1RM tests.

Keywords: Conditioning, Football, H:Q ratio, Peak torque, Training, Youth.

INTRODUCTION

Strength is a component of fitness that is not only crucial for athletes in terms of sports performance, but also in terms of injury prevention [1, 2]. The main components of soccer-specific fitness include acceleration, anaerobic

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repeated sprint ability, and explosive power of the lower extremities [3 - 5], indicating that strength, speed, and endurance are all important while attacking and defending in soccer [6, 7]. Specifically, during specific movements like sprinting, jumping, turning, kicking, tackling, and maintaining balance, the strength of the knee extensors and flexors is of great importance [5, 7, 8].

Although absolute knee flexor and extensor strength play an important role in performance and injury prevention, the relationship between hamstring and quadriceps strength is also an important factor to consider when aiming to reduce the risk of soft tissue injuries around the knee [9 - 11]. A lack of hamstring strength and an overwhelming dominance of quadriceps strength have been shown to be a predisposing factor for hamstring injuries in semi-pro soccer players [12]. Therefore, hamstring-to-quadricep (H:Q) strength ratios are often used to describe the dynamic stability of the knee, to identify potential risk factors for the occurrence or recurrence of hamstring and knee injury, to monitor rehabilitation programs, and to make decisions about when an athlete can safely return to training [13].

Unilateral and bilateral strength asymmetries of the knee flexors and extensors are considered to be the major causes of hamstring injuries and soft tissue injuries to the knee joint in soccer players [13 - 15]. Specifically, unilateral H:Q comparisons are used to assess and identify athletes with a risk of injury and to assess a player's readiness to return to competition after a knee injury [2, 16, 17]. Most authors agree that when the conventional H:Q ($H:Q_{CONV}$) strength ratio (*i.e.* the ratio between concentric knee flexion and concentric knee extension) is less than 0.6 (60%) at a velocity of $60°\cdot s^{-1}$, the probability of hamstring injury increases in elite soccer players [18] and competitive sprinters [19], as the low $H:Q_{CONV}$ ratio indicates that the knee musculature may not be able to optimally position the knee joint during movements, increasing the stress placed on intra-articular structures, possibly resulting in biomechanical changes and soft tissue injury [18, 20].

While some authors paid attention to the $H:Q_{CONV}$ ratio, other authors highlighted the importance of eccentric hamstring actions in dynamically maintaining the stability of the knee joint during active knee extensions [18, 20]. This relationship has led to the development of the so-called functional strength ratio ($H:Q_{FUNC}$) (*i.e.* the ratio between eccentric hamstring strength and concentric quadriceps strength) [21]. While the $H:Q_{CONV}$ ratio has the ability to identify a muscle imbalance, the $H:Q_{FUNC}$ ratio specifically describes the ability of the knee flexors to decelerate rapid knee extension that is initiated by the quadriceps [20]. Therefore, an $H:Q_{FUNC}$ ratio of 1.0 (100%) at an angular velocity of $60°\cdot s^{-1}$ expresses the balance between the strength of the knee flexors and extensors, an in turn, the ability to dynamically stabilize the knee joint during activities such as running and kicking [22].

In accordance with the theory of periodization, the annual training cycles include the stages of strength training aimed at inducing specific adaptations [23, 24]. For example, the post-competitive transition period and the beginning of the pre-season are dominated by general training in order to prepare the muscles, ligaments, tendons, and joints for the sport-specific loads to be experienced in the upcoming season. Hence, the training during the pre-season period aims to increase strength, improve neuro-muscular coordination, and increase skeletal muscle hypertrophy if desired. During the latter stages of this phase, the application of sport-specific movements begins [25, 26]. For example, it has been shown that a 10-week pre-season eccentric hamstring strength training program significantly reduced the rate of hamstring injury and resulted in increases in maximal running speed and isokinetic hamstring muscle strength in the professional male soccer players during the subsequent 10-month season [27]. Although it is common to strengthen the hamstrings concentrically, it is evident that eccentric strengthening is also essential for both injury prevention and optimal performance. Additionally, Mjolsnes *et al.* [28] found that the Nordic hamstring exercise was more effective in developing maximal eccentric hamstring strength than the traditional hamstring curl exercise in well-trained soccer players.

Although studies have focused on isokinetic muscle strength of the lower extremities in multiple periods of the annual training cycle; these studies mostly include adult players [29, 30], and only occasionally include elite youth players, specifically under 17 years old (U17) [31, 32]. Moreover, in studies aimed at U17 players, eccentric strength has rarely been assessed. Therefore, the aim of this study was to evaluate changes in the isokinetic strength of the knee flexors and extensors and H: Q ratios in elite U17 soccer players after the completion of a 10-week pre-season training cycle which included eccentric hamstring training.

MATERIALS & METHODS

The present study was conducted using an intervention study design including pre- and post-testing around a 10-week pre-season training cycle. The pre-test was performed three weeks after the end of the previous season and one day before the first pre-season training session. The post-test occurred at the end of the last week of winter pre-season. On average, the participants performed eight training sessions per week for ten weeks (range of 6-9 training sessions per week).

Participants

Testing was carried out on U17 male soccer players (n = 18; 17.1 ± 0.4 y; 1.78 ± 0.05 m; 70.32 ± 5.51 kg) playing in the Czech first division. Thirteen players had the right leg as the dominant (preferred kicking) leg and five players had the left leg as the dominant leg. The study was approved by the institution's ethics committee and conformed to the Declaration of Helsinki regarding the use of human subjects. After all players and their legal guardians were fully informed of the aim of the study and of all testing procedures, a written informed consent was obtained. None of the players had acute health problems or previous injuries of the lower extremity and all were familiar with isokinetic testing. During the study period, subjects were not given any dietary or physical activity restrictions other than resting for 24 hours leading up to the pre-and post-testing days.

Measurements

For each leg, isokinetic strength of the knee flexors and extensors was measured using an IsoMed 2000 isokinetic dynamometer (D. & R. Ferstl GmbH, Hemau, Germany). Prior to testing, the players completed a supervised general warm-up that included stationary cycling for 6 minutes at a self-regulated low (80W) to moderate intensity (250W), 5 minutes of dynamic stretching exercises for the quadriceps and hamstrings, and ten vertical jumps with progressive jump effort and 20s rest between jumps.

The players were secured to the dynamometer according to standardized guidelines in a seated position with a hip angle of 100°, and the axis of rotation of the dynamometer was aligned with the axis of rotation of the knee (lateral femoral epicondyle). The arm of the dynamometer lever was fixed to the distal part of the shin and the lower edge of the shin pad was placed 2.5 cm above the medial apex of the malleolus. Individual seat settings were stored in the computer before measuring the dominant leg and were automatically activated in the process of measuring the non-dominant leg and all follow-up testing. The participants were instructed to hold the handgrips located at the side of the seat during all testing efforts. An angular velocity of $60°\cdot s^{-1}$ was used, as this speed has been shown to be the most valid speed for exposing strength deficits [33]. Static gravitational correction was applied according to the manufacturer's guidelines. The testing range of motion was 80° and was set from 10–90° of knee flexion (with 0° = full voluntary extension).

The testing protocol on the dynamometer consisted of one warm-up set and one testing set of concentric and eccentric muscle actions. In the warm-up set, the players performed six reciprocal concentric flexion/concentric extension actions with progressive increases in effort until a maximum action was performed during the sixth repetition [34]. After one minute of rest, the players performed a set of six maximal repetitions. The rest time between the measurement of the dominant leg (DL) and the non-dominant leg (NL) was 3 minutes, and the DL was always measured first. During the testing procedure, the players were provided with concurrent visual feedback in the form of an isokinetic strength curve displayed on the dynamometer monitor. Verbal encouragement was not provided. The variables collected from isokinetic testing were absolute peak torque (PT) in Nm and average work (AW) in J, where PT and AW were collected from the trials with the greatest PT and AW, respectively. Lastly, PT was used to determine the $H{:}Q_{CONV}$ and $H{:}Q_{FUNC}$.

Training Program

The training content, match play, and recovery periods were recorded during the 10-week period. Although the exact durations of training sessions slightly varied throughout the 10-week period, the average session time for each session type is shown in Table **1** (30-50min for main training sessions, plus 5-15 minutes for both warm-up and cool-down). Training took place from Monday to Friday and seven pre-season matches were played on Saturdays, leaving three Saturdays and every Sunday as the rest days. A detailed description of the training schedule is set forth in the supplement of this manuscript.

Table 1. Training schedule during the ten-week pre-season period.

	Morning	Afternoon
Monday	Resistance: upper body with 80% of 1RM, Core training (40min), **hamstring session**	Game-like: aerobic (45min)
Tuesday	Technical-Tactical: aerobic (30min), **hamstring session**	Game-like: anaerobic (45min)
Wednesday	Resistance: lower limb with 80% of 1RM, Plyometric training (45min)	Technical-Tactical, game-like (45 min)
Thursday		Technical-Tactical: individual (40min), **hamstring session**
Friday	Speed and agility (30min), Technical-Tactical game-like (20min)	
Saturday	Match: 7 matches in 10 weeks (90min)	
Sunday		Regeneration: massage, sauna, whirlpool (60min)

Caption: 1 repetition maximum–1RM; minutes–min.

The training intervention consisted of soccer-specific training as well as what can be considered as normal pre-season soccer conditioning. Additionally, the players also participated in supervised strength training with a special focus on eccentric hamstring exercises such as the Nordic curl. This exercise was performed according to the previously established guidelines [27, 28, 35, 36]. The starting position began with the players on their knees, with the knees flexed to 90°, with the hips slightly flexed, and an erect torso. While an exercise partner manually secured the athlete's ankles to the floor throughout the exercise, the athlete allowed the knees to slowly extend while maintaining slight flexion of the hips, resulting in the hamstrings eccentrically acting against the gravity-induced knee extension. As the athlete's upper body approached the ground, the hands were used to buffer the fall, letting the chest touch the ground. Upon completion of one repetition, the athletes were told to immediately return to the starting position by thrusting themselves back up using their hands to minimize concentric hamstring loading in the upward phase. The hamstring-focused training was progressively incorporated into the training schedule. In the beginning of the 10-week preseason period, the players performed one set of five repetitions, once per week. The volume of eccentric hamstring training progressively increased each week and by the 5th week of preseason program, the players were performing three sets of 8-12 repetitions three times per week [35] (see supplement **1**). During the first four weeks, eccentric hamstring training was completed with 72 hours of rest between the sessions; however, from the 5th week onward, eccentric hamstring sessions were completed on two consecutive days and for the third time after 48 hours of rest. The previous papers [28, 35, 36] have recommended to perform eccentric hamstring training up to 3 times per week during pre-season, but did not recommend the specific number of rest days between the sessions. The previous research implemented five repetitions of the Nordic curl during each warm-up training session for six weeks [37]. Therefore, it appears as though a minute of daily training allows for daily application of eccentric hamstring exercises, leading to the progressive prescription of three eccentric hamstring sessions in four days in the present study.

Statistical Analysis

The mean and standard deviation values were calculated for all PT, AW, and H:Q ratios Tables (**2**-**4**). To determine the effectiveness of the intervention, one-sample t-tests were used to compare the absolute differences between the pre-test and the post-test values for each variable. The range of the effect was determined by the ω coefficient ($0.00 \leq \omega \leq 0.05$ small effect; $0.6 \leq \omega \leq 0.13$ medium effect; $\omega \geq 0.14$ large effect) [35], and the significance level for all the tests was set at $p < 0.05$. Statistical analyses were performed using the data analysis software system Statistica, version 12 (StatSoft, Inc., Tulsa, USA). Although differences were not compared between the legs, as the purpose of the training program was not to improve the strength of a specific limb, percentage change values were calculated from the pre-season to the post-season for each variable in order to further describe the results Tables (**2**-**4**).

Table 2. Peak torque pre- and post-training.

PT [Nm]	Pre-test M±SD	Post-test M±SD	Δ	t	% Change
$PT_{H\_C\_DL}$	127.22 ± 22.94	129.27 ± 20.08	2.05	0.54	3.02
$PT_{Q\_C\_DL}$	205.50 ± 24.54	211.88 ± 29.48	6.38	0.94	3.64
$PT_{H\_C\_NL}$	117.16 ± 12.91	114.72 ± 17.29	2.44	0.88	2.07
$PT_{Q\_C\_NL}$	200.55 ± 29.97	203.55 ± 29.08	3.00	0.59	2.11

(Table 2) contd.....

PT [Nm]	Pre-test M±SD	Post-test M±SD	Δ	t	% Change
$PT_{Q\_E\_DL}$	227.38 ± 38.79	251.00 ± 52.70	23.61	1.88	12.58
$PT_{H\_E\_DL}$	130.94 ± 19.25	136.38 ± 24.47	5.44	1.05	5.02
$PT_{Q\_E\_NL}$	222.94 ± 45.81	246.94 ± 40.94	24.00	2.61*	13.45
$PT_{H\_E\_NL}$	116.83 ± 22.24	124.00 ± 21.57	18.82	1.61	7.64

Caption: PT–peak torque; $_{Q}$–quadriceps; $_{H}$–hamstrings; $_{C}$–concentric action; $_{E}$–eccentric action; $_{DL}$–dominant leg; $_{NL}$–non-dominant leg; M–mean; SD–standard deviation; Δ–absolute change; t–criterion of the one-sample t-test ($p < 0.05$)*. % change from pre- to post-training.

Table 3. Average work pre and post-training.

AW [J]	Pre-test M±SD	Post-test M±SD	Δ	t	% Change
$AW_{H\_C\_DL}$	116.00 ± 24.81	120.72 ± 19.60	4.72	0.83	1.64
$AW_{Q\_C\_DL}$	167.16 ± 20.99	177.44 ± 25.64	10.27	1.95	6.65
$AW_{H\_C\_NL}$	105.56 ± 12.24	106.56 ± 20.20	1.00	0.27	0.88
$AW_{Q\_C\_NL}$	165.77 ± 19.29	163.11 ± 34.08	2.66	0.41	1.89
$AW_{H\_E\_DL}$	99.28 ± 23.29	113.78 ± 22.10	14.50	3.02*	19.13
$AW_{Q\_E\_DL}$	160.72 ± 34.09	178.17 ± 41.17	17.44	2.50*	12.28
$AW_{H\_E\_NL}$	94.94 ± 17.44	108.00 ± 22.14	13.05	3.42**	14.65
$AW_{Q\_E\_NL}$	158.17 ± 36.15	177.61 ± 28.98	19.44	2.67*	15.92

Caption: AW–average work; $_{H}$–hamstrings; $_{C}$–concentric action; $_{E}$–eccentric action; $_{DL}$–dominant leg; $_{NL}$–non-dominant leg; M–mean; SD–standard deviation; Δ–absolute change; t–criterion of the one-sample t-test ($p<0.05$)*; ($p<0.01$)**. % change from pre- to post-training.

RESULTS

Values of the measured variables for the pre- and post-tests are reported in Tables (**2**-**4**). A statistically significant increase was observed for $PT_{Q\_E\_NL}$ ($p = 0.018$; $\omega = 0.24$), $AW_{H\_E\_DL}$ ($p = 0.007$; $\omega = 0.23$), $AW_{Q\_E\_DL}$ ($p = 0.02$; $\omega = 0.31$), $AW_{H\_E\_NL}$ ($p = 0.003$; $\omega = 0.25$), and $AW_{Q\_E\_NL}$ ($p = 0.01$; $\omega = 0.37$). There were no statistically significant changes in the $H{:}Q_{CONV}$. A significant increase was observed in the $H{:}Q_{FUNC\_NL}$ ($p = 0.04$; $\omega = 0.31$), with no other significant changes in the $H{:}Q_{FUNC}$.

DISCUSSION

The purpose of the present study was to explore the changes in the knee flexor and extensor PT with respect to the changes in various H:Q ratios after 10 weeks of pre-season training with the inclusion of progressive eccentric hamstring exercises. The main findings of this study were that: 1) PT significantly changed only in the NL knee extensors during eccentric isokinetic actions; 2) eccentric AW increased in the knee extensors and flexors of the DL and NL; and 3) the $H{:}Q_{FUNC}$ ratio increased in the NL but no changes were present for the $H{:}Q_{CONV}$. Collectively, these data suggest that 10 weeks of pre-season soccer training including eccentric hamstring exercises may not have affected the maximal strength (*i.e.* no changes in isokinetic PT), but may have increased the ability for the players to maintain the eccentric torque during isokinetic testing evidenced by the greater AW. Therefore, it is probable that eccentric mean force increased in the quadriceps and hamstrings, as the AW increased but the testing range of motion (*i.e.* distance) did not change.

The PT results of the current study indicate that the pre-training PT values in our group of players were similar to or greater than the PT of other young elite players of the similar age groups [2, 38 - 40]. Therefore, it is possible that the subjects in this study started the preseason period well prepared in terms of lower limb strength, meaning that any additional strength gains might have been difficult to achieve, especially during a training program including soccer-specific running (See supplement) and might have resulted in an interference effect [41]. The PT data from the present study are in accordance with the previously published data [32] in which the researchers also assessed the changes in the concentric PT at $60°{\cdot}s^{-1}$ in a group of young elite soccer players of similar age (age 16.7±0.7 years). After completing the 10-week pre-season period, the authors observed no change in the hamstring or quadriceps PT in both the DL and NL. Similarly, no differences in the PT were present within the DL and NL in a study by Erdemir *et al.* [42] employing U17 soccer players. At first glance, the combined results of these studies suggest that pre-season training may not result in any desirable increases in the maximal strength. Although isokinetic testing is a valid and reliable tool for assessing muscular strength [43], it often lacks specificity. Therefore, it is possible that more specific strength tests such as a back squat 1 repetition maximum (1RM) might have indicated that dynamic muscular strength changed during the course of pre-season training. Moreover, the detailed parameters of strength training were not reported in any of the previously mentioned studies, leaving the reader without the knowledge of any strength training program within the training period of players with a similar age and skill level as the ones in the present study. On the other hand, after collegiate soccer players utilized the Nordic hamstring curl for 10 weeks, they experienced an 11% increase in the eccentric hamstring PT measured at $60°s^{-1}$, as well as a 7% increase in the isometric hamstring strength at 90°, 60° and 30° of the knee flexion [28]. Although the authors did not report the loading parameters used during the pre-season training period, it could be assumed that the players in the present study experienced a similar eccentric hamstring training load if similar guidelines were followed. As the players of the present study presented insignificant increases in the hamstring strength, it is possible that increasing the sessions of strength training and decreasing the sessions of soccer-specific training in the present study may result in similar strength increases as those in the previously mentioned study [28]. However, this interference effect is simply hypothetical, as the lack of training details in another study [28] does not allow a direct and conclusive comparison between the studies.

Table 4. Peak torque ratios pre and post-training.

H:Q ratio	Pre-test M±SD	Post-test M±SD	Δ	t	% Change
$H{:}Q_{CONV\_DL}$	0.61 ± 0.09	0.62 ± 0.1	0.01	0.20	1.01
$H{:}Q_{CONV\_NL}$	0.59 ± 0.07	0.56 ± 0.08	0.03	1.74	3.02
$H{:}Q_{FUNC\_DL}$	0.65 ± 0.09	0.67 ± 0.15	0.02	0.77	2.01
$H{:}Q_{FUNC\_NL}$	0.56 ± 0.11	0.61 ± 0.01	0.05	2.16*	5.03

caption: $H{:}Q_{CONV}$–isokinetic concentric hamstrings-to-concentric quadriceps conventional ratio; $H{:}Q_{FUNC}$–isokinetic eccentric hamstrings-to-concentric quadriceps functional ratio; M–mean; SD–standard deviation; Δ–absolute change; t–criterion of the one-sample t-test ($p<0.05$)*. % change from pre- to post-training.

After 10 weeks of pre-season training, the average $H{:}Q_{CONV}$ ratio of the subjects reached from 0.56 to 0.62. Achieving a ratio of 0.60 is considered to be the "injury threshold" meaning that a value below 0.60 when measuring strength at $60°{\cdot}s^{-1}$ indicates a possible muscle imbalance and may increase the probability of hamstring or ACL injury [20, 34]. Although such diagnostics are applicable in the present study (according to previous recommendations set forth using $60°{\cdot}s^{-1}$), the angular velocity must be considered because the $H{:}Q_{CONV}$ ratios change as the angular velocity changes [44]. There are several ways how to increase the $H{:}Q_{CONV}$ which include: increasing the strength of the knee flexors and extensors, but a greater increase in the knee flexors; increasing strength only in the knee flexors; or maintaining the strength of the knee flexors accompanied by a decrease in the extensor strength. From the aforementioned possibilities, the first could be considered as the most beneficial response to the pre-season training. Although an increase in the knee flexor strength could be considered as beneficial, a significant increase in the extensor strength without an accompanying increase in the flexor strength may be seen as undesirable, decreasing the $H{:}Q_{CONV}$ ratio and possibly resulting in hamstrings injuries. However, none of these cases were observed using isokinetic testing in our study. One possible explanation for the lack of hamstring strength and the resultant lack of increase in the $H{:}Q_{CONV}$ could be an inappropriate application of eccentric hamstring training. As mentioned within the methods, the second half of the training program included eccentric hamstring sessions that were applied three times in four days (Monday, Tuesday, and Thursday), which may not have provided sufficient time for hamstring regeneration. Therefore, it is possible that the hamstring training of the present study did not include an appropriate volume or might have not have been optimally applied. The previous recommendations range from performing five repetitions of the Nordic curl every day [37] to multiple sets of multiple repetitions up to three days per week [28, 35, 36]. Based on the results of the present study, it appears as though combining the previous recommendations of successive days and multiple sets may not result in increases in the eccentric hamstring strength. However, possibly just as important, it should be noted that there were no reported hamstring injuries in the present study. Therefore, it appears that although eccentric hamstring strength did not increase in the present study, the risk of injury did not increase either. Hence, further research should investigate the effects of eccentric hamstring training density on the strength and injury rates.

Similar to the $H{:}Q_{CONV}$, an $H{:}Q_{FUNC}$ ratio below 0.6 indicates an increased likelihood of knee injury [18]. According to other authors, $H{:}Q_{FUNC}$ values ranging from 0.7–1.0 indicate insufficient dynamic stabilization of the knee [45, 46], and a value of 1.0 indicates adequate dynamic joint stability [47]. The average $H{:}Q_{FUNC}$ in the subjects of this study (range of 0.61 to 0.67) was above the "injury threshold," but was far from the optimal value. In addition, significant increases in the $H:Q_{FUNC}$ were generally not present, indicating that the pre-season training program employed in the present study was not successful in increasing the eccentric hamstring strength relative to concentric quadriceps strength. Therefore, the pre-season training of our subjects might not have adequately prepared the muscles to perform in an optimal manner, possibly due to the low volume of lower limb resistance training, infrequent rest days, or too many high-intensity game-like training sessions resulting in an interference effect. As with the $H:Q_{CONV}$, although the players' $H:Q_{FUNC}$ ratio was not ideal, no hamstring or knee injuries occurred during the pre-season program. Additionally, the average $H:Q_{FUNC}$ values increased only in the NL, further supported by a large effect size. It is possible that the high volume of soccer-specific training included a lot of kicking exercises and the DL (*i.e.* kicking leg) was more accustomed to rapid eccentric actions in the hamstrings in order to slow the movement of leg during the follow-through of repetitive kicking actions [20, 48]. Thus, the increase in the $H:Q_{FUNC}$ of the DL seems beneficial, as an increase in the antagonistic eccentric hamstring activation may act as a natural protective mechanism because it reduces unnecessary tension of the anterior cruciate ligament [49, 50]. Although previous studies and the present study used slow-velocity isokinetic testing to identify functional muscle imbalances, it must be remembered that angular velocities of the knee observed during the soccer were much faster than 60° per second, so it is possible that a more sport-specific $H:Q_{FUNC}$ test should be implemented in the future.

This study primarily focused on changes in the PT and the H:Q ratios, whereas other studies also assessed the differences between the Q and H strength and between the DL and NL. In these studies, greater PT values were found in the quadriceps compared to the hamstrings [2, 32, 51] and during eccentric actions compared to the concentric actions [52, 53]. As the present study aimed to quantify changes in strength in response to the same training program (*i.e.* no control group) throughout a season with subjects, such detailed comparisons were of no interest. However, the absence of H and Q comparisons and laterality analyses could be viewed as a limitation of the present study and should be investigated in future research. Additionally, since the subjects in this study only had a 3-week off-season period before starting their pre-season training associated with this study, it is possible that the 3-week off season served as a taper, actually enabling the players to recover from the high demands of the previous season, resulting in the "optimal" strength levels during the pre-training testing in the present study. Had the off-season period been longer, the players would have become detrained, lowering their pre-season strength levels, possibly allowing greater improvements during the 10-week pre-season period. Unfortunately, in the conclusion, data regarding the player's strength levels of the previous season were not available, leaving this proposition purely hypothetical. Therefore, although the pre-season program that included mostly game–like training may not have prepared the players in terms of thigh muscle strength development and knee injury prevention when considering hamstring and quadriceps strength ratios, no players experienced a soft tissue lower-limb injury during the study period.

CONCLUSION

The results of this study indicate that the isokinetic strength of the knee flexors and extensors responded differently to 10 weeks of pre-season training in young elite soccer players. Due to sport-specific demands of pre-season soccer training and various recommendations of Nordic curl training that range from five repetitions daily to three days of multiple sets of multiple repetitions, the present study implemented a progressive increase in the eccentric hamstring training's frequency which ultimately included two consecutive days of eccentric training. Although the pre-season program that included mostly game–like training did not result in inculcating thigh muscle strength and knee injury prevention in the players when considering the isokinetic hamstring and quadriceps strength ratios, no players experienced a soft tissue lower-limb injury during the study period. Therefore, it can be concluded that the training program used in the present study sufficiently prepared the players for the upcoming season. However, the lack of injuries combined with an apparent lack of preparedness explained by slow velocity isokinetic testing indicates that future research should investigate other forms of strength testing to determine sport preparedness, such as isokinetic dynamometry at higher speeds (*i.e.* $180°.s^{-1}$ or $240°.s^{-1}$) and traditional weight-room testing such as 1RM tests.

LIST OF ABBREVIATIONS

H:Q	=	Hamstrings:Quadriceps ratio Introduction:
H:QCONV	=	Conventional Hamstrings:Quadriceps ratio Introduction:
H: QFUNC	=	Functional Hamstrings:Quadriceps ratio Introduction:
U17	=	Under seventeen years old Introduction:
DL	=	Dominant leg Methods:

NL	=	Non-dominant leg Methods:
PT	=	Peak torque Methods:
AW	=	Average work Methods:
H	=	Hamstrings
C	=	Concentric action
E	=	Eccentric action

SUPPLEMENTARY MATERIAL

Supplementary material is available on the publishers Website along with the published article.

CONFLICT OF INTEREST

The author confirms that this article content has no conflict of interest.

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