Seasonal variation in neuromuscular control in young male soccer players

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Highlights

1. Certain neuromuscular control variables were susceptible to seasonal variation
2. SLCMJ absolute and relative peak landing force increased significantly PRE-MID
3. 75%HOP absolute peak landing force increased significantly in the left leg
4. TJA knee valgus reduced in the right leg but remained 'moderate' in the left leg
5. Alterations in neuromuscular control were weakly related to anthropometric changes

Abstract

Objective: Determine how lower limb neuromuscular control changes over the course of a competitive soccer season.
Design: Repeated measures.
Setting: Academy soccer club.
Participants: 43 male youth soccer players (age 13.1 ± 2.2 yr; height 160.1 ± 15.7 cm; body mass 49.4 ± 14.3 kg; maturity offset 0.2 ± 1.9 yr).
Main outcome measures: Pre-, mid- and end of season assessments of peak landing forces during single leg 75% horizontal hop and stick (75%HOP) and a single leg countermovement jump (SLCMJ), single leg hop for distance (SLHD), knee valgus during the tuck jump assessment (TJA) and inter-limb symmetries.

Results: Hop distance increased significantly. Absolute peak landing forces in the left leg during the SLCMJ and 75%HOP increased significantly, with significant increases also present in the same leg for SLCMJ relative peak landing force. TJA knee valgus score was reduced in the right leg, but remained at a 'moderate' level in the left knee.
Conclusion: Neuromuscular control, as evidenced by increased absolute and relative peak landing forces, appears to reduce over the course of a competitive season. Young soccer players should engage in neuromuscular training throughout the season to offset any decrements in neuromuscular control and to facilitate appropriate landing strategies.

Key words: landing force, injury, knee valgus, youth, football

1. Introduction

Elite male youth soccer players participating in regular training and competitions display an inherent risk of injury (3, 24, 32, 36), which may be heightened at certain time points throughout a competitive season. For example, peak injury rates have been shown during the pre-season period and following a mid-season break (1, 7, 8, 24, 32), albeit with some variation in injuries obtained during competition versus training (32). However, it remains unclear how neuromuscular control fluctuates throughout the season, and whether it shows a similar trend to the reported injury rates. Heightened incidence of injury during early season periods could be linked to environmental factors such as firm ground and climate; however, accumulated fatigue and reduced neuromuscular control due to high preseason workloads and/or heightened intensity of and stress associated with competitive matches could also be contributing factors. Similarly, a spike in injury rates following the mid-season break could indicate a lack of preparatory conditioning, whereby, players are not accustomed to the physical demands of training after a period of detraining (14, 32). In sports with long seasons, frequent training and competitions may limit opportunities for recovery and decrease performance, leading to changes in neuromuscular control and altered movement mechanics (4). In-season monitoring is typically used by practitioners to objectively determine functional changes that may be indicative of heightened injury risk (42).

Previous research has examined changes in a range of physiological variables in 10-14 year old male youth soccer players from pre- to post-season, which included different jumping tasks (19). Specifically, the study aimed to investigate whether seasonal changes in anthropometric and physiological characteristics differed between young players that were selected in the first team versus those selected as reserve players. Significant declines in drop jump height were reported at the end of the season for both groups, which may have indicated a reduced ability to attenuate landing forces and ineffective utilisation of neurophysiological stretch-shortening cycle mechanisms. While the study showed jump performance deteriorated throughout the course of the season, particularly in the reserve players, bilateral jump height on its own does not provide insight into potential injury risk factors associated with jump-landing tasks.

While previous paediatric literature has attempted to identify injury risk factors amongst youth of varying maturity status using cross-sectional research designs, these approaches fail to account for the non-linear and dynamic nature of youth development, which is often mediated by amongst other factors, physical training, competition and training exposure, growth and maturation (9, 10). Currently, there are limited data to examine the seasonal variation in performance or injury risk of elite male youth soccer players. End of season isokinetic knee flexor but not extensor peak torque has been shown to significantly increase in youth soccer players following the off-season and an additional 6 weeks of training leading into the next competitive season, likely due to dissipation of accumulated fatigue (25). Similarly, jump height and selected markers of isokinetic leg strength have been shown to increase during the competitive period compared to pre-season values in adolescent female volleyball players (41). The authors attributed changes in jump performance to improvements in coordination, effective utilisation of the stretch-shortening cycle and enhanced force production.

It is evident that the existing literature base examining seasonal variations in young athletes has focused predominantly on changes in performance-based measures (e.g. jump height, isokinetic strength). However, lower limb non-contact injuries often occur when young players experience dynamic knee valgus during landing and deceleration (43). If ground reaction forces upon landing exceed the force absorption capacity of muscle, then additional loading will be directed to other connective tissues, thereby increasing the risk of ligamentous injury (21). Therefore, if attempting to track lower limb injury risk throughout the course of a season, it seems prudent to monitor force absorption during landing-based activities (37).

Cumulatively, due to the shortage of data from youth cohorts and the absence of studies that have included repeated within-season measures of neuromuscular control, further research is warranted to investigate the seasonal variation of injury risk factors in this population. Additionally, in light of the potential influence of growth and maturation on injury risk factors in developing athletes, research is required to determine whether changes in performance in tests of neuromuscular control are related to changes in anthropometric variables. Thus, the aims of the current study were to (1) examine seasonal changes and variability in tasks that require repeated maximal jumps, single leg jump-landing, dynamic balance and quantification of landing force at three time points during an academy soccer season, and (2) investigate the relationships between changes in neuromuscular control and changes in height, mass and leg length.

1. Methods

1.1. Experimental design

This study employed a repeated measures design to evaluate the seasonal variation in a range of field-based neuromuscular control protocols. Participants were required to attend the club training ground and complete three experimental test sessions throughout the course of the season; session 1 (July) during pre-season (PRE); session 2 (January) during mid-season (MID); session 3 (May) at the end of season (END). Anthropometric measures (standing height, leg length and body mass, and growth rate) and four different jumping protocols were measured at each session, including: (1) single leg hop for distance (SLHD); (2) single leg 75% horizontal hop and stick (75%Hop), and (3) single leg countermovement jump (SLCMJ) and (4) ten-second repeated tuck jump assessment (TJA). Growth rates (cm/month) were also calculated over the course of the study period. Prior to each testing session, a 10-minute standardised warm up was completed consisting of dynamic stretching. Practice trials were provided for each test to ensure participants could competently perform the movements. Three trials of each jump protocol were completed interspersed with one minute of recovery between each, and the best score was used for analysis. In the event that a participant failed to perform a trial in accordance with the protocol specifications, then they performed additional attempts until three completed trials were recorded. Testing was completed by the same research group, at the same venue, on the same day of the week and at the same time on each day. During each test session, tests were completed in a randomised order to reduce the influence of an order effect. Participants were asked to wear the same training kit and footwear at each session, and refrain from strenuous exercise at least 48 hours prior to testing. Participants were also asked to eat according to their normal diet and avoid eating and drinking substances other than water one hour prior to each test session.

1.1.1 Participants

Forty-three elite male youth soccer players (age 13.1 ± 2.2 yr; height 160.1 ± 15.7 cm; body mass 49.4 ± 14.3 kg; maturity offset 0.2 ± 1.9 yr) from the academy of an English Premier League soccer club volunteered to take part in this study. Participants were familiar with regular performance assessments, reported no injuries at the time of testing and were all participating regularly in football training and competitions. All players were participating regularly in football training and competitions in accordance with the regulations set out by the Premier League's Elite Player Performance Plan (EPPP). While specific exposure was not tracked during the study period, participants would have been exposed to weekly volumes of soccer training, competitive match play and physical training in line with the respective age group's contact hours as outlined in the EPPP framework. Parental consent and participant assent were collected prior to the commencement of testing. Ethical approval was granted by the institutional ethics committee in accordance with the declaration of Helsinki.

1.2 Procedures

Single leg hop for distance (SLHD). Hop distances were recorded using a tape measure marked out to a length of 3 m. Players began by standing on the designated test leg with their toe on the marked starting line, the hip of the free leg flexed at 90° to avoid contralateral propulsion, and their hands on their hips. Participants were instructed to hop forward as far as possible, landing on the same leg with the hands remaining on their hips throughout. For each test to be recorded, players had to stick the landing and hold for three seconds without any other body part touching the floor in accordance with previous guidelines (17). The test was performed on both legs and the distance in line with the heel was recorded to the nearest 0.1 cm using a ruler stick to increase accuracy of the measurement. The reliability of maximum hop distance during this test has previously been shown to be acceptable with ICC = 0.91 (20).

Single leg 75% horizontal hop and stick (75%HOP). A tape measure was marked out to a 3 m distance and taped to the floor on a horizontal line with the 0 cm mark positioned in line with the center of a force plate (Pasco, Roseville, California, USA). Due to the size of the force plates, a custom-designed frame built to surround the force plates was used to increase the landing area in the event that participants failed to land in the middle of the plate. Participants began by standing in line with the force plate on the designated test leg, hands on their hips and toe in line with a distance marker on the tape measure representing 75% of their predetermined maximal single leg hop and stick performance. Thus, 75% provided a sufficient challenge to examine the participants landing kinetics while maintaining adequate reliability (26). Participants were instructed to hop forward onto the force plate, landing on the same leg with the hands remaining on their hips throughout. For each test to be recorded, players had to stick the landing and hold for 3 s, remaining as still as possible without any other body part touching the floor. To aid with the performance of this technique, participants were encouraged to "land quietly". Both absolute (N) and relative (N/kg) peak vertical landing force (PF) was measured for each jump. All data were recorded at a sampling rate of 1,000 Hz and filtered through a fourth-order Butterworth filter at a cut-off frequency of 18 Hz. Reliability of PF during the 75%HOP protocol has been reported as acceptable (mean coefficient of variation = 10.2%) in male youth soccer players (33).

Single leg countermovement jump (SLCMJ). Participants stood atop the force plate (Pasco, Roseville, California, USA) in a unilateral stance with their hands on their hips and the opposite hip flexed at 90° to ensure minimal contributions from the contralateral leg. Instructions were to jump as high as possible using a countermovement by dropping to a self-selected depth and then immediately triple extending at the ankle, knee, and hip in an explosive concentric action. On ground contact, subjects were required to stick the landing and hold for a period of 5 seconds remaining as still as possible. Bending of the knees while airborne was not permitted, and hands remained in contact with hips throughout the test (15). The sampling rate and filtering techniques were the same as used in the 75%HOP protocol, and both absolute (N) and relative (N/kg) peak vertical landing force (PF) were measured for each jump. The reliability of PF during the SLCMJ protocol has been reported as acceptable (mean coefficient of variation = 10.1%) in male youth soccer players (33).

Tuck jump assessment (TJA). Participants stood on two vertical strips of tape which were 35 cm apart and connected by a horizontal line forming a H-Shape to ensure correct foot positioning (28). The test began by performing a countermovement followed by a jump in a vertical direction as high as possible while simultaneously pulling their knees up towards their chest. Tuck jumps were then repeatedly performed in place for a period of 10 seconds. One trial of the TJA protocol was performed. Instructions were to jump as high as possible, land in the same footprint with each jump and to minimize ground contact time (28). Two-dimensional (2D) video cameras were used to capture the test with all trials retrospectively assessed. Kinematic data were collected at 50 Hz using a high-definition video camera (Samsung, New Jersey, USA) positioned in the frontal plane at a height 0.70 m, and a triangulated distance of five meters from the center of the capture area. To allow visible tracking of the knees, subjects were required to wear shorts with a line at approximately mid-thigh. In accordance with previous reliability data (34), lower extremity knee valgus was the only variable evaluated within each trial. In accordance with previous research, knee valgus was scored as follows: 0 (*no valgus*), 1 (*minor valgus*), 2 (*moderate valgus*), 3 (*severe valgus*) (35). Deficits were recorded if the respective knee valgus score was present on two or more repetitions (29), and the maximum score was used for analysis. The same rater marked and recorded each trial to maximize intra-rater consistency. Research has shown that knee valgus during the TJA has substantial agreement (kappa coefficient = 0.67-0.78) in pre- and post-PHV male soccer players, respectively (34).

Symmetry calculation

For all jump protocols, inter-limb asymmetry was calculated as the percentage difference between the highest versus lowest performing limb, with the value obtained expressed as the absolute percentage of performance

Table 1. Descriptive statistics (mean ± *sd*) for anthropometric variables across each test session throughout the season

Test Variable	**PRE**	**MID**	**END**	**Between Test Session effect size (*d* ± 95% CI)**		
				PRE-MID	MID-END	PRE-END
Height (cm)	160.1 ± 15.5	162.2 ± 15.4	163.7 ± 14.9	0.15 (-0.28-0.57)*	0.10 (-0.33-0.52)*	0.34 (-0.09-0.76)**
Mass (kg)	49.4 ± 14.3	52.1 ± 14.7	53.6 ± 14.3	0.19 (-0.23-0.61)**	0.10 (-0.32-0.53)**	0.29 (-0.13-0.72)**
Leg Length (cm)	83.0 ± 9.2	85.7 ± 8.4	86.5 ± 8.1	0.32 (-0.11 -0.74)**	0.09 (-0.33-0.52)*	0.40 (-0.03-0.82)**

* Significant at the level of $p < 0.05$
** Significant at the level of $p < 0.01$

Symmetry % = (lowest performing limb/strongest performing limb)*100

Table 2. Descriptive statistics (mean ± *sd*) for each test protocol across each test session throughout the season

Test Variable	**PRE**	**MID**	**END**	**Between test session effect size (*d* ± 95%CI)**		
				PRE-MID	MID-END	PRE-END
SLHD R (m)	1.43 ± 0.26	1.47 ± 0.25	1.52 ± 0.25	0.16 (-0.26-0.58)	0.27 (-0.15-0.70)*	0.43 (0.0-0.85)**
SLHD L (m)	1.42 ± 0.26	1.42 ± 0.24	1.51 ± 0.24	0.04 (-0.38-0.46)	0.35 (-0.08-0.78)**	0.38 (-0.05-0.81)**
SLHD sym (%)	92.9 ± 4.4	92.9 ± 5.9	95.8 ± 3.1	0.00 (-0.42-0.42)	0.70 (0.25-1.12)*	0.67 (0.23-1.10)*
75%HOP PF R (N)	1690 ± 490	1695 ± 543	1753 ± 577	-0.03 (-0.39-0.46)	0.12 (-0.30-0.54)	0.09 (-0.33-0.51)
75%HOP PF L (N)	1619 ± 430	1637 ± 494	1761 ± 496	0.06 (-0.36-0.48)	0.25 (-0.18-0.67)**	0.32 (-0.11-0.75)**
75%HOP PF R (N/kg)	34.71 ± 6.3	32.67 ± 5.4	32.79 ± 6.5	-0.39 (-0.81-0.04)	0.03 (-0.40-0.45)	-0.34 (-0.77-0.15)
75%HOP PF L (N/kg)	33.49 ± 5.9	31.77 ± 5.9	33.17 ± 5.0	-0.27 (-0.70-0.15)	0.23 (-0.20-0.65)	-0.05 (-0.37-0.48)
75%HOP PF sym (%)	86.5 ± 9.1	89.4 ± 7.5	90.6 ± 7.5	0.36 (-0.07-0.79)	0.09 (-0.33-0.52)	0.43 (0.00-0.85)
SLCMJ PF R (N)	1550 ± 495	1605 ± 434	1668 ± 433	0.11 (-0.31-0.54)	0.17 (-0.26-0.59)	0.27 (-0.15-0.70)*
SLCMJ PF L (N)	1286 ± 257	1615 ± 487	1829 ± 502	0.73 (0.28-1.16)**	0.43 (-0.01-0.85)**	1.21 (0.74-1.65)**
SLCMJ PF R (N/kg)	31.41 ± 4.9	31.15 ± 4.4	31.42 ± 4.1	-0.02 (-0.45-0.40)	0.05 (-0.37-0.47)	0.03 (-0.40-0.45)
SLCMJ PF L (N/kg)	27.10 ± 4.9	31.16 ± 5.0	34.32 ± 4.6	0.75 (0.30-1.19)**	0.60 (0.16-1.04)**	1.26 (0.79-1.72)**
SLCMJ PF sym (%)	81.9 ± 11.2	90.1 ± 7.3	89.4 ± 7.9	0.85 (0.39-1.29)	-0.06 (-0.49-0.38)	0.70 (0.25-1.13)

* Significant at the level of $p < 0.05$
** Significant at the level of $p < 0.01$
SLHD = single leg hop for distance; 75%HOP = Single leg 75% horizontal hop and stick; SLCMJ = single leg countermovement jump; PF = peak vertical landing force; sym = symmetry; R = right; L = left

achieved using the highest performing limb as the reference. The equation has previously been used to determine inter-limb symmetry in young male soccer players (39), and is presented below:

1.3 Statistical analyses

Descriptive statistics for each variable were determined at each test session throughout the study period (PRE/MID/END). Normality of data were assessed using the Shapiro-Wilk test. Repeated measures analysis of variance (ANOVA) was used to test for significant differences between each test session. Sphericity of the data was checked by Mauchly's statistic, and where violated the Greenhouse-Geiser adjustment was applied. Bonferroni and Games-Howell post-hoc tests were used to identify the origin of any significant differences between test sessions when equal variance was or was not assumed. The magnitudes of change between test sessions for all anthropometric and neuromuscular control variables were calculated using Cohen's effect statistic (*d*) (11), and interpreted according to the following thresholds: <0.2 (trivial), 0.20-0.59 (small), 0.60-1.19 (moderate), 1.20-1.99 (large), 2.00-3.99 (very large) and >4.00 (extremely large) (22). Pearson correlation coefficients were also used to examine the relationships between changes in anthropometrics and each outcome measure from PRE to END, with the following classifications used to interpret the strength of associations: < 0.2 trivial; 0.2-0.5 small; 0.5-0.8 moderate; > 0.8 large (11). The level of statistical significance was set at alpha level $p < 0.05$. All statistical analysis was performed using SPSS® (V.21. Chicago Illinois).

2. Results

Descriptive statistics for each test session (PRE, MID, END) and between test session effect sizes are displayed in *table 1* and *table 2* for anthropometric and neuromuscular control variables, respectively. All anthropometric variables showed small, significant increases at each test session throughout the season; whereas, a less consistent pattern was reported for the neuromuscular control tests. In the SLCMJ, significant, moderate to large increases were shown in both absolute and relative peak vertical landing forces in the left leg between each test session throughout the season. Absolute peak vertical landing force on the left leg during the 75%HOP also increased throughout the season, with small, significant increases reported between PRE-END and MID-END. SLHD increased significantly in both legs, with small changes evident between both PRE-END and MID-END. SLHD symmetry showed a significant, moderate increase throughout the season; while increases in peak vertical landing force symmetry in both the 75% hop and SLCMJ were also observed, although these did not reach statistical significance. All other force-related variables showed trivial to moderate, non-significant changes across the course of the season.

In the assessment of knee valgus during the TJA, scores ranged from 0 – 3 across all players at each test session. Knee valgus mode scores were 2 for both limbs at PRE, with the right knee valgus reducing to 1 at MID. No further changes in knee valgus mode score were observed for either limb from MID-END, with the mode score remaining at 1 and 2 for the right and left leg respectively.

Except for the asymmetry scores for each protocol, all variables recorded at each test session showed moderate to very large relationships with height, mass or leg length ($r = 0.55 - 0.99$; $p < 0.01$). While some significant correlations were reported between changes in anthropometrics (including growth rate) and changes in each neuromuscular control test across the season, the correlations for these relationships were consistently small ($r < 0.50$).

3. Discussion

The current study assessed the seasonal variation in performance of a field-based neuromuscular control screening battery in elite male youth soccer players. Expectedly, results showed that height, weight and leg length increased throughout the season; whereas, changes in neuromuscular control were more susceptible to seasonal variation. Increased peak vertical landing forces were displayed throughout the season, especially in the left leg, in addition to greater distances achieved during the SLHD. Relationships between changes in anthropometrics and changes in neuromuscular control were predominantly small and non-significant.

Both absolute and relative peak landing forces during the SLCMJ showed significant, moderate to large increases between each test session throughout the season. Absolute peak landing force in the left leg during the 75%HOP also showed small, significant increases during the season. Of note, the magnitudes of change in absolute peak force during both protocols were greater than the typical errors previously reported for these variables in the literature (33), thereby indicating the presence of meaningful change. Intuitively, increases in body mass could be deemed a contributing factor, especially for absolute values; however, relative peak landing force during the SLCMJ increased significantly (moderate to large effects) on the left leg at each testing session across the season, while weak relationships were also shown between changes in landing force and changes in body mass (r = -0.19) . Therefore, our data indicate that other factors could be influencing these changes. For example, the increases shown in SLHD across the study period reflects improved jumping performance, and the resultant increase in centre of mass displacement during any jump task will further challenge dynamic stability and dissipation of landing forces (18). Thus, our findings could reflect a developmental lag over the course of the season in the attenuation of ground reaction forces upon landing, in-spite of improvements in propulsive jump performance. Ultimately, this would indicate that players are enhancing their ability to express explosive propulsive force when jumping, without simultaneously developing their ability to safely absorb forces upon landing. Similarly, these findings may attest to the fact that adolescents can experience a temporary 'awkwardness' in their motor control strategies (38), which is often highlighted during landing-based activities. Cumulatively, these interpretations would highlight the need for in-season monitoring and year-round training interventions that include a focus on neuromuscular control during single leg jump-landing tasks.

There is a paucity of literature that has examined seasonal changes in landing forces, and to the authors' knowledge no data are available for male youth soccer players. Available literature has shown that fatigue may induce changes in drop jump performance (40) and biomechanical and neuromuscular function such as muscle activation sequences, kinetics and kinematics (31). While not representative of long-term changes, the acute effects of soccer-specific exercise on landing forces have been measured in male youth soccer players (30). Expectedly, reductions in jump height were present during squat jumps, countermovement jumps and drop jumps; however, impact forces during the drop jumps were the only landing force variables to show a significant change in response to a 42-minute soccer simulated treadmill protocol. The current study used single leg tasks, which are arguably more representative of the loading patterns experienced during game play, and thus may also be more sensitive in identifying fatigue than bilateral jump-landing variations. Increased impact forces, greater leg length and larger body mass are associated with decrements in landing performance; therefore, the interaction of these variables might be of relevance for identifying injury risk, especially when accounting for maturation and accumulated fatigue.

The results of the current study showed that SLHD increased significantly throughout the season on both the right and left legs. These performance increases are consistent with previous research in elite male youth soccer players, whereby sprint and jump performances improved consistently over a three year period assessed at 6-month intervals (44). Conversely, in professional male soccer players, countermovement jump height has been shown to peak at mid-season (6), followed by a general plateau towards the end of the season (5, 6); potentially explained by an accumulation of fatigue from a more congested match schedule and reduced opportunities to train in the latter part of the season in older players. The extent to which growth, maturation and on-going training facilitated adaptations to jump performance in the young players in the current study is unclear; however, it is possible that the interaction of these factors could explain the continued improvements in function in spite of the expected accumulation of fatigue.

While research has examined the effects of in-season neuromuscular training on TJA performance in adolescent females (23), no corresponding literature has investigated seasonal variation in knee valgus in male athletes during the TJA. Absolute knee valgus, a recognised risk factor for severe injury, reduced from those reported during pre-season screening on the right leg, and this remained consistent towards the end of season testing. Previous literature has indicated that due to the typical error associated with the TJA, a change in score > 1 is required to reliably state that a meaningful change has occurred (34). Data showed that knee valgus remained consistently at a 'moderate valgus' level in the left leg throughout the season, with a mode score of 2 reported at each test session. While speculative, the combination of a similar valgus angle, significant increases in SLCMJ and 75%HOP landing forces on the left leg (which for most players was their dominant stance and jumping limb) and the increased limb length resulting from growth, will have likely increased joint moments around the knee. Thus, it is conceivable that there was an overall reduction in dynamic frontal plane stabilisation upon ground contact over the course of the season (45), placing the lower limb at an increased risk of injury.

Despite the SLHD being the only task to show significant changes in symmetry throughout the season, there was a general trend for increases in symmetry across all tests. This finding is unexpected due to the accumulation of sport-specific training and competition that could result in the emergence of increased leg dominance due to the repeated exposure to kicking action on a preferred limb (13). However, asymmetry has been reported to reduce with a greater training age in professional soccer players (16), which may in part explain the findings of the current study. Research has also indicated that asymmetry is best analysed on an individual basis due to the large differences in magnitude and direction across tests (2). Thus, longitudinal tracking of asymmetry could be recommended to identify individuals who demonstrate large changes in these variables due to its reported associations with injury in elite male youth soccer players (12, 36).

Relationships between the change in anthropometrics (including growth rate) and change in each neuromuscular control variable were consistently small ($r < 0.50$). This suggests that alterations in performance were weakly related to anthropometric changes and thus, other underlying factors need to be considered to explain seasonal variations in neuromuscular control. The lack of relationship of injury risk proliferation and growth are consistent with previous literature assessing seasonal changes in performance measures with elite male youth soccer players (19, 44). For example, longitudinal tracking of sprint and jumping tasks reported weak associations between changes in body size and performance (44); while, despite significant correlations being reported between anthropometrics and changes in jumping performance in youth soccer players (19), the strength of these relationships were only weak to moderate ($r < 0.5$).

Certain limitations should be noted when interpreting the findings of the current study. Due to the challenges associated with capturing longitudinal data, the eventual sample size restricted sub-dividing the cohort into maturity groupings to examine the effect of maturation on seasonal variation in neuromuscular control. However, relationships between the change in anthropometrics (including growth rate) and the change in neuromuscular control variables were determined, with the stated associations deemed small; thus, indicating that other factors were likely contributing to the observed changes. While a number of the reported neuromuscular control variables failed to show any significant change throughout the course of the season; the magnitudes of change in those variables that did show significant changes between test sessions were greater than previously reported typical errors. Previous research has shown that peak landing forces were significantly associated with anterior cruciate ligament injury risk (27), which justifies its inclusion as a key outcome variable in the current study. However, future research would benefit from examining how both kinetic and kinematic variables potentially change over the course of competitive seasons. Finally, injuries were not recorded during the season and residual deficits may be present in cases of incomplete rehabilitation; therefore, future research may also wish to examine how neuromuscular control changes in response to lower limb injuries.

4. Conclusions

This study aimed to examine the seasonal variation for a range of field-based neuromuscular control protocols in elite male youth soccer players. The findings suggest that neuromuscular control is reduced over the course of a competitive season, most notably via increases in peak vertical landing forces, which could increase the relative risk of lower extremity injury. This information can be used to guide targeted preparatory and in-season training to address potential lower limb injury risk factors. The data can also be used to help identify meaningful changes following a training intervention and/or potential alterations in injury risk factors throughout the course of a season.

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