Title: The effects of small-sided game variation on changes in hamstring strength

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ABSTRACT

Small-sided games are commonly used by soccer practitioners to condition players. This form of exercise can result in fatigue, potentially exposing the muscle to injury risk. The purpose of this study was to determine the effects of small sided game (SSG) variations on hamstring torque in semi-professional soccer players. In a counter-balanced cross-over design, 10 male semi-professional soccer players took part in both small relative area (3 *vs*. 3; 300 m^2) and large relative area (4 *vs.* 4; 1000m^2) SSGs. The games comprised 6 x 4 min bouts, with 90 s recovery. Both movement and heart rate (HR) responses were monitored by Global Positioning Systems (GPS) and hamstring isometric torque was measured pre- and post-training using a NordBord®. There were differences ($P < 0.05$) between the small and large relative area games for peak hamstring force decrement (5.78 N and -13.62 N, respectively) and mean hamstring force decrement at 90° (11.11 N and - 4.78 N, respectively). The number of accelerations were related to ($r = 0.46$, $P = 0.039$) reduced hamstring peak torque at 90°. In conclusion, larger relative area SSGs elicited the greatest internal and external loads, resulting in decrements in hamstring force. The number of accelerations performed in the session increases the likelihood of hamstring fatigue and can be controlled with the relative pitch area.

Key words: torque, fatigue; global positioning systems; soccer

INTROUDCTION

To prepare for the physical and physiological demands of competition, soccer players must adopt specific training modalities. SSGs are frequently used by coaches to train the technical abilities of players, whilst also developing aerobic capacity using sport-specific movement patterns (34, 20). Despite the regularity of this training modality, no study to date has investigated the potentially fatiguing effects of SSG on muscle function, particularly that of the hamstring group. This is important since SSG are used throughout a training week and such information would inform their incorporation into the micro-cycle of soccer players.

Hamstring function is integral to the performance of soccer-specific movement skills, such as decelerating, jump landing and changes of direction (COD), where the hamstrings provide stability to the knee joint (12, 14, 32, 29). During kicking actions, the hamstrings contract concentrically at the start of the backswing on the striking leg, and eccentrically activate to decelerate the lower limb to control the follow-through (31, 8). These actions, among others, will cumulatively tax the hamstring musculature and are likely to lead to fatigue over a prolonged period. This has connotations for injury risk, with over 47% of hamstring strains occurring during competitive soccer matches in the final 15-min of each half (17). Furthermore, fatigue-induced reductions in hamstring muscle strength have been shown to effect cutting and landing mechanics (29) and this may heighten the risk of knee injury.

SSGs of different sizes are often used by coaches to prepare players for competition in a sports-specific manner. The format of the game can be manipulated to increase the number of players, reduce pitch size or imbalance the ratio of players participating (19). For example, the physiological response to smaller area SSGs are typically greater, with blood lactate concentration and increased heart rate compared to larger versions, yet the kinematic demands are notably different (20). Furthermore, coaches can choose to place conditions on the game, such as implementing offside rules and possession constraints or by restricting the number of ball touches (2). Different types of SSG alter the external demands of the activity, with larger absolute pitch sizes producing greater peak speeds compared to smaller areas (19). Increasing the relative pitch area per player also increases the amount of distance travelled at high-speed (>18 km/h) (20). It is thought by reducing the relative pitch area, players will be encouraged to accelerate and decelerate more frequently, thus increasing distance travelled at lower speeds (<18 km/h). Fatigue is task-specific (38), meaning that the nature of the tasks performed will determine the way in which fatigue is expressed. For example, sprinting at higher velocities is associated with greater hamstring activation, as this muscle group eccentrically governs hip flexion and knee extension during the swing phase (37). Given the multifaceted nature of soccer performance, fatigue is likely to manifest in various ways. Therefore the choice of SSG variation, in particular the pitch size, will change the demands imposed on players and alter the expression of fatigue. However, there are no studies that have systematically examined this hypothesis in relation to hamstring isometric function changes induced by SSG.

This study investigated the differences in the external demands of two different SSG using 'small' or 'large' relative pitch areas and the relationship to hamstring strength. It was hypothesised that the larger relative pitch sizes would elicit higher speed movements (peak speeds and distance at high-speed thresholds) and greater reductions in hamstring force compared to the smaller relative pitch size.

METHODS

Experimental Approach to the Problem

Participants performed one familiarisation session, where all tests were practiced until players were technically competent. A YOYO-Intermittent Recovery Level 1 test (2) was also performed at this time to obtain their end stage speed, which was later used to determine a high-speed threshold. A total of four testing sessions were completed on the same day and time across the subsequent four weeks. A standardized warm up protocol was performed prior to each session. In a counterbalanced manner, the players took part in small relative area SSGs (20 m x 15 m) for two of the four weeks and large relative area SSGs (40 m x 25 m) for the other two sessions. Each player was monitored with a GPS device and a synchronised HR monitor. The SSGs were performed on the same grass pitch in dry, calm weather conditions. In addition, isometric hamstring strength was measured before and after each SSG.

Subjects

10 male semi-professional soccer players (age 23 ± 5 years; stature 178 ± 7 cm; body mass 73.4 ± 10.6 kg) provided written informed consent to participate in this study, which was given institutional ethical approval. Players were required to be free from injury during the previous two months. The players were payed to train twice per week and compete at the weekend in one match. Given the typical effect sizes (Cohen's d = 1.0 – 1.5, (25) reported using soccer-specific performance to induce hamstring fatigue, G*Power (Version 3.0.10; Universität Düsseldorf, Germany) was used to calculate *a-priori* sample size of 7, which was sufficient to identify differences between groups with a statistical power of 0.90. We recruited 10 players to account for drop-out, which did not occur. This provided a statistical power of 0.95.

Procedures

The players were selected to ensure that each team had an equal distribution of players from different skill rankings, which was subjectively determined *a-priori* with the coaching staff at the club. The smaller area SSG comprised three players on each team (3 *vs.* 3), performed in an absolute area of 300 m^2, equating to a relative playing area of 50 m^2. The large SSG included four players per team (4 *vs.* 4) in an absolute area of 1000 m^2, equating to a relative playing area of 125 m^2. To ensure all players were active at the same time, multiple SSGs were played concurrently, meaning that some additional players from the squad were included to make up the numbers. However, there was always a balance of players under analysis in each team. There was a goal at each end of the pitch and no goalkeepers. The pitch size was measured using a 30 m tape and was marked out by cones (small pitch = 20 m x 15 m; large pitch = 40 m x 25 m). Six 4-min SSGs were played by each player in one testing session (24-min), each interspersed by 90-s rest.

The point of the SSGs was to score more goals than the opposition. Additional rules were applied to each game to facilitate the players' participation and maintain motivation to participate. For three of the six SSGs, players were instructed that all of their team must be in the attacking half for a goal to stand. The rule for the following three SSGs were based on points system, whereby points were awarded for goals scored, depending on the area where the ball was won back from the opposing team. To achieve this, the pitch was divided into thirds, with three points awarded for scoring a goal after winning the ball in the oppositions attacking third; two points awarded for winning the ball in the middle third and one point for winning back in your own teams defensive third. Once a goal was scored, play was temporarily stopped while the ball was retrieved from investigators at pitch-side. Play was restarted from the conceding team's goal line. Four investigators were positioned evenly around the pitch side with spare balls, so that play could be restarted immediately if the ball was to leave the designated area. All players were reminded verbally to keep themselves within the designated playing area. Players wore the same standard squad uniform (kit and footwear) for each session.

An isometric hamstring strength test was performed in the 7-min before and after each testing session (i.e. SSG type). Isometric hamstring function can be impaired by performing running-based tasks, such as soccer performance (24, 25). The isometric hamstring test is sufficiently reliable to detect a change (25) and provided a measure of hamstring strength that had potential to change as fatigue ensued. The order that players were tested, before and after each game, remained consistent throughout all sessions. The isometric hamstring strength test was performed on a Nordbord (Vald Performance, Brisbane, Australia), with the players' dominant limb assessed, which was based on the players' preferred kicking side, at 90° and 30° knee flexion (KF). Testing was performed on the dominant limbs so that players could be measured as soon as possible after the SSG, without time for recovery. These joint angles were specifically selected because the biceps femoris musculature is maximally activated between 15° and 30° of KF, while the semi-membranosus and semitendinosus musculature are maximally activated between 90° and 105° KF (30). Players positioned themselves on the Nordbord, with their knee on the pad, foot in the ankle strap and hands out in front of them. The ankle position was checked to ensure the strap was in a completely vertical position. The hips and knees of the participants were flexed to the relevant angle, as determined by a goniometer (Lafayette Instrument Company, USA). Knee position was recorded by referencing the number on the Nordbord mat, which was maintained throughout the four weeks of testing. Players were instructed to 'pull their heel towards the ceiling' with as much force as possible, to produce an isometric contraction against the ankle straps. The participants were given a countdown of '3-2-1-go', after which they contracted maximally for 3-s until the investigator instructed them to stop. This was repeated twice, with 20-s rest between efforts at both 90° and 30° KF and the highest force (N) and mean force of both trials being recorded on the Nordbord dashboard software (version 1.3.1, Vald Performance, Brisbane, Australia). The final analysis was performed on the change in peak (peak-Force) or mean (mean-Force) hamstring force from pre- to post-trial. A standardised non-specific verbal cue was provided during each contraction but no knowledge of performance was provided. An average of the hamstring testing results for the two small area SSGs and two large area SSGs were calculated. The inter-day reliability of the Nordbord, expressed as the coefficient of variation (CV%), for measuring isometric hamstring force production was 4.2% to 6.4 % for 90° and 30° knee flexion, respectively.

Player movements were recorded during the SSGs using portable GPS devices (StatSports, Apex, Co. Down, Northern Ireland), which sampled at 18 Hz. The GPS unit is also fitted with a 6 g accelerometer (100 Hz), gyroscope, magnetometer and high-impact accelerator. The GPS units were simultaneously activated and left for 15-min prior to testing. The typical number of available satellite signals ranged between 16 and 20 with a mean horizontal dilution of position (HDOP) of 0.54 ± 0.20 throughout the testing period. Players were given an individual GPS unit and HR monitor (Polar, T31 Oy, Kempele, Finland) to record, which remained with them for the duration of the study. The units were placed inside a tightly fitted vest from the manufacturer and positioned between the player's scapulae. Distance covered (m) in six separate speed zones was reported, based on the players' individual end-test speed during the YOYO-Intermittent Recovery Level 1 test, which was measured by the GPS unit. The mean end stage speed (maximum speed; MS) of the players was 17.85 ± 1.16 km/h, equating to a mean end stage score of 20.7. The zones used were: (Zone 1 (< 25% of MS); Zone 2 (25-50% MS); Zone 3 (50-75% of MS); Zone 4 (75-100% of MS); Zone 5 (100-125% of MS); Zone 6 (≥ 125% of MS). This approach was deemed appropriate based on the physiological relevance of the speed at the end of the test and its similarity to previous approaches (38). Other collected external workload variables were: total distance covered (m), MS (km/h), total number of accelerations >1 $m.s^{-2}$ and decelerations >-1 $m.s^{-2}$; and mean metabolic power (W/kg). All analyses were performed in the StatSports Apex software (version 2.1.0.4, StatSports, Apex, Co. Down, Northern Ireland). The reliability of the device was evaluated *a-priori* using the same group of 10 players, performing a YOYO-IR1 test one week apart. The CV for all variables was: total distance = 0.41%; total accelerations = 4.34%, total decelerations = 2.83%. We have previously conducted in-house reliability testing of 10 m and 20 m peak sprint speed on a separate group of players, which demonstrated CVs of 6.9% and 4.1%, respectively.

Statistical analysis

A two-way repeated measures analysis of variance (ANOVA) was used to evaluate the effects of condition (small or large SSG) and knee angle (30° and 90°) on the change from pre to post-SSG (peak-Force and mean-Force). If tests of Sphericity were violated in the ANOVA, a Greenhouse-Giesser correction was used. In the event a statistical difference was identified, a *post-hoc* Bonferroni test was used to identify differences. Differences between GPS variables between small or large SSGs were assessed using a paired *t*-test. Effect sizes (*d*) were also calculated for pairwise comparisons, defined as: trivial = 0.2; small = 0.21–0.6; moderate = 0.61–1.2; large = 1.21–1.99; very large > 2.0 (5). Bivariate correlations (Pearson's *r*) were used to assess the relationships between movement variables and Force. For the purpose of the correlational analysis, the speed zones were collapsed into low-velocity (zones 1-4) and high- velocity (zones 5-6). The strength of the relationships were considered as: < 0.3 = weak, 0.3-0.5 = moderate; > 0.5 = strong (10). An alpha level of $P < 0.05$ was set for all analyses. Statistical analysis was conducted through IBM SPSS (Software V22.0, IBM, New York, USA).

Results

Descriptive statistics for all GPS metrics measured during both types of SSG are presented in Table 1. Total distance covered, distance covered in zones 3, 4, 5 and 6, MS, total amount of accelerations, total amount of decelerations, metabolic power and both mean and maximum HR were significantly higher in the larger SSG (P < 0.001). However, there were no meaningful differences shown for distance covered in speed zones 1 or 2 between games.

Table 1. Movement and HR measurements during small and large relative area games (mean ± s).

	Small	Large	***P***	**Effect size (*d*)**
Total distance (m)	2727 ± 320	3099 ± 297	0.001	1.50
Distance in zone 1 (m)	784 ± 137	757 ± 145	0.235	0.18
Distance in zone 2 (m)	918 ± 128	937 ± 97	0.294	0.11
Distance in zone 3 (m)	675 ± 205	817 ± 187	0.001	0.62
Distance in zone 4 (m)	280 ± 72	424 ± 88	0.001	1.62
Distance in zone 5 (m)	67 ± 34	136 ± 42	0.001	1.76
Distance in zone 6 (m)	4 ± 8	28 ± 26	0.001	1.19
Maximum speed (km/h)	23.7 ± 1.8	26.1 ± 2.0	0.001	1.29
Total accelerations (>1 m/s^2)	294 ± 40	280 ± 20	0.004	0.58
Total decelerations (> -1 m/s^2)	273 ± 47	261 ± 25	0.048	0.42
Metabolic power (W/kg)	8.1 ± 1	8.7 ± 0.9	0.003	0.38

Maximum HR (b/min)	188	±	28	194	±	13	0.001	0.27
Mean HR (b/min)	157	±	25	163	±	16	0.003	0.26

Mean and SD of peak-Force and mean-Force across both SSGs at 90° knee angles are presented in Figure 1 and 2, respectively. An interaction was found between SSG type and knee angle for peak-Force ($F_{(1, 156)}$ = 5.431, P = 0.021) and mean-Force ($F_{(1,156)}$ = 4.750, P = 0.031). *Post-hoc* tests showed pairwise differences between small SSG and large SSG for the peak (P = 0.037 and d = 0.60) and mean (P = 0.044 and d = 0.51) decrements in 90° knee angle force.

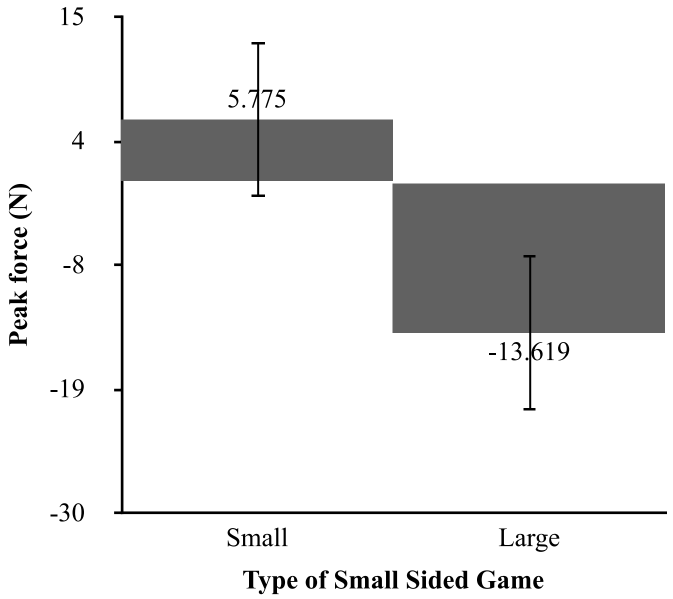

Figure 1. Peak pre-post changes in 90° hamstring force (mean ± SD) in small or large relative area SSG variations. * = significant difference between SSG types (P < 0.05).

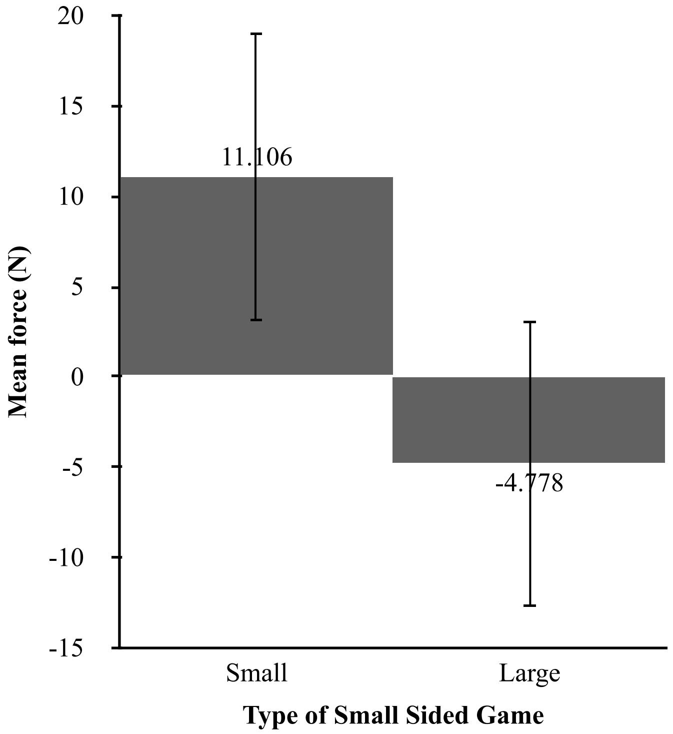

Figure 2. Mean pre-post changes in 90° hamstring force (mean ± SD) in small or large relative area SSG variations. * = significant difference between SSG types ($P < 0.05$).

There was a relationship (r = 0.46, P = 0.039) between the number of accelerations in both SSGs and peak-Force at a knee angle of 90º. No other relationships were found (Table 2).

Table 2. Relationships (r) between movement variables and hamstring force delta

	Distance (m)	**Low velocity distance (m)**	**High velocity distance (m)**	**Max. sprint speed (km/h)**	**Accelerations (*n*)**	**Decelerations (*n*)**	**Metabolic power (W/kg)**
Peak force 90° (N)	0.09	0.34	0.21	-0.25	0.46*	0.37	0.05
Peak force 30° (N)	0.01	0.12	-0.16	-0.80	0.22	0.25	0.04
Mean force 90° (N)	0.03	0.34	0.10	0.01	0.22	0.30	-0.03
Mean force 30° (N)	0.05	0.14	-0.10	-0.06	0.11	0.26	-0.08

*Note: * = significant relationship (P < 0.05)*

DISCUSSION

The primary finding indicates that SSGs with larger relative pitch area induce the greatest reductions in peak and mean isometric force of the hamstring. The larger SSG increased the relative pitch area per player, meaning that there was a greater amount of pitch space available for higher speed efforts. GPS analysis demonstrated greater movement demands in the larger relative area SSG, particularly in high-speed categories and peak speed (Table 1). There were indications of hamstring force reductions (fatigue) in both conditions but notably greater fatigue occurred in the 90˚ knee position, which we speculatively suggest indicates that the hamstring is more sensitive to fatigue when the semi-membranous and semitendinosus muscle groups are predominantly engaged (30).

The fatigue (9.8% reduction) induced by both SSG variants is consistent with the findings of others (33), where a treadmill-based, 90-min soccer simulation reduced the strength of the hamstrings by 15.3% between baseline and half-time or baseline and full-time. (13) also identified 23.9% reductions in hamstring isometric force during and after a treadmill-based soccer simulation. The longer duration of these simulations most likely accounts for the slightly greater reductions in hamstring force than found herein. Significant deficits in eccentric and concentric strength of the hamstring have also been reported following repeat sprint running of shorter duration, yet higher intensity (36), indicating the susceptibility of the hamstring muscle group to fatigue during different modes of activity. However, treadmill-based protocols do not account for COD and consistent accelerating and decelerating movements that occur during soccer-specific activity. For example, professional players complete 727 ± 203 swerves and turns within a single match (7). The Loughborough Intermittent Shuttle TEST (LIST) has also been used to induce match-like fatigue in soccer players, demonstrating reductions in eccentric hamstring force (9). However, the LIST is a linear protocol and also doesn't account for many soccer-specific actions. Therefore, soccer matches (25, 24) or more ecologically valid soccer simulations (4) have been used to induce fatigue, demonstrating a range of functional impairments. For example, (35) demonstrated reduced hip flexion and knee extension angles during sprinting movements, as well as decreased stride length at the end of each half of the SAFT90. The authors attributed these results to a reduction in hamstring length under fatigue. The same authors also showed that eccentric peak force of the hamstrings was reduced by 16.8% across the course of an identical soccer simulation (35). Collectively, these impairments may increase the risk of hamstring injury, particularly during high speed movements, due to a reduced ability to effectively decelerate the high segmental velocity of the lower-limb.

Consistent with the conclusions of previous investigations, the current study showed that isometric force was reduced more markedly at the larger knee angles. A fatigue-induced reduction in hamstring strength, particularly with the knee flexed at 90˚, impairs the ability to decelerate the forward motion of the thigh and lower-leg in the swing phase (35). Whilst we appreciate that eccentric hamstring strength would be a more suitable indication of this, the loss in isometric force production is likely to be related (24). Furthermore, hamstring fatigue is associated with a loss of motor activity in the local musculature and can also affect mechanical knee stability (26, 16) during soccer-type activities, such as jump landing (39) or COD (14). Based on these observations, reduced hamstring force is likely to predispose the player to heightened risk of injury during high-velocity movements (such as those observed in the large SSGs) or during other soccer-type activities. The fatigue observed in the hamstring over a brief SSG is, therefore, similar to longer soccer simulations (33) and increases susceptibility to hamstring injury. Indeed, hamstring injuries are more common during the last third of the first and second halves of soccer match-play (41) and, based on the current data, the same risks are posed during training games.

A positive relationship was found between the number of accelerations and the change in hamstring peak force at 90º (Table 2). This indicates that repeated accelerations are partly responsible for the decline in hamstring force. There is typically a knee flexor moment of greater magnitude during early acceleration phases of a sprint (40) and the knee joint is considerably more involved in concentric activity during the early stages of acceleration. This places greater demand on the hamstring muscle group during acceleration (6). Therefore, these findings suggest that manipulation of SSGs based on pitch area is one way to alter the number of accelerations > 1 $m \cdot s^{-2}$, thus changing the work performed by the hamstrings and subsequent hamstring fatigue. However, a surprising finding of the current study was that the smaller SSG induced lower reductions in hamstring force, despite having a higher number of accelerations. Therefore, the number of accelerations is not the only factor responsible for hamstring force reductions and that this might be attributed to a combination of other factors. The non-significant, yet small, relationships between low velocity distance, decelerations and changes in hamstring force at 90° of knee flexion provides some evidence of this.

The present study demonstrated a significantly higher amount of decelerations in the smaller SSG compared to the larger format. These findings contradict that of (21) who reported that absolute pitch size, relative pitch area per player and number of players, were related to both the amount of accelerations and decelerations. These differences could, in part, be due to the type of conditions and the smaller number (3 *vs*. 3) of players in the current study. The smaller area game induced more accelerations compared to the larger area game, thus, necessitating more frequent decelerations. Consistent decelerations during locomotion require larger braking forces than accelerative actions, and are produced predominantly via eccentric muscle contractions (21). The athlete must absorb force, primarily through flexion of the ankle, knee, and hip, placing high eccentric demand on the quadriceps, hamstrings and gastrocnemius (18). Muscle damage occurs when the muscle involved is lengthened under high tension, causing disturbance to sarcomeres (27) and reductions in force production capabilities (28). With this in mind, it was somewhat surprising that the smaller SSG did not produce the same level of force reduction. However, this is most likely explained by the higher running speeds performed in the larger SSG, which require a higher magnitude of deceleration, rather than frequency.

A limitation of this study is that only two hamstring movements were performed, under one mode of contraction, despite other musculature and contraction types being involved in the execution of soccer-specific tasks. Future research should consider testing a wider range of involved joints and muscle contractions. For example, and examination of eccentric hamstring strength and its ratio with quadriceps strength changes, would help to evaluate the (21) effects of SSG more comprehensively. Current literature indicates that co-activation of the quadriceps and hamstrings are important to safely decelerate from dynamic movements and provide stability of the knee joint (21, 10, 2, 35). The inclusion of a concurrent quadriceps test would, therefore, provide greater insight into the effects of SSG-induced fatigue on lower-limb muscle function. In addition, a pre-post design was used which did not account for the time-course of recovery to baseline. Future research could consider investigating the temporal effects of SSG on hamstring force production.

PRACTICAL APPLICATIONS

Larger relative area SSGs elicited the greatest internal and external loads, resulting in greater decrements in hamstring force. The number of accelerations performed in the session also increased the likelihood of hamstring fatigue and can be controlled with the relative pitch area. These findings enable practitioners to plan training sessions and apply SSGs more effectively, with a greater understanding of the effect of relative pitch area. Due to the potential risks posed by reducing hamstring force production, utilising the larger SSGs during a busy time of the season, when hamstring force production is important to monitor (40), could increase the risk of injury. The findings suggest that the larger SSG would be better used further away from match day, due to the greater fatigue induced or, alternatively, to condition the hamstring when greater training stress is required for adaptation.

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