Sport Sciences for Health (2021) 17:403–413
https://doi.org/10.1007/s11332-020-00703-w

ORIGINAL ARTICLE

The effect of a periodized small-sided games intervention in hurling on physical and physiological measures of performance

Shane Malone[1,2] · John Keane[1] · Adam Owen[3] · Giuseppe Coratella[4] · Damien Young[5] · Kieran Collins[1,2]

Received: 11 April 2020 / Accepted: 22 September 2020 / Published online: 5 January 2021

Abstract

The current investigation examined the effect of a periodized small-sided games (SSG) intervention across a 4-week pre-season period on physical and physiological performance measures within hurling players. Twenty-five ($n = 25$) hurling players were observed across the training intervention with GPS and HR technologies. Players participated in 12 sessions of exclusive 4 min SSG bouts (4 v 4) across differing pitch dimensions from 100 to 200-m^2 with the number of bouts of SSG increasing across the intervention period (from 4 up to 8 bouts). Pre and post intervention tests included physiological (VO_{2max} (mL kg^{-1} min^{-1}), vVO_{2max} (mL kg^{-1} min^{-1}), PTV (km h^{-1}), oxygen consumption (mL kg^{-1} min^{-1}), vLT (mmol L^{-1}), vOBLA (mmol L^{-1}) and HR_{max}) and physical [5-, 10-, 20-m speed (s), Yo-YoIR1 (m) and RSA_b (s)] testing methodologies. Across the period significant improvements in physical and physiological qualities were observed with these being *trivial* to *large* in nature. Significant *large* improvements in VO_{2max} (ES 1.79; 95% CI 1.02–2.01) and vLT (ES 1.56; 95% CI 1.12–1.78) were reported with moderate improvements in vVO_{2max} (ES 0.93; 95% CI 0.77–1.11) and vOBLA (ES 0.89; 95% CI 0.34–0.99) respectively. *Moderate* improvements in Yo-YoIR1 (ES 0.65; 95% CI 0.33–0.78) and RSA_b (ES 0.41; 95% CI 0.21–0.66) were also observed across the period with *trivial* improvements observed for speed across 5-, 10- and 20-m. Furthermore, SSG also led to an improvement in oxygen consumption across varying speeds as indicated through significantly reduced VO_2 and HR at running speeds of 8-, 10-, 12-, 14- and 16-km h^{-1} (ES 0.99–1.78). The present study provides coaches with a periodization strategy for pre-season hurling specific SSG. Overall, the data demonstrate that implementing a structured periodized SSG training intervention can improve the physical and physiological fitness characteristics of hurling players across a pre-season.

Keywords Small-sided games · GAA · Training intervention · HR · GPS

Introduction

Hurling is an intermittent team sport played with a stick (camán) and ball (sliothar), the skills required to successfully play the game are complex in nature [1]. This is a high-intensity dynamic team sport where 2 goalkeepers and 28 outfield players (15 players-a-side) compete on an average pitch dimension of 140-m by 88-m (422 m^2). Competitive match-play takes place across differing durations depending on the standard of play [2]. At the elite level of hurling, match-play is 70 min plus additional time with sub-elite match-play taking place across 60 min plus additional time which is at the discretion of the referee [2]. High catching of the sliothar with one hand is a feature of the game, as is striking the ball in the air, both skills requiring extraordinary hand–eye coordination [1]. The camán can also be used to block the ball or to "hook" an opponent attempting to strike

✉ Shane Malone
shane.malone@mymail.ittdublin.ie

1 Department of Science, Gaelic Sport Research Centre, Technological University Dublin, Tallaght, Dublin, Ireland

2 The Tom Reilly Building, Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK

3 Claude Bernard University Lyon, Villeurbanne, Centre de Recherche et d'Innovation sur le Sport (CRIS), Villeurbanne, France

4 Department of Biomedical Sciences for Health, University of Milan, Milan, Italy

5 Limerick Institute of Technology, Thurles Campus, Thurles, Tipperary, Ireland

it. The sport requires players to engage in total distances of 7506 ± 1364-m, interspersed with 1169 ± 260-m of high-speed distance (≥ 17 km h^{-1}) and 350 ± 93-m of sprint distance (≥ 22 km h^{-1}) [3]. Hurling constitutes a form of intermittent exercise within which the timing of high-intensity efforts is acyclical following the nature of the game [4]. Key characteristics of the sport are that players are required to engage in high-speed running, rapid acceleration, and deceleration movements intertwined with changes of directions, jumping, and body contacts [3, 5]. These patterns of play are likely to contribute to the observed high levels of aerobic and anaerobic turnover experienced by players during competitive match play [1]. Therefore, these players need to be exposed to training regimens which include elements of aerobic and anaerobic conditioning [1].

Small-sided games (SSG) are now commonly used as methods of conditioning players within team sports including hurling [6–9]. These games take place on condensed pitch dimensions allowing coaches the opportunity to develop both technical and tactical proficiency within players. Furthermore, these games represent a concurrent method of training allowing for the development of aerobic and anaerobic fitness characteristics simultaneously. Practically, hurling coaches face the challenge of improving athletic and physiological performance without encroaching on the technical and tactical side of the training process [10–12]. Therefore, the concurrent characteristic of SSG has resulted in these games representing a major component of the hurling training [10, 13]. During SSG, players' heart rates can exceed an intensity deemed high enough to promote aerobic capacity development (90–95% of maximal heart rate; HR_{max}) [14]. Recently, there has been an increased interest in these SSG within hurling, with a number of prescriptive variables such as player number [9], rule changes [15, 16], competitive nature [11], game type [11, 17], work to rest ratio [12, 18] and pitch size [10, 19] all shown to alter the physical and physiological demands placed on players. Overall, SSG has been shown to stimulate physiological and workload intensities like that of actual match play. Therefore, it appears of paramount importance to understand how to appropriately periodize these games across the hurling training process to improve players' physical and physiological performance.

Across sports appropriately planned SSG have been shown to be a useful concurrent modality to stimulate training adaptations when compared to generic interval training [20–22]. Indeed, initial investigations comparing SSG (6 × 4-min bouts (5 vs 5), 3-min of active recovery (jogging at 50–60% of HR_{peak}) and traditional aerobic training (6 × 4-min bouts of running at 85–90% HR_{peak}, 3-min active recovery (jogging at 50–60% HR_{peak}) within soccer showed negligible differences between methods for improving players fitness characteristics. Following on from these findings, higher heart rates were observed during SSG (1v1, 2v2 games, 8 sessions, 5 bouts per session) (178 ± 7 b min^{-1}) when compared to repeated bouts of running (15 s:15 s, 30 s:30 s efforts, 8 sessions, 4 sets 7–10 reps) (167 ± 4 b min^{-1}) [20]. However, SSG are known to have higher inter-individual variations due to the open and self-paced nature of these games when compared to the closed and controlled nature of interval training. This has resulted in coaches using SSG less as a sole conditioning modality within hurling [20, 22]. However, given the amateur nature of Gaelic sports, coaches are time-poor across a training week, typically having players for 2–3 h per week [23]. Therefore, these concurrent methodologies may allow for a more refined conditioning programme centered solely on competitive skill execution at high enough speed and physiological cost to accrue improvements in physiological and performance profiles of players across a training period.

To date, however, only one investigation has compared SSG (4 × 4 min; 4 v 4; 80 × 20-m) against continuous training (4 × 4 min) [21]. Pre-to post assessments showing that SSG resulted in possibly to likely beneficial improvements in maximal oxygen uptake (VO_{2max}; 6.3%), running economy (13.8%), Yo-Yo intermittent recovery test level 1 (Yo-YoIR1; 18.5%), and repeated sprint ability (5.8%) when compared to the trivial improvements shown for continuous training across the same period [21]. Within Gaelic sports, many coaches plan training in an ad hoc manner with sessions changing based on team results or coaching perception [23]. Therefore, the appropriate periodization of SSG fails to take place [24]. Interestingly, a structured step load for periodized SSG intervention has been shown to improve the fitness characteristics of soccer players [25]. Currently, within hurling, it is unknown how best to periodize SSG. Therefore, the aim of the present investigation was to examine the effects of a periodized four-week SSG training intervention on players physical [5, 10, 20-m speed, repeated sprint ability (RSA), Yo-YoIR1] and physiological performance [VO_{2max}, oxygen consumption at varying speeds, the velocity at VO_{2max} (vVO_{2max}), the velocity at lactate threshold (vLT), the velocity at the onset of blood lactate accumulation (vOBLA)] characteristics. It was hypothesised that a structured SSG approach across the four-week period would induce significant improvements in both aerobic and anaerobic measures of performance within hurling players. These findings could potentially provide valuable information to coaches on how best to plan and structure their pre-season SSG as a conditioning strategy for hurling cohorts given the time-poor nature of the training process within these Gaelic sports [23].

Methods

Experimental approach to the problem

During the pre-season, twenty-five ($n=25$) hurling players, competing at senior level volunteered for the study across a 4-week SSG intervention period with testing weeks either side resulting in a six-week total investigation period (November–December). To examine the effect of a periodized SSG intervention, all players were tested during three testing sessions, either side of the 4-week intervention period. All tests were completed at the same time of day in a standardised manner to account for any diurnal variation in performance. During the intervention phase players were not involved in any competitive fixtures which resulted in the designated phase that could be strictly controlled and allowed for a periodized approach across all SSG completed by the coaches of the team. During the intervention period players were monitored through the use of global positioning system (GPS) technology (VX Sport, Lower Hutt, New Zealand, 4-Hz) and heart rate (HR) monitors (Polar Team Sport System; Polar Electro Oy, Kempele, Finland) to best monitor players physical and physiological performance during each SSG session.

Subjects

Twenty-Five ($n=25$) hurling players competing at the top level of hurling (age 24.5 ± 2.2 years; height 178.9 ± 3.2 cm; body mass 81.5 ± 4.5 kg) took part in the study. Players were part of the same team, a division 1 team with a minimum playing experience of 3-years (range 3–8 years playing experience). The players completed SSG specific training sessions a week throughout the investigation period. After ethical approval, participants attended an information evening where they were briefed about the purpose, benefits, and procedures of the study. Written informed consent and medical declaration were obtained from participants in line with the procedures set by the local institutions' research ethics committee (Technological University Dublin, Tallaght).

Physical performance assessment

Players completed several field-based physical performance assessments for aerobic and anaerobic fitness. Firstly, players completed a Yo-Yo intermittent recovery test level 1 (Yo-YoIR1). The Yo-YoIR1 tests consisted of 20-m shuttle runs performed at increasing speeds, with 10 s of active recovery between runs (intermittent recovery version). The Yo-YoIR1 has been reported to assess a player's endurance capacity with a high aerobic energy contribution [26]. The audio-cues of the tests were broadcast using a portable CD player (Philips, Az1030 CD player, Netherlands). The test ended when the participant either stopped voluntarily or twice failed to reach the front line in time with the audio cue. Furthermore, players completed a repeated sprint test (RSA). Specifically, this test consisted of six repeated 35-m shuttles with 10 s of passive recovery [27] with the best sprint time (RSA_b; s) recorded. Additionally, the first sprint of the RSA was used to assess linear sprint speed assessed by a 5-, 10- and 20-m timing gate splits to monitor sprint speed (s).

Physiological performance assessment

Players completed an incremental staged treadmill assessment (Cosmed T170, Roma, Italy) for blood-lactate concentration profiling, mean HR (HR_{mean}), maximal HR (HR_{max}) and VO_{2max} (mL kg^{-1} min^{-1}). The protocol consisted of 4 min stages at 8 km h^{-1}, 10 km h^{-1}, 12 km h^{-1}, 14 km h^{-1}, 16 km h^{-1} and then a ramp stage that increased in speed by 1 km h^{-1} min^{-1} [13, 28]. Participants were instructed to run until volitional exhaustion. The individual lactate profiles were assessed according to the procedures suggested by Akubat et al. [28]. During the incremental test, each stage was separated by a 1-min period where capillary blood lactate (5 µL) was taken in duplicate with the mean value for each stage recorded. Blood lactate was used to derive (1) velocity at 2 mmol L^{-1} (vLT) and (2) velocity at 4 mmol L^{-1} (vOBLA). Additionally, VO_{2max} was recorded as the highest mean VO_2 value obtained for a 1-min period, when the following criteria were met: (1) a plateau in VO_2 despite increasing treadmill speed, (2) respiratory ratio above 1.10, (3) attainment of age-predicted HR [13, 28, 29]. Velocity at VO_{2max} (vVO_{2max}) was defined as the highest speed attained when VO_{2max} was achieved, with peak tredmill velocity (PTV) defined as the end speed at which volitional exhaustion occurred. HR was recorded using HR belts (Polar, Polar Electro, OY, Finland). The oxygen consumption of players was assessed at all stages of the incremental test to assess players' oxygen utilisation at various speeds of movement [13, 25, 28].

Small-sided game training intervention

The periodization of SSG across the intervention period is shown in Table 1. SSG were performed in all training sessions during the intervention period. Training sessions were completed on the same pitch at the same period of the day (18:00–20:00) to avoid any circadian variation in performance during these games. Prior to each pitch-based session, a standardised warm-up of 15 min was completed consisting of technical skill execution, dynamic stretching, and low to moderate speed movements. Each SSG were supervised by the coaching team, any time the ball went out of play a

Table 1 The periodization of SSG during the intervention period

Week	Session progression	SSG format (m)	Player area (m^2/player number)	Progressive overload	Total time in SSG (min)
Week 1	SSG 1	40×20	100	4×4 min	16
	SSG 2	40×20	100	5×4 min	20
	SSG 3	40×20	100	6×4 min	24
Week 2	SSG 4	40×20	100	7×4 min	28
	SSG 5	60×20	150	4×4 min	16
	SSG 6	60×20	150	5×4 min	20
Week 3	SSG 7	60×20	150	6×4 min	24
	SSG 8	60×20	150	7×4 min	28
	SSG 9	80×20	200	5×4 min	20
Week 4	SSG 10	80×20	200	6×4 min	24
	SSG 11	60×20	150	7×4 min	28
	SSG 12	80×20	200	8×4 min	32

All SSG played with a 4 v 4 format for a 4-min duration with a 3 min passive skills-based recovery between bouts

replacement was readily available to allow for higher physical and physiological demands in addition to increasing the continuity of these SSG. Furthermore, during these games, the coaches encouraged players to perform a high-press in line with the team's specific tactical set up during match-play environments. During the period, all SSG were standardised by time (4-min). During the intervention period, the SSG employed was a touchdown-based game, were the aim of the game was for teams within the SSG to retain ball possession and work the ball into a designated touchdown area. Once the team had worked the ball into this area the team retained possession and aimed to work the ball back down the pitch to the opposite touchdown area [10, 21].

Physical and physiological monitoring of SSG during the intervention

During all SSG, participants wore an individual GPS unit (VXSport, New Zealand, Lower Hutt, Issue: 330a, Firmware: 3.26.7.0) sampling at 4 Hz and containing a triaxial accelerometer and magnetometer in all training sessions. The GPS unit (mass 76 g; 48 × 20 × 87 mm) was encased within a protective harness between the player's shoulder blades in the upper thoracic-spine region. Fifteen minutes before the commencement of training, the GPS device was turned on and fixed to the athlete, to establish a satellite lock. The validity and reliability of this device have previously been communicated [30]. The number of satellites for GPS was satisfactory during all sessions: range: 7–12 with an average of 9.5 ± 3 satellites per training respectively. The horizontal dilution of position (HDOP) which reflects the geometrical arrangement of the satellites and is related to both the accuracy and quality of the signal was not collected which is a limitation of the current study. Proprietary software provided instantaneous raw velocity data at 0.25 s intervals, which was then exported and placed into a customised Microsoft Excel spreadsheet (Microsoft, Redmond, USA). The spreadsheet allowed analysis of distance covered (m) and speed calculated (km h^{-1}) in the following categories; total distance; high-speed running distance (≥ 17 km h^{-1}); Sprint distance (≥ 22 km h^{-1}) [10–12]. Physiological performance during SSG was assessed based on HR analysis, which was recorded every 5 s using a telemetric device (Polar Team Sport System; Polar Electro Oy, Kempele, Finland). The heart rate maximum of each player was determined by means of an incremental treadmill test performed. The mean heart rates for each SSG were recorded and expressed as a percentage of each individual maximum to provide an indication of the overall intensity of the SSG in relation to the mean and maximum HR obtained during the incremental treadmill assessment.

Statistical analysis

Descriptive results are presented as means ± SD and 95% Confidence intervals (95% CI). The assumption of normality was verified using a Shapiro–Wilks test. Differences in aerobic and anaerobic fitness variables between the pre- and post-testing were assessed with paired samples *T* tests. Standardised effect size is reported as Cohen's *d*, using the pooled standard deviation as the denominator. Qualitative interpretation of *d* was based on the guidelines provided by Hopkins and colleagues [31]: trivial: 0–0.19; small: 0.20–0.59; moderate: 0.60–1.19; large: 1.20–1.99; very large: ≥ 2.00.

Results

The typical running and physiological performances across the intervention period for SSG are shown in Figs. 1 and 2.

Physiological performance measures

When physiological performance measures were considered *moderate* to *large* effects were observed overall across the intervention period. Specifically, VO_{2max} (54.97 ± 3.44 to 58.33 ± 2.44 mL kg^{-1} min^{-1}; $p = 0.032$; 95% CI 1.32–4.53 mL kg^{-1} min^{-1}; ES 1.79; large), PTV (19.3 ± 1.5 to 20.7 ± 11.35 km h^{-1}; $p = 0.041$; 95% CI 1.0–2.5 km h^{-1}; ES 0.99; Moderate), vVO_{2max} (17.4 ± 1.8 to 18.9 ± 1.4 km h^{-1}; $p = 0.041$; 95% CI 1.5–2.8 km h^{-1}; ES 0.93; Moderate) and HR_{max} (198 ± 5 to 193 ± 4 b min^{-1}; $p = 0.049$; 95% CI 4–8 b min^{-1}; ES 0.48; Small) were significantly improved pre-SSG intervention to post-SSG intervention. When the blood lactate profiles of players were analysed significant moderate to large effects were observed across the SSG intervention period with both vLT (8.1 ± 1.5 to 10.3 ± 1.3 km h^{-1}; $p = 0.003$; 95% CI 1.1–3.5 km h^{-1}; ES 1.56; Large) and vOBLA (10.6 ± 0.8 to 13.9 ± 0.8 km h^{-1}; $p = 0.023$; 95% CI 1.0–3.8 km h^{-1}; ES 0.89; Moderate) improving across the hurling cohort (Table 2).

Physical performance measures

Across the intervention period, physical performance measures showed *trivial* to *moderate* improvements. Specifically, Yo-YoIR1 running performance (1640 ± 276 to 1880 ± 177 m; $p = 0.021$; 95% CI 200–410 m; ES 0.63; Moderate) significantly increased pre to post the SSG intervention period. Non-significant trivial effects were observed for 5 m (1.00 ± 0.44 to 1.00 ± 0.44 s; $p = 0.678$; 95% CI − 0.10 to 0.1 s; ES 0.01; Trivial), 10 m (2.11 ± 0.65 to 2.11 ± 0.77 s; $p = 0.713$; 95% CI − 0.12 to − 0.01 s; ES 0.01; Trivial) and 20-m (3.44 ± 0.78 to 3.33 ± 0.76 s; $p = 0.815$; 95% CI − 0.11 to 0.18 s; ES 0.15; Trivial) speed across intervention period. Figure 3 shows the oxygen consumption improvements across running performance at different speeds pre

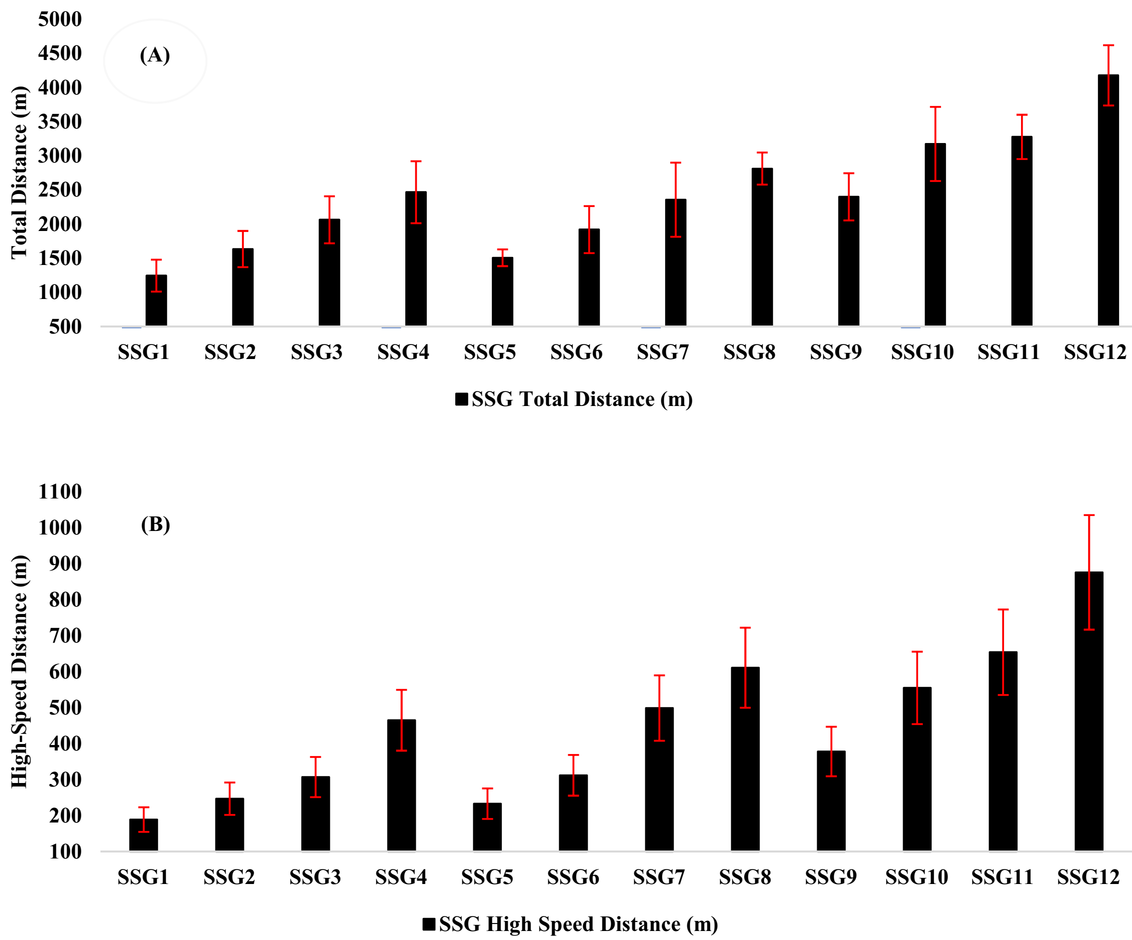

Fig. 1 The **a** Total distance (m) and **b** High-speed distance (m) covered in SSG during the intervention period

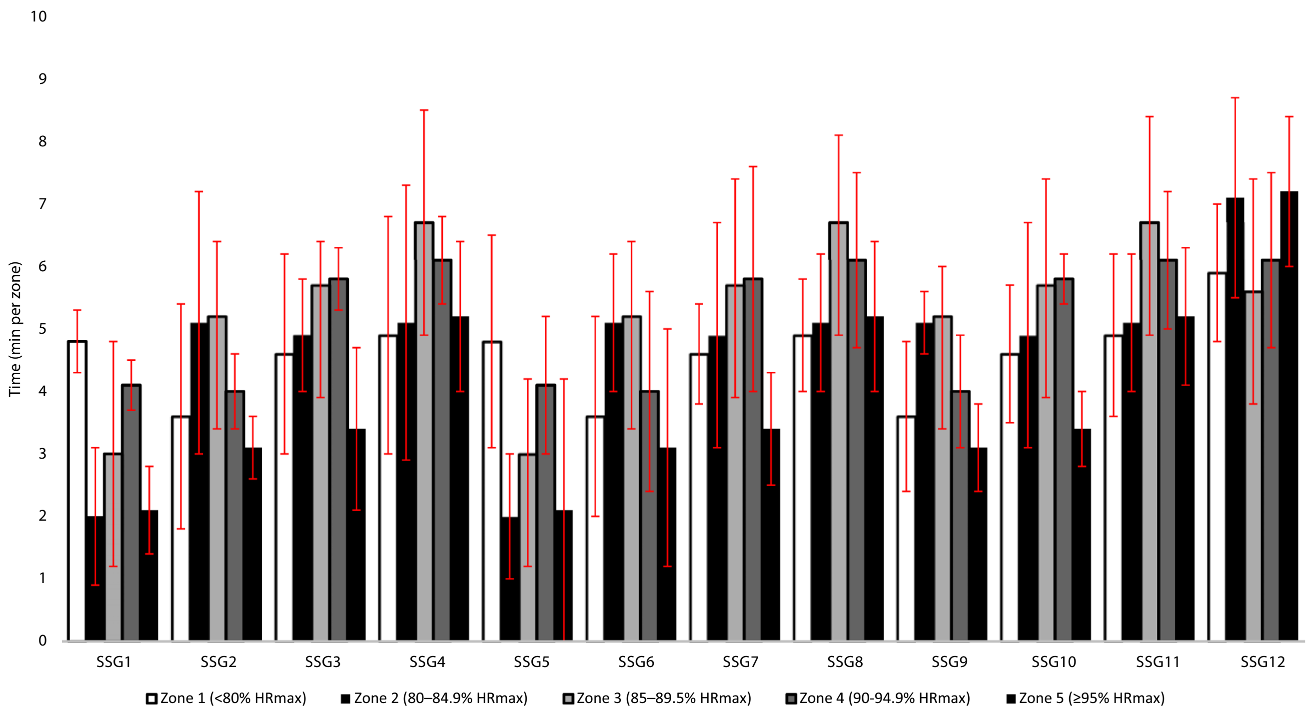

Fig. 2 Mean SSG HR Profile of Hurling players at varying HR intensity zones during the intervention period

Table 2 The effect of the SSG intervention on physiological and physical performance measures ($n = 25$)

Physiological performance	Pre-intervention	Post-intervention	Effect size	Magnitude
VO_{2max} (mL kg^{-1} min^{-1})	54.97 ± 3.44 (50.78–57.99)	58.33 ± 2.44 (54.78–62.44)	1.79 (1.02 to 2.01)	Large
Peak treadmill velocity (km h^{-1})	19.3 ± 1.5 (16.7–19.8)	20.7 ± 1.3 (17.7–20.9)	0.99 (0.56 to 1.10)	Moderate
vVO_{2max} (km h^{-1})	17.4 ± 1.8 (16.7–18.9)	18.9 ± 1.4 (17.2–19.6)	0.93 (0.77 to 1.11)	Moderate
vLT (km h^{-1})	8.1 ± 1.5 (6.8–9.3)	10.3 ± 1.3 (7.9–12.8)	1.56 (1.12 to 1.78)	Large
vOBLA (km h^{-1})	10.6 ± 0.8 (9.3–11.1)	13.9 ± 0.8 (12.1–14.9)	0.89 (0.34 to 0.99)	Moderate
HR_{max} (b min^{-1})	198 ± 5 (195–201)	193 ± 4 (188–197)	0.48 (0.21 to 0.67)	Small
Physical performance				
Yo-YoIR1 (m)	1640 ± 276 (1220–1860)	1880 ± 177 (1420–2120)	0.65 (0.33 to 0.78)	Moderate
5-m Speed (s)	1.00 ± 0.44 (0.99–1.33)	1.00 ± 0.43 (0.98–1.23)	0.01 (− 0.21 to 0.11)	Trivial
10-m Speed (s)	2.11 ± 0.65 (1.87–2.78)	2.11 ± 0.77 (1.75–2.65)	0.01 (− 0.11 to 0.09)	Trivial
20-m Speed (s)	3.44 ± 0.78 (2.99–3.98)	3.33 ± 0.76 (2.87–3.76)	0.15 (0.08 to 0.19)	Trivial

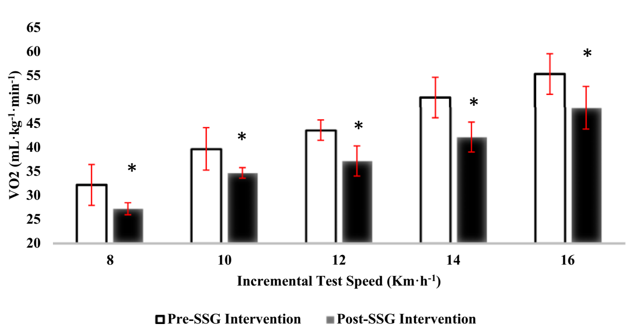

Fig. 3 Pre and Post SSG intervention oxygen consumption of Hurling players at varying running speeds

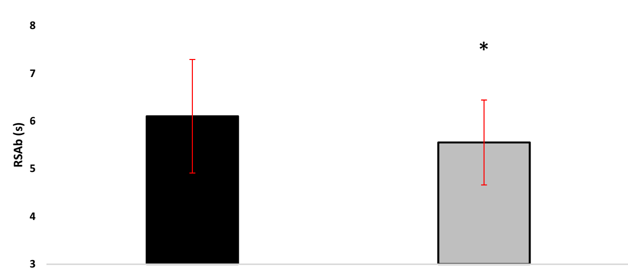

Fig. 4 Pre and Post SSG intervention best-repeated sprint ability (RSA_b) of Hurling players

and post the intervention period. Finally, Fig. 4 shows the observed significant *moderate* effect for RSA_b (6.31 ± 1.90 to 5.35 ± 0.70 m; $p = 0.031$; 95% CI 0.21–0.65 s; ES 0.67; Moderate) across the SSG intervention period.

Discussion

The aim of the current investigation was to observe the efficacy of a 4-week periodized SSG intervention on the physical and physiological characteristics of hurling players. The main findings of the study show that a periodized SSG intervention can improve aerobic and anaerobic capacities within hurling cohorts. Specifically, our data showed significant *moderate* to *large* improvements from pre to post-testing across physiological variables such as aerobic capacity, vLT, vOBLA and vVO_{2max}. Furthermore, the SSG intervention had a *trivial* impact on acceleration and 20-m speed measures. Given the present results, it may be suggested that a periodized approach to planning SSG may result in improvements across aerobic and anaerobic characteristics within hurling players. However, these improvements may differ across physiological and physical capacities. Overall, the results support the idea that coaches who employ a games-based philosophy with respect to conditioning across a pre-season period may improve aerobic and anaerobic fitness within hurling cohorts. However, it appears that for specific physical capacities such as speed and acceleration coaches may need to combine these methodologies with supplementary modalities to ensure a holistic performance programme is administered to hurling players.

The current findings are the first within hurling cohorts to show that a periodized training block of SSG during a pre-season period can have a *moderate* to the *large* positive effect on the physical and physiological characteristics of hurling players. Our findings add to the literature on SSG as a training modality and confirm previous findings that show SSG can act as a viable alternative to generic training within the hurling training process (tempo running, interval running training, skill circuits) and are capable of improving physical and physiological characteristics. Indeed, previous investigations within hurling have shown across a 10-week period that SSG (4 × 4 min) can result in similar improvements when compared to traditional continuous training [21] with no significant differences between physical and physiological testing between groupings. Furthermore, within soccer cohorts, a 7-week preseason training period of SSG to significantly improve Yo-Yo intermittent recovery test performance, although not VO_{2max} (16), while a 3% improvement in running economy has been found in youth players after 12 weeks (4 weeks preseason and 8 weeks in-season) of SSG [32]. Despite the agreement between our findings and previous literature, it would seem appropriate to provide a mechanistic appreciation of the physiological adaptations that may have taken place across the intervention period while also comparing the results from the present study to those previously conducted, particularly given that the sports differ in nature and as such the metabolic and physical stressors will vary greatly when manipulating these sport-specific SSG training variables (e.g., pitch dimensions, number of players, coach encouragement).

One of the primary goals of coaches during the pre-season period is to increase the aerobic capacity of players given that aerobic fitness is associated with increased running performance and a reduction in injury risk [29, 33, 34]. Within team sport athletes' improvements in VO_{2max} could potentially allow players to cover increased running distances during match-play [29], while also improving players ability to repeat sprints, and perform high-intensity actions both with and without the ball [35, 36]. The culmination of which may increase the likelihood of these players having a positive impact on overall team performance. Interestingly, within the current investigation, a significant large effect was observed across VO_{2max} with improvements observed across the intervention period. Given the interval nature of these games across the period (4–8 × 4 min intervals), it is important for coaches to understand the specific physiological mechanisms that may have resulted in these improvements in aerobic power across the intervention period. The physiological responses by players to any intervention period will depend on the initial training state of the individual, the protocol design, and the specific intensity attained during the completion of the protocol [14, 37]. Overall, given the duration of each bout these SSG could be classified as a game-specific modality of high-intensity interval training [14]. It is likely that across the duration of the intervention these athletes experienced both 'central' and 'peripheral' improvements in cardiorespiratory fitness with potential mechanistic improvements in the arteriovenous difference in blood oxygen content, stroke volume, and maximal cardiac output [14, 38]. These improvements were likely facilitated by an expansion of red blood cell volume and an associated increase in stroke volume, which can also adapt independently of changes in red blood cell volume [14, 38]. It is likely that the above mechanistic improvements aided the *moderate* improvement reported across Yo-YoIR1 running performance during the intervention period. These findings are taken together suggest that hurling specific SSG if appropriately periodized can evoke improvements in aerobic capacity across a pre-season period. Given the limited time available for collective training in hurling 3 times per week), the current SSG provided physical and physiological improvements while participating in technical and tactical match-like hurling situations. Specifically, hurlers are required to perform highly complex technical skills during match-play [39, 40], which need to be practiced at every opportunity. Furthermore, SSG have been shown to demand different tactical behaviors from players in team sports [41]. With the use of one ball in the SSG, players will spend most of the game time without it. During this time, players will make decisions while on and off the ball. The SSG used in the current study allows the integration of these hurling specific technical and tactical demands in a time-efficient manner, which may be lost if more of a traditional running only conditioning approach was implemented.

Oxygen consumption at differing speeds is an important physical determinant of team sport athletes and can be related to the fact that changes in fitness experienced during the season may be better detected through sub-maximal indices of aerobic fitness [25, 42, 43]. Therefore, SSG can decrease the cost at a sustained workload that may culminate in reduced oxygen demand, which may allow players to either exercise at a lower or similar HR but with greater intensity across both training and match-play phases of play. Given the noted improvement in oxygen consumption across differing speeds, it is possible that primary skeletal muscle responses contributed to training-induced changes in oxygen extraction at different speeds. These have previously been related to the increased capillarization and enhanced mitochondrial volume post an intervention period within trained cohorts [38]. Indeed, short-term interval training such as the intervention within the current investigation has been shown to induce vascular remodelling as evidenced by increased skeletal muscle microvascular and capillary density [14, 44], which could potentially have improved local blood perfusion. It may also be suggested that the interval methodology within the current investigation provided a potent enough stimulus to allow for mitochondrial biogenesis and rapidly increased biomarkers of mitochondrial content and respiration [14, 37]. Whereby the capacity for skeletal muscles oxidative respiration exceeded the capacity for systemic oxygen transport. However, training-induced increases in capillarization, and mitochondrial volume density are typically larger than for VO_{2max} [14, 37, 38]. The above mechanistic changes across the intervention period may also be related to the observed improvement in vLT and vOBLA across the training period. Indeed, the lactate threshold has previously been found to be a sensitive indicator to changes in fitness in professional team sports players [42]. While we have suggested numerous mechanistic possibilities to explain the observed improvements in physiological and physical performance it must be remembered that given the nature of the game, ‘performance’ within hurling is not as easily determined. This is related to factors such as skill execution, opposition set-up, stage of the competition, decision making, and many other contextual factors that contribute to successful performance, therefore coaches should aim to have a holistic approach across developing players, with a focus placed on fitness parameters but also skill execution and tactical understanding.

During hurling match-play, the performance of repetitive sprint efforts, changes of direction, jumping, tackling, and collisions are characteristics that increase physiological strain [4]. Within SSG these efforts may be exacerbated due to the condensed nature of games. Furthermore, these movements may be completed with increased intensity given the reduced time frame of repeated intervals within a specific SSG periodized plan. Indeed, these movements may result in an auxiliary neuromuscular stimulus because the ability to perform technical and tactical requirements under fatigued conditions is considered important during hurling match-play [5, 14, 39]. Within the current investigation, we observed that a periodized SSG intervention within hurling players could result in significant moderate improvements across repeated sprint ability. We hypothesise that SSG including the ball imitate the unorthodox movements commonly associated with match-play it is very likely that the higher intensity and repetitive nature of sprint actions within SSG created a sufficient stimulus to result in improvement across RSA indices. Sprinting, speed and acceleration capacities are important physical qualities within hurling given that players complete 126 ± 25 accelerations, 350 ± 93-m of sprint distance with an average maximal velocity of 8.08 ± 0.58 m s^{-1} attained during match-play [3] with the majority of these elements of physical outputs accruing during important phases of play such as breaking balls, attacking movements to create space and the creation of scoring plays [5, 39, 40]. Within the current investigation, the SSG intervention had a trivial impact of speed and acceleration characteristics. These results although surprising given the increase in the number of acceleration opportunities within the confined spaces created during SSG, are in line with previous investigations across sports with respect to SSG. Indeed, previously it has been shown that SSG has limited effects on running speed within soccer players [45]. Furthermore, an SSG intervention analysis has shown that the time measured during the 5 m and 20 m runs did not change significantly across a training period within team sport athletes [46]. However, it must be noted that individual drills with balls obtained a greater effect on RSA and peak sprinting performance in football players, compared to SSG training [47]. These results and ours taken together suggest that while SSG may improve the physical and physiological performance of hurling and team sports players. Coaches may need to have a combined methodology to ensure they are prescribing training that best prepares players for the specific demands of hurling match-play. Overall, in spite of the results obtained across different studies, hurling coaches should take into consideration that SSG need to be periodized and have specific conditions to improve hurling players' physical and physiological fitness measures.

The current investigation needs to be considered within the confines of specific limitations. Firstly, a single cohort of hurling players was observed during the pre-season period, as such, it represents a case study on the impact of a periodized SSG intervention across a pre-season period. Furthermore, the lack of a control group reduces the impact of the findings and it could be argued that the gains in physical and physiological performance, may be attributed to the completion of technical and tactical elements of training during the intervention period. However, it is worth noting that the SSG were the only sessions performed during this period. Therefore, it can be inferred that physical improvements exhibited during the SSG training intervention may culminate in greater fitness levels of physical qualities displayed during actual competitive match play. Given the trivial improvement in acceleration and speed-based measures during the intervention and the increase in coaches moving towards simulated phases of play as a conditioning intervention, it may be suggested that future research should compare SSG intervention and simulated phases of play intervention. These simulated phases of play represent a condensed time period of 15 v 15 match play with specific conditions. Finally, it would be of interest for coaches and conditioning coaches alike for a comparative analysis of the physical, physiological, technical, and tactical execution within SSG and match-play to understand the ability of these smaller condensed games to replicate match-play elements.

Conclusion

The current investigation demonstrates that the implementation of a 4-week periodized SSG training intervention within a hurling cohort can improve the physiological and performance characteristics of these players. Coaches should be aware that SSG allows for the attainment of technical and tactical elements of training while also allowing for improvements in physiological and performance characteristics. Subsequently, the ability to integrate SSG into the training process is important within hurling to improve the physical and technical capacity of players. These games should be seen as an important methodology of conditioning for coaches ahead of generic non-specific drills in sessions. Despite the potential advantages of SSG, care should be considered when implementing SSG within a periodized program. Due to SSG being non-constrained in terms of players' ability to complete the distance at a self-selected intensity, an overreliance on SSG could potentially lead to both under and overtraining effects for particular playing cohorts. Ultimately these games will always require stringent control and standardization by coaches to avoid influential factors such as duration, pitch sizes, player numbers, and game types. The practical implications of this study may be further enhanced by quantifying the optimal load and intensities of SSG. This can be completed by coaches collating the GPS and HR variables from SSG completed across a longitudinal period to provide SSG drill databases for teams with normative values for SSG. Coaches should aim to use SSG to continually develop physiological and performance characteristics of players while also allowing for players to best replicate the technical and tactical elements of match-play in conjunction with one another rather than in isolation.

Acknowledgements The authors would like to state that they have no conflicts of interest to declare while also thanking the management and players of the teams involved in the current investigation

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

Ethical approval Ethical approval for the current investigation was granted by the research ethics committee of the Technological University of Dublin, Tallaght. All procedures performed in the study involving human participants were in accordance with the ethical standards of the Trust and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Reilly T, Collins K (2008) Science and the Gaelic sports: Gaelic football and hurling. Eur J Sport Sci 8:231–240
2. Young D, Collins K, Mourot L, Coratella G (2019) The match-play activity cycles in elite u17, u21 and senior hurling competitive games. Sport Sci Health 15:351–359
3. Young D, Malone S, Collins K, Mourot L, Beato M, Coratella G (2019) Metabolic power in hurling with respect to position and halves of match play. PLoS ONE 14(12):e0225847
4. Young D, Malone S, Beato M, Mourot L, Coratella G (2018) Identification of maximal running intensities during elite hurling match-play. J Strength Cond Res. https://doi.org/10.1519/JSC.0000000000002674**(Epub ahead of print)**
5. Young D, Beato M, Mourot L, Coratella G (2019) Match-play temporal and position-specific physical and physiological demands of senior hurlers. J Strength Cond Res. https://doi.org/10.1519/JSC.0000000000002844**(Epub ahead of print)**
6. Gaudino P, Alberti G, Iaia FM (2014) Estimated metabolic and mechanical demands during different small-sided games in elite soccer players. Hum Mov Sci 36:123–133
7. Hill-Haas SV, Dawson B, Impellizzeri FM, Coutts AJ (2011) Physiology of small-sided games training in football: a systematic review. Sports Med 41(3):199–220
8. Los Arcos A, Vazquez JS, Martin J, Lerga J, Sanchez F, Villagra F, Zulueta JJ (2015) Effects of small sided games vs. interval training in aerobic fitness and physical enjoyment in young elite soccer players. PLoS ONE 10(9):e0137224

9. Malone S, Collins K (2016) The physical and physiological demands of small-sided games: how important is winning or losing? Int J Perform Anal Sport 16(2):422–433
10. Malone CKD (2017) The influence of pitch size on running performance and physiological responses during hurling specific small-sided games. J Strength Cond Res 31(6):1518–1524
11. Malone S, Collins KD (2017) Effect of game design, goal type and player numbers on physiological and physical demands of hurling specific small-sided games. J Strength Cond Res 31(6):1493–1499
12. Malone S, Hughes B, Collins K (2019) The influence of exercise-to-rest ratios on physical and physiological performance during hurling specific small-sided games. J Strength Cond Res 33(1):180–187
13. Malone S, Hughes B, Collins K, Akubat I (2020) Methods of monitoring training load and their association with changes across fitness measures in hurling players. J Strength Cond Res 34(1):225–234
14. Buchheit M, Laursen PB (2013) Hugh intensity interval training, solutions to the programming puzzle: Part 1: cardiopulmonary emphasis. Sports Med 43(5):313–338
15. Castellano J, Casamichana D, Dellal A (2013) Influence of game format and number of players on heart rate responses and physical demands in small-sided soccer games. J Strength Cond Res 27(5):1295–1303
16. Gimenez JV, Hongyou L, Lipinska P, Szwarc A, Rompa P, Gomez MA (2018) Physical responses of professional soccer players during 4 vs. 4 small-sided games with mini-goals according to rule changes. Biol Sport 35(1):75–81
17. Gonzalez-Rodenas CF, Aranda R (2015) Effect of the game design, the goal type and the number of players on the intensity of play in small-sided games in youth elite players. J Hum Kinet 49:229–235
18. Koklu Y, Alemdaroglu U, Dellal A, Wong DP (2015) Effect of different recovery durations between bouts in 3-a-side games on youth soccer players' physiological responses and technical activities. J Sports Med Phys Fitness 55(5):430–438
19. Hodgson C, Akenhead R, Thomas K (2014) Time-motion analysis of acceleration demands of 4v4 small-sided games played on different pitch sizes. Hum Mov Sci 33:25–32
20. Dellal A, Varliette C, Owen A, Chirico EN, Pialoux V (2012) Small sided games versus interval training in amateur soccer players: effects on aerobic capacity and ability to perform intermittent exercises with changes of direction. J Strength Cond Res 26(10):12–20
21. Malone S, Hughes B, Collins K (2017) Are small-sided games an effective training methodology for improving fitness in hurling players: a comparative of training methodologies. Int J Sports Sci Coach 12(5):685–694
22. Reilly T, White C (2005) Small-sided games as an alternative to interval training for soccer players. In: Reilly T, Cabri J, Araújo D (eds) Science and soccer V. Routledge, New York, pp 344–347
23. Cullen BD, McCarren AL, Malone S (2020) Ecological validity of self-reported wellness measures to assess pre-training and pre-competition preparedness within elite Gaelic football. Sport Sci Health. https://doi.org/10.1007/s11332-020-00667-x
24. Young D, Coratella G, Malone S, Collins K, Mourot L, Beato M (2019) The match-play sprint performance of elite senior hurlers during competitive games. PLoS ONE 14(4):e0215156. https://doi.org/10.1371/journal.pone.0215156
25. Owen AL, del Wong P, Paul D, Dellal A (2012) Effects of a periodized small-sided game training intervention on physical performance in elite professional soccer. J Strength Cond Res 26(10):2748–2754
26. Bangsbo J, Iaia FM, Krustrup P (2008) The Yo-Yo Intermittent Recovery Test: a tool for evaluation of physical performance in intermittent sports. Sports Med 38:37–51
27. Bishop D, Girard O, Mendez-Villanueva A (2011) Repeated-sprint ability—Part II: recommendations for training. Sports Med 41(9):741–756
28. Akubat I, Patel E, Barrett S, Abt G (2012) Methods of monitoring the training and match load and their relationship to changes in fitness in professional youth soccer players. J Sports Sci 30(14):1473–1480
29. McMillan K, Helgerud J, MacDonald R, Haff J (2005) Physiological adaptations to soccer-specific endurance training in professional youth soccer players. Br J Sports Med 39:273–277
30. Malone S, Collins DK, McRobert AP, Morton J, Doran DA. (2014) Accuracy and reliability of VXsport global positioning system in intermittent activity. In: Presented at: The 19th annual congress of the European college of sportscience, 5th July; Amsterdam. https://doi.org/10.13140/RG.2.1.1559.6245
31. Hopkins W, Marshall S, Batterham A, Hanin J (2009) Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41(1):3–12
32. Iaia FM, Rampinini E, Bangsbo J (2009) High-intensity training in football. Int J Sports Physiol Perform 4:291–306
33. Gabbett TJ (2016) The training-injury prevention paradox: should athletes be training smarter and harder? Br J Sports Med 50(5):273–280
34. Malone S, Hughes B, Doran DA, Collins K, Gabbett TJ (2019) Can the workload-injury relationship be moderated by improved strength, speed and repeated-sprint qualities. J Sci Med Sport 22(1):29–34
35. Durandt J, Tee JC, Prim SK et al (2006) Physical fitness components associated with performance in a multiple-sprint test. Int J Sports Physiol Perform 1(2):150–160
36. Sirotic AC, Coutts AJ (2007) Physiological and performance test correlates of prolonged, high intensity intermittent running performance in moderately trained women team sport athletes. J Strength Cond Res 21(1):138–144
37. Gibala MJ (2020) Physiological basis of interval training for performance enhancement. Exp Physiol. https://doi.org/10.1113/EP0088190
38. Lundby C, Montero D, Joyner M (2017) Biology of VO_2 max: looking under the physiology lamp. Acta Physiol 220(2):218–228
39. Collins DK, McRobert A, Morton JP, O'Sullivan D, Doran DA (2018) The work-rate of elite hurling match-play. J Strength Cond Res 32(3):805–811
40. Young D, Mourot L, Coratella G (2018) Match-play performance comparisons between elite and sub-elite hurling players. Sport Sci Health 14:201–208
41. Castelao D, Garganta J, Santos R, Teoldo I (2014) Comparison of tactical behaviour and performance of youth soccer players in 3 v 3 and 5 v 5 small-sided games. Int J Perform Anal Sport 14:801–813
42. Castagna C, Impellizzeri FM, Chaouachi A, Bordon C, Manzi V (2011) Effect of training intensity distribution on aerobic fitness variables in elite soccer players: a case study. J Strength Cond Res 25:66–71
43. Impellizzeri FM, Marcora S, Castagna C, Reilly T, Sassi A, Iaia FM, Rampinini E (2006) Physiological and performance effects of generic versus specific aerobic training in soccer players. Int J Sports Med 27(6):483–492
44. Scribbans TD, Edgett BA, Vorobej K, Mitchell AS, Joansse SD, Matusiak JBL, Parise G, Quadrilatero J, Gurd BJ (2014) Fibre-specific responses to endurance and low volume high-intensity interval training: striking similarities in acute and chronic adaptation. PLoS ONE 9(6):e98119
45. Jastrzebski Z, Barnat W, Dargiewicz R, Jaskulska E, Szwarc A, Radzimiński Ł (2014) Effect of in-season generic and soccer-specific high-intensity interval training in young soccer players. Int J Sports Sci Coach 9(5):1169–1180

46. Hill-Haas SV, Coutts AJ, Roswell GJ, Dawson BT (2009) Generic versus small-sided game training in soccer. Int J Sports Med 30(9):636–642
47. Mohr M, Krustrup P (2016) Comparison between two types of anaerobic speed endurance training in competitive soccer players. J Hum Kinet 51:183–192