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Small-Sided Games Are Not as Effective as Intermittent Running to Stimulate Aerobic Metabolism in Prepubertal Soccer Players

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Purpose: The purpose of this study was to investigate the influence of the soccer pitch area during small-sided games (SSG) in prepubertal children on physiological and technical demands, and to compare them, for the physiological demands, to high-intensity interval training (HIIT). ***Methods:*** Ten young soccer players (13.0 [0.3] y) performed a HIIT and 3 SSG of various field sizes (30 × 20 m, 42 × 38 m, and 51 × 34 m). Each SSG was performed with 5 players per team, during 4 × 4-minutes interspaced with 1 minute of passive recovery in between. HIIT also followed a 4 × 4-minute protocol with running speed set on an individual basis. Heart rate (HR) was continuously monitored during training sessions. For each exercise modality, time spent above 90% of HR_{max} ($T_{\geq 90\%,HRmax}$) was calculated, and technical actions were quantified during SSG by video analysis. ***Results:*** $T_{\geq 90\%,HRmax}$ was similar between the 3 SSG (~587 [276] s; $P > .2$) but 24% to 37% lower than during HIIT (826 [140] s, $P < .05$). Coefficients of variations in $T_{\geq 90\%,HRmax}$ were 2.3 to 3.5 times larger in SSG compared with HIIT. For technical actions, greater number of possessions (21 [6] vs ~14 [4]), and lower ball touches per possession (2.4 [0.6] vs ~2.9 [0.6]) were found in the small SSG compared with larger SSG, respectively ($P < .05$). ***Conclusion:*** The 3 SSG led to lower acute stimulation of the aerobic metabolism, suggesting a lower potential for chronic aerobic adaptations, compared with HIIT. Moreover, interindividual variability in the physiological response was substantially greater in SSG compared with HIIT, indicating increased heterogeneity among players performing the same training protocol.

Keywords: aerobic capacity, endurance exercise performance, football, high-intensity interval training, young soccer athletes

While soccer performance is multifactorial,[1] suggesting that time is needed to develop every required technical skill or physical quality, games frequency rises, leading to reduction in training sessions (ie, time). In this context, small-sided games (SSG), characterized by modified games played on reduced pitch areas and often using adapted rules involving a smaller number of players compared with traditional games,[2] is an attractive exercise modality to simultaneously develop endurance capacity and technical soccer skills.[3] Indeed, as SSG are performed with the ball and require dribbling, passing, and shooting, they are thought to stimulate technical aspects.[4,5] In terms of physical demand, SSG may be an effective training mode to enhance aerobic fitness,[6] which plays a pivotal role in soccer. For example, it was found that significant improvements in maximal oxygen uptake ($\dot{V}O_2max$) led to a higher number of sprints per game and a higher distance covered during competitive match play in elite junior players.[7]

Endurance aerobic intensity is often assessed using heart rate (HR) during training sessions, based on the linear relationship between HR and $\dot{V}O_2$.[8] However, studies investigating the acute influence of SSG on aerobic fitness often reported the mean HR throughout the session,[6,9] which does not provide accurate indications for potential improvements in $\dot{V}O_2max$. Instead, the time spent at or above 90% $\dot{V}O_2max$ has been identified as a key indicator for aerobic adaptations,[7,10,11] but is almost absent from SSG scientific literature with only few exceptions.[2,12] Importantly, it is possible to observe similar mean HR for 2 training sessions while the time spent at or above 90% ($T_{\geq 90\%,HRmax}$) would be drastically different. It is therefore crucial to assess aerobic intensity using the $T_{\geq 90\%,HRmax}$.

During SSG, a wide range of parameters influence the physiological demand, such as the number of players, the rules, or the pitch area.[2] More specifically, the bigger is the pitch area, the higher is the aerobic contribution in adult players.[13] However, it is also important to compare these physiological demands to high-intensity interval training (HIIT), established as the "gold-standard," most effective method to improve aerobic metabolism (ie, $\dot{V}O_2max$).[14] HIIT is characterized by repeated bouts of high-intensity work performed above the lactate threshold, interspersed by periods of low-intensity exercise or complete rest.[15] The major difference between HIIT and SSG in terms of physiological stress is that HIIT is set on an individual basis (ie, running distance/speed calculated for each player to reach a targeted HR) while it is not for SSG, meaning that training intensity is more difficult to control. Therefore, it would be insightful to investigate both the intensity and the interindividual variability of the physiological response when comparing HIIT and SSG.

Previous studies found that SSG HR responses were similar to HIIT in adults.[16] However, data are missing, using the above-mentioned methodology, in prepubertal players. While SSG are already widely utilized in elite soccer academies to develop aerobic capacity in young players, it is important to emphasize that results found for adults may not be translated into prepubertal children characterized by substantial differences in their physiology due to their immature system.[17] Of note, aerobic metabolism of prepubertal children seems close to well-trained adult endurance athletes for several aspects,[17] strengthening the idea that they likely need to be exposed to a high-intensity exercise to get significant $\dot{V}O_2max$ improvements. Then, if SSG are often preferred by coaches for the development of young players because they are undeniably more

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soccer specific[18] and also more enjoyable by players,[9] it is still critical to assess their efficacy compared with HIIT to provide insights for coaches interested in fine-tuning physical/technical stimuli for their training programs.

The purpose of the present study was to investigate the influence of the soccer pitch area during SSG in prepubertal children on physiological and technical demands, and to compare them, for the physiological demands, to HIIT. We hypothesized that larger SSG would lead to greater physiological demand (ie, time spent at high intensity), while reducing technical demand (ie, less passes, more ball touches per possession), compared with a smaller SSG, in prepubertal players. Moreover, we hypothesized that SSG would lead to reduced time spent at high intensity as well as larger interindividual variability in the HR response compared with HIIT sessions.

Methods

Participants

Ten boys from the academy of an elite French soccer team took part in the present study (age 13.0 [0.3] y; height 152 [8] cm; weight 41 [7] kg). Mean age from peak height velocity was calculated (−1.5 [0.6] y) using a validated, noninvasive method based on anthropometric variables to assess player's maturity.[19] Participants practiced 2 to 3 training sessions per week and played 1 game of 80 minutes per week on a regular-sized soccer pitch (60 × 100 m) with the rules of 11-a-side football. Written informed consent was obtained from each participant prior to the beginning of the study. The study was approved by the local ethics committee and conducted according to the Declaration of Helsinki for human experimentation.

Experimental Protocol

Study participation included 5 visits, each separated by 3 to 7 days, and were performed at the same time on each day. During the first session, participants performed a maximal incremental test to determine their individual speed for the subsequent HIIT session. Then, on 4 different sessions, participants performed 3 SSG with various pitch areas and 1 HIIT session, following the same exercise pattern (4 × 4 min interspersed with 1 min of passive recovery).

Maximal Incremental Test

Participants performed the 30-15$_{IFT}$ maximal incremental exercise test[20] on a turf soccer pitch to determine their end-test speed (S_{peak}) and maximal HR (HR_{max}). The test (30-s run and 15-s rest) started at 8.0 km·h^{-1} and speed was increased by 0.5 km·h^{-1} every 45 second. HR was continuously measured during testing using HR monitors (Polar Team^2; Polar Electro Oy, Kempele, Finland). For each subject, individual HR_{max} was collected and 90% and 95% of HR_{max} were calculated. $\dot{V}O_2max$ was estimated using the following equation[21]:

$$\dot{V}O_2max\ \ mL \cdot min^{-1} \cdot kg^{-1} = 28.3 - 2.15 \times G - 0.741 \times A - 0.0357 \times BM + 0.0586 \times A \times S_{peak} + 1.03 \times S_{peak}$$

where G is the gender (female = 2 and male = 1), A is the age (years), BM is the body mass (in kilogram) of the participant, and S_{peak} is the end-test speed of the 30-15$_{IFT}$ maximal incremental test.

Small-Sided Games

The 3 SSG were performed on a natural turf surface with 5 players per team with small (SSG_{Sm}), medium (SSG_{Md}), and large (SSG_{Lg}) pitch areas of similar length × width proportions (Table 1). Compared with SSG_{Sm},[16,22,23] playing area was doubled (SSG_{Md}) and tripled (SSG_{Lg}) to presumably promote $T_{\geq 90\%,HRmax}$,[21,23] to give the opportunity of SSG to reach, or surpass, HIIT intensity. Each SSG followed the same exercise pattern, with 4 × 4 minute playing bouts interspersed with 1 minute of passive recovery, for a total duration of 20 minutes. Players had to stop the ball with their foot backside to the limits of the pitch to score while the number of ball touches per possession was free. Several balls were placed all around the pitch to ensure fast throw-in when the ball went out of play. Uniform verbal encouragements were given to all participants by the team's fitness coach throughout the sessions. Time spent at high intensity from the HR response were calculated (ie, $T_{\geq 90\%,HRmax}$ and $T_{\geq 95\%,HRmax}$) for each SSG.

Each game has been filmed using a full high-definition camera (DH-SD22404T-GN; Dahua Technology, Binjiang, China) located on an extendable mast (height 7.30 m) to assess technical actions during SSG. Three categories of technical actions were analyzed for each player, namely number of passes, dribbles, and possessions.[24] Video analysis was conducted using LongoMatch (version 3.1.7; Fluendo SA, Barcelona, Spain).

High-Intensity Interval Training

Similar to SSG, participants performed 4 sets of 4 minutes of exercise interspersed with 1 minute of passive recovery during the HIIT session. Each set consisted of 30-second running intervals at 100% of the participant's individual S_{peak} interspersed with 30 seconds of passive recovery. Of note, the 30- to 30-second intermittent exercise has been described as a training modality maximizing the time spent at high intensity.[25] HIIT was performed in shuttle with one 180° change of direction. HR was recorded throughout the session.

Statistical Analysis

Normality of all dependent variables and sphericity of variance of the distribution were assessed using the Kolmogorov–Smirnov test

Table 1 Characteristics of the 3 SSG

	Number of players	Pitch dimensions, m	Pitch area, m^2	Work/rest ratio, min	Number of sets	Total duration, min
SSG_{Sm}	5 vs 5	30 × 20	600	4/1	4	20
SSG_{Md}	5 vs 5	42 × 28	1176	4/1	4	20
SSG_{Lg}	5 vs 5	51 × 34	1734	4/1	4	20

Abbreviations: SSG, small-sided games; SSG_{Sm}, small SSG; SSG_{Md}, medium SSG; SSG_{Lg}, large SSG. Note that SSG were matched for length × width proportions despite changes in the pitch area.

and the Mauchly test, respectively. A Greenhouse–Geisser correction was used when sphericity was violated. One-way analysis of variances were used to test differences between each training modality (SSG_{Sm}, SSG_{Md}, SSG_{Lg}, and HIIT) in physiological and technical responses. When a significant difference was identified, multiple-comparison analysis was performed using Fisher least significant difference test. Between-subjects coefficients of variation were calculated for $T_{\geq 90\%,HRmax}$ and $T_{\geq 95\%,HRmax}$ to evaluate differences in interindividual variability between training sessions. Statistical analyses were conducted using Statistica (version 8.0; StatSoft Inc, Tulsa, OK). The relationship between S_{peak} and $T_{\geq 90\%,HRmax}$, during the 3 SSG were tested by calculating Pearson correlation coefficients (r^2). Data presented are expressed as mean (SD). Statistical significance was set at $P < .05$.

Results

Maximal Incremental Test

The S_{peak} observed at end test was 19.5 (0.8) $km \cdot h^{-1}$, and HR_{max} was 202 (4) beats per minute. Estimated $\dot{V}O_2max$[21] was 50.0 (0.8) $mL \cdot min^{-1} \cdot kg^{-1}$.

Cardiac Responses to SSG and HIIT

Intensity of the Response. As illustrated in Figure 1A, $T_{\geq 90\%,HRmax}$ was 24% to 37% greater in HIIT (826 [140] s) compared with SSG_{Sm} (613 [244] s, $P = .02$), SSG_{Md} (628 [278] s, $P = .03$), and SSG_{Lg} (519 [307] s, $P = .001$). $T_{\geq 90\%,HRmax}$ was similar between the 3 SSG. $T_{\geq 95\%,HRmax}$ (Figure 1B) was 32% to 61% greater in HIIT (387 [235] s) compared with SSG_{Sm} (150 [159] s, $P = .01$) and SSG_{Lg} (218 [275] s, $P = .04$), but not different compared with SSG_{Md} (264 [271] s, $P = .13$). $T_{\geq 95\%,HRmax}$ was similar between the 3 SSG. Average relative intensity was similar between the 3 SSG (SSG_{Sm}, 85% [4%] HR_{max}; SSG_{Md}, 87% [4%] HR_{max}; and SSG_{Lg}, 85% [5%] HR_{max}). Average relative intensity during HIIT (90% [3%] HR_{max}) was greater than during SSG_{Sm} ($P = .01$) and SSG_{Lg} ($P = .002$), but not different compared with SSG_{Md} ($P = .13$).

Interindividual Variability of the Response. As illustrated in Figure 1C, coefficients of variations in $T_{\geq 90\%,HRmax}$ were 2.3 to 3.5 times larger in SSG compared with HIIT. For $T_{\geq 95\%,HRmax}$ (Figure 1D), coefficients of variations were 1.7 to 2.1 times larger in SSG compared with HIIT. Figure 2 illustrates this interindividual variability in the HR response via the comparison of 2 representative subjects. While the 2 subjects spent substantial and similar $T_{\geq 90\%,HRmax}$ during HIIT (~900 s for both; Figure 2D–2H), for SSG, subject 2 spent 71% to 89% less $T_{\geq 90\%,HRmax}$ compared with subject 1. Therefore, subject 2 spent 77% to 82% less $T_{\geq 90\%,HRmax}$ during SSG compared with HIIT. Importantly, if subject 1 spent substantial $T_{\geq 90\%,HRmax}$ during the 3 SSG, $T_{\geq 90\%,HRmax}$ was still 5% to 30% lower than during HIIT. This result is even more demonstrative for $T_{\geq 95\%,HRmax}$, where subject 2 spent absolutely no time at or above 95% HR_{max} in any SSG (0 s), while subject 1 did (219 s in SSG_{Sm}, 527 s in SSG_{Md}, and 572 s in SSG_{Lg}). Here again, for HIIT, the 2 subjects spent similar $T_{\geq 95\%,HRmax}$ (524 vs 493 s for subject 1 vs subject 2, respectively). No correlations were found between S_{peak} and $T_{\geq 90\%,HRmax}$ (SSG_{Sm}, $r^2 = .11$, $P = .76$; SSG_{Md}, $r^2 = .34$, $P = .33$; SSG_{Lg}, $r^2 = .54$; $P = .11$). Moreover, no correlations were found between S_{peak} and $T_{\geq 95\%,HRmax}$ (SSG_{Sm}, $r^2 = .18$, $P = .22$; SSG_{Md}, $r^2 = .10$, $P = .37$; SSG_{Lg}, $r^2 = .25$; $P = .14$).

Technical Demand During SSG With Various Pitch Areas

As shown in Figure 3, number of passes (~13 [7], $P = .16$), number of possessions (~14 [4], $P = .46$), and number of ball touches per possession (~2.9 [0.6]; $P = .73$) were similar between SSG_{Md} and SSG_{Lg}. However, greater number of possessions (+41% and +57%, $P = .01$ and .001) and lower number of ball touches per possession (−14% and −29%, $P = .03$ and .01) were found in SSG_{Sm} compared with SSG_{Md} and SSG_{Lg}, respectively. A 63%

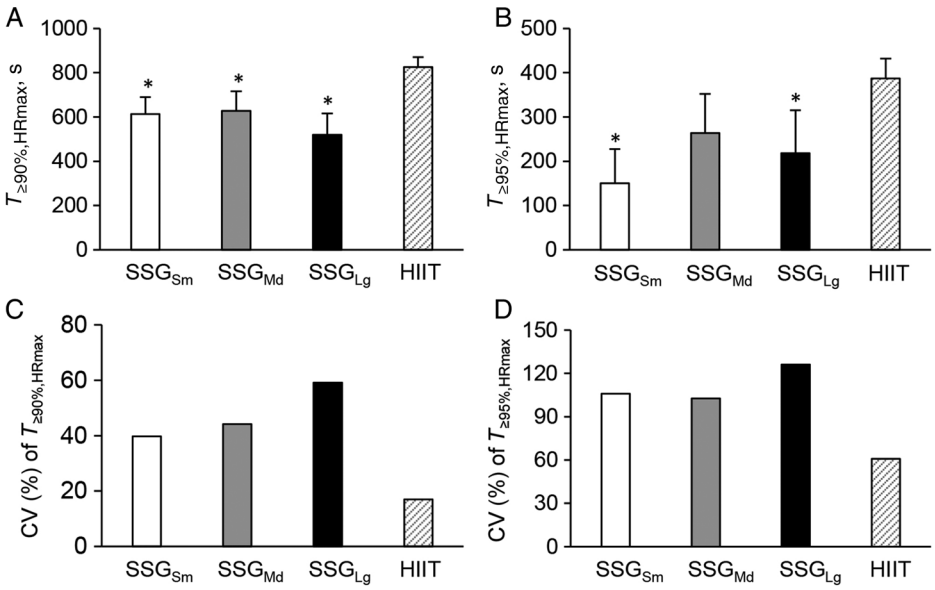

Figure 1 — Time spent above 90% (A) and above 95% (B) of HR_{max} during SSG and HIIT and their associated coefficients of variation (C and D). Data are presented as mean ± SEM. HR_{max} indicates maximum heart rate; HIIT, high-intensity interval training; SSG, small-sided games. *$P < .05$ versus HIIT.

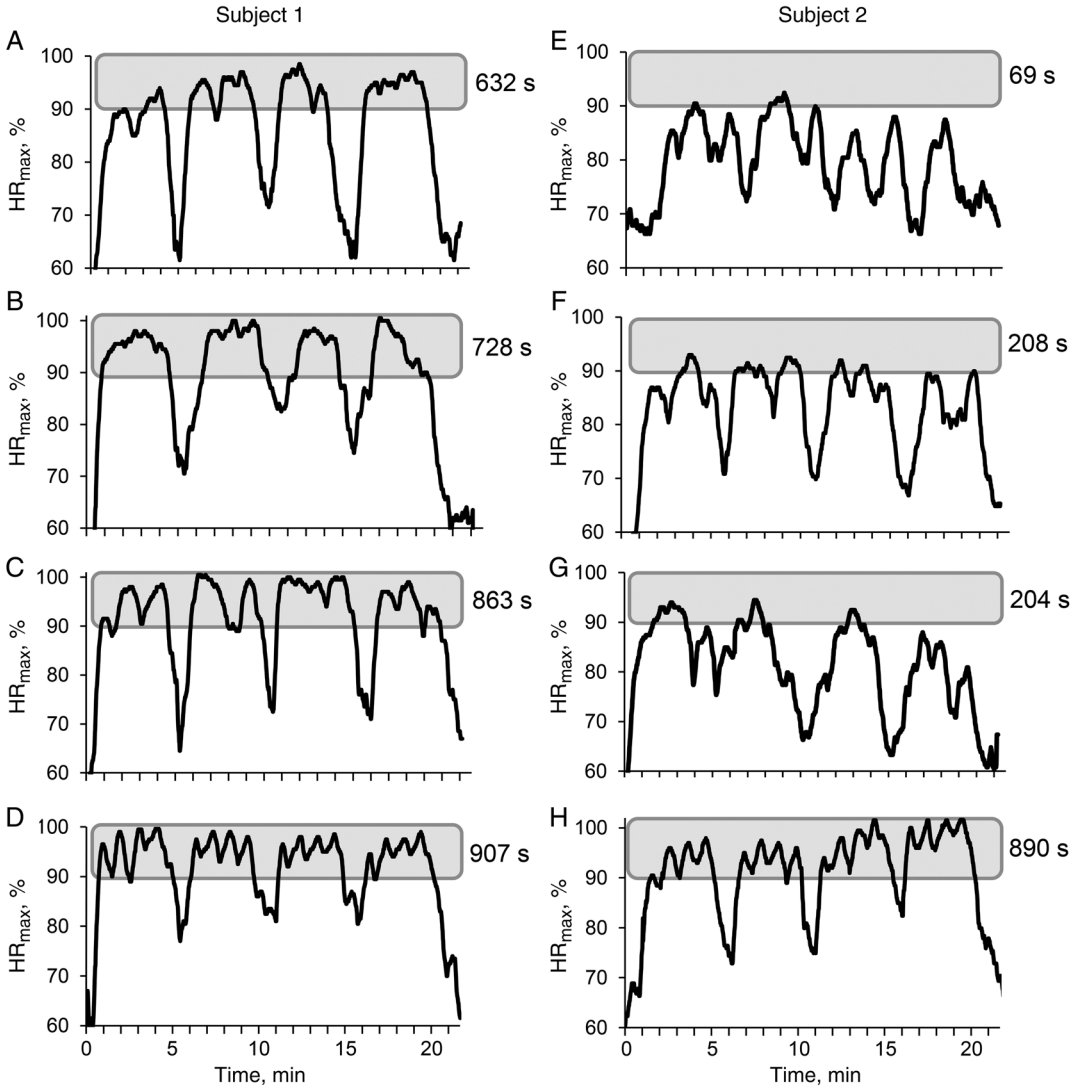

Figure 2 — Heart-rate responses during SSG_{Sm} (A and E), SG_{Md} (B and F), SSG_{Lg} (C and G), and HIIT (D and H), for 2 representative subjects. The 2 subjects spent substantial $T_{\geq 90\%,HRmax}$ during HIIT (~900 s for both). However, for SSG, only subject 1 spent substantial $T_{\geq 90\%,HRmax}$ (632–863 s) while subject 2 did not (69–208 s, ie, 71%–89% less time than during HIIT). A similar observation can be made for the $T_{\geq 95\%,HRmax}$ between subjects 1 and 2 (SSG_{Sm}, 219 vs 0 s; SSG_{Md}, 527 vs 0 s; SSG_{Lg}, 572 vs 0 s; HIIT, 524 vs 493 s, respectively). HR_{max} indicates maximum heart rate; HIIT, high-intensity interval training SSG indicates small-sided games; SSG_{Sm}, small SSG; SSG_{Md}, medium SSG; SSG_{Lg}, large SSG.

greater number of passes was found in SSG_{Sm} compared with SSG_{Lg} ($P = .03$). No difference was found between the 3 SSG for the number of dribbles.

Discussion

The aim of the present study was to investigate the influence of the soccer pitch area during SSG in prepubertal soccer players on physiological and technical demands. As HIIT is established as the "gold-standard" method to improve aerobic metabolism,[26] we also compared acute physiological responses to SSG with those from a HIIT session. The physiological demand ($T_{\geq 90\%,HRmax}$) was similar between the 3 SSG modalities while the technical demand was increased in SSG_{Sm} compared with SSG_{Md} and SSG_{Lg}, as evidenced by significant differences in the number of passes and possessions per session. However, the 3 SSG led to 24% to 37% reduction in $T_{\geq 90\%,HRmax}$ compared with HIIT, indicating a lower aerobic stimulus (ie, acute response), and suggesting a lower training effect on endurance capacity (ie, chronic adaptations). Moreover, interindividual variability in the HR response was 2.3 to 3.5 times greater in SSG compared with HIIT, indicating increased heterogeneity among players performing the same training protocol. Together, these findings indicate that HIIT is more effective than SSG to stimulate aerobic metabolism in prepubertal soccer players and might be interesting to consider for training sessions where the primary outcome is the development of endurance capacity.

Implication of the Aerobic Metabolism During SSG Versus HIIT

In the present study, modifications of the pitch area from 600 to 1734 m^2 led to unchanged physiological demand during SSG in prepubertal soccer players, based on the $T_{\geq 90\%,HRmax}$ or $T_{\geq 95\%,HRmax}$. This result is supported by a study reporting no change in $T_{\geq 90\%,}$

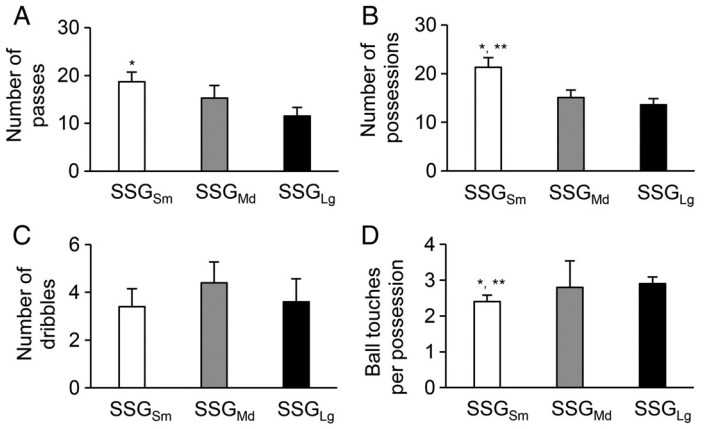

Figure 3 — Number of technical actions performed per player during each of the 3 SSG. Data are presented as mean ± SEM. *$P < .05$ versus SSG_{Lg}. **$P < .05$ versus SSG_{Md}. SSG indicates small-sided games; SSGSm, small SSG; SSG_{Md}, medium SSG; SSG_{Lg}, large SSG.

$_{HRmax}$ during SSG from different dimensions.[22] However, this study, also performed in prepubertal players, did not compare SSG with HIIT, making it difficult to ascertain whether SSG is as effective as HIIT to stimulate the aerobic metabolism. It is also important to note that participants spent ≤ 20% of the training session above 90% of HR_{max} (ie, ≤ 4.8 min).[22] Moreover, studies investigating the acute influence of SSG on endurance capacity often reported the mean HR throughout the session,[13,27] which does not provide accurate indications for potential improvements in $\dot{V}O_{2max}$. Instead, $T_{\geq 90\%,HRmax}$ has been identified as a key indicator.[7,10] The present study revealed that SSG led to significantly lower $T_{\geq 90\%,HRmax}$, whatever the pitch area, compared with iso-time HIIT, indicating a lower stimulation of the aerobic metabolism during SSG versus HIIT. This observation is consistent with others[28] but not all SSG studies[6] investigating its acute physiological demand in prepubertal children.

It is important to emphasize that this acute study provides direct evidence of the HR activation, and indirect evidence on the potential of each training modality to improve endurance capacity following a training cycle (ie, chronic adaptations). Indeed, training studies are requisite to directly assess the potential of a training modality to develop $\dot{V}O_{2max}$. Interestingly, studies that compared chronic effects on $\dot{V}O_{2max}$ of SSG versus HIIT in young soccer players report either similar[29] or greater[30] improvements for HIIT. Of note, a recent meta-analysis[31] based on training studies found that HIIT and SSG can provide similar benefits on endurance and soccer-specific performance. However, this conclusion is based on studies performed on older adolescents (mean age: 16 y old) than the present investigation. Regardless, it appears that training should include at least 4 sets of 4 minutes each interspersed with 3 minutes of recovery between sets to maximize endurance capacity through SSG in young players.[32] Alternatively, it is also possible to prescribe a combination of HIIT and SSG, which has been found to better develop endurance capacity than SSG alone in young players.[18]

Variability of the Aerobic Metabolism Response During SSG Versus HIIT

Interindividual variability in the HR response was 2.3 to 3.5 times greater in SSG compared with HIIT, indicating larger heterogeneity among players getting the same training protocol during SSG compared with HIIT. This result, consistent with a previous investigation performed in professional adult players,[33] may not be surprising and is likely explained by the level of control of each training modality. Indeed, HIIT was individually fine tuned based on the player's endurance capacity (ie, run speed set at 100% of their S_{peak}). Conversely, SSG is unpredictable in format and training intensity is therefore difficult to control.[32] This observation likely explains why 2 participants can get similar substantial $T_{\geq 90\%,HRmax}$ during HIIT but drastic differences during SSG (Figure 2).

The present investigation also sought to provide insights on the individual characteristics leading to small $T_{\geq 90\%,HRmax}$ during SSG. We found no correlation between S_{peak} and $T_{\geq 90\%,HRmax}$, indicating that the players with highest endurance capacity did not get specifically the lowest aerobic stimulus during SSG. While outside the scope of the present investigation, we can speculate that factors related to individual technical/tactical skills and displacement efficiency might explain why some players are not getting a large aerobic stimulus when other teammates are.[34] Further interventions are needed to test this hypothesis.

Influence of the Pitch Size on the Technical Actions During SSG

Technical skills are fundamental for children to develop, and the idea of performing SSG is to stimulate endurance capacity while also including technical actions. Therefore, while our 3 SSG with different pitch sizes were similar in terms of physiological demand, potential differences in the number of technical actions might be insightful to determine the most interesting modality. Interestingly, our results showed that SSG_{Sm} led to an increase in the number of passes and possessions, and a reduction in the number of touches per ball possession compared with SSG_{Md} and SSG_{Lg} (Figure 3). This is explained by the higher spatio-temporal pressure during SSG_{Sm} because of the greater players' density[5] and is consistent with other studies performed on adult players showing greater technical demand with smaller pitches.[24,35] Therefore, SSG_{Sm} might be the most interesting modality to stimulate technical skills without compromising the physiological demand compared with SSG_{Md} and SSG_{Lg}.

In contrast to HIIT, the soccer-specific approach of SSG favors technical and tactical skills[36] as well as multifaceted physical actions such as changes of direction or jumps.[37] Moreover, SSG is more enjoyable than HIIT for young players,[9] which is also a criterion to consider for coaches when programming training contents.

Practical Applications

Based on the present investigation, it appears that SSG are not as efficient as HIIT to stimulate aerobic metabolism in prepubertal soccer players. Therefore, we would suggest promoting HIIT if the development of endurance capacity is the primary focus, as the training intensity is set on an individual basis and therefore easy to control. In contrast, SSG is unpredictable in format and therefore difficult to control and might be preferred when the technical component is important. In this context, we suggest prescribing SSG with small pitch areas, as they are technically more challenging for the players and do not compromise the physiological demand compared with larger SSG. Then, the combination of both HIIT and SSG in training programs[3] might be a great strategy for the multifaceted development of the young soccer player. Regardless, we recommend to coaches to assess the aerobic

contribution of their SSG sessions with HR monitors by (1) using $T_{\geq 90\%,HRmax}$ and not only the mean HR, and (2) to analyze and validate their efficacy on an individual basis due to their large interindividual variability.

Conclusion

The 3 SSG led to lower acute stimulation of the aerobic metabolism, suggesting a reduced training effect on the player's endurance capacity, compared with HIIT. Moreover, interindividual variability in the physiological response was substantially greater in SSG compared with HIIT, indicating increased heterogeneity among players performing the same training protocol. Based on these observations, we suggest prescribing HIIT, and not only SSG, in prepubertal soccer players from elite soccer academies if the primary focus is the development of endurance capacity ($\dot{V}O_2$max). If the development of the technical soccer skills is also targeted, we suggest prescribing SSG with small pitch areas, as they are technically more challenging for the players without compromising the physiological demand compared with larger SSG.

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