Analysis of International Competition and Training in Men's Field Hockey by Global Positioning System and Inertial Sensor Technology

Andrew D. White and Niall G. MacFarlane

School of Life Sciences, College of Medical, Veterinary and Life Sciences, University of Glasgow, Glasgow, United Kingdom

Abstract

White, AD and MacFarlane, NG. Analysis of international competition and training in men's field hockey by global positioning system and inertial sensor technology. *J Strength Cond Res* 29(1): 137–143, 2015—This study assessed the relative demands of elite field hockey training and competition to determine whether familiar exercise prescription strategies provide an appropriate training stimulus. Sixteen elite male field hockey players (age, 25 ± 4 years; body mass, 70.9 ± 6.6 kg; and maximal oxygen consumption, 61.0 ± 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ [mean ± *SD*]) participated in the study. Seventy-five elite level competition and 37 training analyses from 8 games and 4 training sessions were obtained. Training duration was longer than competition and covered a greater total distance (109 ± 2.5 vs. 74 ± 0.3 minutes and 7318 ± 221 vs. 5868 ± 75 m; $p < 0.001$ in both). The distance covered sprinting and running at high intensity was not different between training and competition (114 ± 6 vs. 116 ± 9 m when sprinting and 457 ± 6 vs. 448 ± 7 m for high-intensity running). More high-intensity accelerations were performed during training than in competition (37 ± 3 vs. 20 ± 2). Despite having lower predicted aerobic capacity and covering less distance in competition than in some previous studies, these data support the suggestion that it is high-intensity activity that differentiates international level competition and further suggests that international players can replicate the intensity of competition during small-sided games.

Key Words periodization, physiological demand, time-motion analysis

Address correspondence to Dr. Niall G. MacFarlane, niall.macfarlane@glasgow.ac.uk.

29(1)/137–143

Journal of Strength and Conditioning Research

Introduction

Understanding the physiological demands of competition is vital for appropriate training prescription and planning. In recent years, global positioning system (GPS) analysis has become a widely used tool to quantify competition demands, inform training prescription, and monitor the training stimulus. Currently, there are few studies that report the physiological demands of elite field hockey but all to date demonstrate field hockey to be an intermittent, high-intensity sport (13-15,21,22).

Elite field hockey has been suggested to be played at higher intensity than other team sports with relative distances (i.e., the distance covered as a function of the time elapsed) in excess of 130 $m \cdot min^{-1}$ reported (compare 110 $m \cdot min^{-1}$ in soccer, etc) (1,8). However, hockey is different from most team sports in that rolling substitutions allow players the additional ability to recover "off the pitch" before returning to play; recovery from intermittent high-intensity efforts do happen "on the pitch" during play in the same way as other team sports, but omitting bench periods from data analysis will overestimate relative distances (24).

Previous studies have analyzed competition and training load to assess the training stimulus of athletes in a variety of sports (4–6,10,11,17). In all these studies, training is suggested to be performed at a lower relative intensity than in competition. Similar results have been shown in sub-elite male field hockey (14) and more recently in elite female field hockey using GPS analysis (9). These data draw the obvious conclusion that training prescription is inadequate across the majority of team sports. However, such a conclusion may be unwarranted because the "stop-start" nature of any training session will reduce the relative intensity overall. Moreover, during training, the session may not focus entirely on conditioning and consequently the nature of the exercise components will influence the observed training intensity.

The aim of this study was, therefore, to assess the physiological demands of elite field hockey during competition and training with data expressed relative to the available "active" time (i.e., only omitting breaks between playing periods in competition and breaks between specific training drills [e.g., any prolonged transition between running drills and small-sided games (SSGs), where players might stop to put on shin guards or retrieve sticks]). The rationale is to provide a fuller comparison of competition and training (with less potential for data to be skewed by restricted analysis).

Methods

Experimental Approach to the Problem

The physiological demands of elite male field hockey were investigated using GPS and triaxial accelerometers during competition and training. The data are presented in raw format to allow comparison with the previous literature and also express the data relative to the 70-minute playing period that is available for field hockey competition (referred to as "Drill [per 70 minutes]" [{70/drill duration} × variable]). The mean data for a full training session is the average distance over the 4 sessions (the sum of running, SSGs, full pitch practice, and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity).

Subjects

Sixteen elite male field hockey players (age, 25 ± 4 years; body mass, 70.9 ± 6.6 kg; maximal oxygen uptake, predicted from a multistage fitness test, 61.0 ± 2.1 $ml \cdot kg^{-1} \cdot min^{-1}$ [mean ± *SD*]) participated in the study. Athletes were all members of the Scottish National Hockey team. Players had completed a 3-month special preparatory program consisting of strength and power gym-based work, interval running and speed training in addition to their hockey-based pitch sessions before the competition phase of their season observed (International 4 Nations Tournament and EuroHockey Nations Trophy). All participants were in peak physical condition and free from injury at the time of the study. Global positioning system and inertial sensor analysis was completed as part of the normal squad performance monitoring. The University of Glasgow, College of Medical and Life Sciences research ethics committee approved all procedures. The players gave consent for any data collected during their training and/or competition to be used for audit purposes and for that data to be submitted for publication.

Competition Analyses

A total of 75 elite level competition analyses were completed. Each player was observed at least once (some players analyzed in all games) in 8 competitive games against 7 teams ranked between 2 and 32 in the FIH World Rankings 2011.

Training Analyses

Thirty-seven training analyses from 4 training sessions were observed before competition. Training data were split into individual drills and further classified into 4 categories: running, technical/tactical, SSGs with pitch dimensions between 14.6 × 22.9 m and 45.6 × 45.0 m, and full pitch practice.

The specific aim of the drills being monitored was determined by the head coach in the final phase of preparation for competition (so the main focus tended to be technical/tactical development and improvement of player "sharpness" ahead of competition). Only 1 category, the running drills, was used for conditioning and aimed to maintain fitness levels achieved in the previous months. Rest periods within each drill were retained, but transitions between drills were omitted (to replicate the competition analysis where only the half-time rest period was omitted).

Apparatus

The Catapult MinimaxX 5-Hz GPS system was used for all recordings (MiniMaxX; Catapult Innovations, Melbourne, Australia). This GPS device has been previously shown to be valid for team sports (16). The GPS was turned on and left stationary for at least 10 minutes before use, as per manufacturer's instructions, and then worn within a specifically designed bib with neoprene pouch that holds the unit between the shoulder blades of the wearer. All players had previously worn these in training and competition. Units were fitted at the start of the pregame warm-up to allow time for adjustments before playing.

Environmental Conditions

Games were played in 2 different countries: Scotland (SCO) and Ukraine (UKR). Three games were played in a temperate climate (~14° C) and the other 5 games were played in a warmer climate (~19° C). All games were played on water-based Astroturf and away from overhead obstructions. Only 2 pitches were used for testing. Satellite signal strength (12.3 ± 1.0 and 10.3 ± 1.2, SCO and UKR, respectively) and horizontal dilution of position were strong (1.3 ± 0.4 and 1.0 ± 0.4, SCO and UKR, respectively).

Global Positioning System Analyses

Data were downloaded, analyzed, and reported using Logan Plus v4.4.0 analysis software. Logan Plus has been developed to work alongside the Catapult MinimaxX system and reported as previously described (24). All downloading and reporting of data were carried out immediately after the game by the same observer.

The velocity (speed) zones were through via analysis of the published literature and initial data collection and fit. These were adapted from Lythe and Kilding (15) to include slightly more data at low speed (10–15 $km \cdot h^{-1}$) and reduce data at moderate speed running (15–19 $km \cdot h^{-1}$). High-speed running was measured between 19 and 23 $km \cdot h^{-1}$ and sprinting at speeds above 23 $km \cdot h^{-1}$. All acceleration thresholds were set for a period of 1 second with efforts greater than 2 $m \cdot s^{-2}$ taken to indicate a relatively large rate of velocity change. Player Load is a software-derived parameter that aims to describe the combined internal and external loads from an activity (3).

Statistical Analyses

One-way analyses of variance were performed and Tukey confidence interval (CI) tests were used for post hoc analysis of continuous data (e.g., distance, relative distance, and player load). Poisson rate and Mann-Whitney tests were

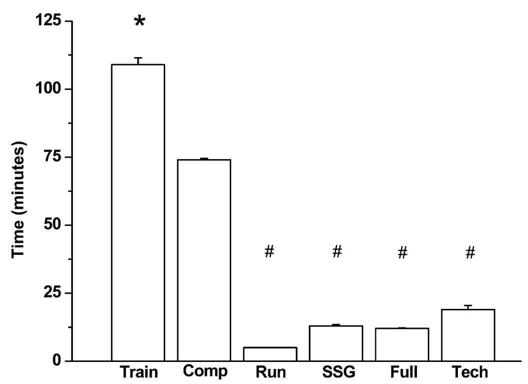

Figure 1. The duration of hockey competition, categories of specific training drills, and the full training session are shown. Train = full training session; Comp = competition; Run = running drills; SSG = small-sided games; Tech, tactical/technical drills. Data are mean ± *SD* with *$p <$ 0.01 comparing full training and competition and #$p < 0.001$ comparing specific drills to full training and competition.

used for post hoc analysis of other variables (e.g., number of efforts in velocity or acceleration zones). Statistical significance was taken as $p \leq 0.05$ and all data are reported as mean and 95% CI (unless otherwise stated) with indication of the post hoc test applied.

Results

Training and Competition Duration and Average Maximum Velocities

Figure 1 shows that full training sessions had a longer duration than competition at 109 minutes (104–114) vs. 74 minutes (74–76) ($p < 0.001$) by Tukey CI test. However, individual component drills for the sessions were all shorter in duration than competition (5 [5–5] minutes, 13 [12–14] minutes, 12 [13–14] minutes, 19 [16–22] minutes for running drills, SSGs, full pitch practices, and tactical technical drills, respectively; $p < 0.001$ by Tukey CI test).

Time omitted from analysis (for transition between drills in training and the half-time rest period in competition) was similar at 18 minutes (15–20) vs. 20 minutes (15–22); however, this represented a lower proportion of the full training duration than in competition at 16.5% (14.4–17.5) vs. 27% (20–29); $p < 0.001$ by Tukey CI test.

Running drills produced the highest average maximum velocities (29.3 $km \cdot h^{-1}$ [28.7–30.0]; $p < 0.001$). Small-sided games, full pitch practices, and tactical/technical drills all produced lower average maximum velocities compared with competition (22.4 $km \cdot h^{-1}$ [22.0–22.8], 23.4 $km \cdot h^{-1}$ [22.2–24.6], 12.6 $km \cdot h^{-1}$ [11.1–14.0] vs. 26.6 $km \cdot h^{-1}$ [26.3–26.8], respectively; $p < 0.001$ by Tukey CI test).

Absolute Data

Table 1 shows that absolute distance covered during running, SSGs, full pitch, and tactical/technical drills were all lower in training than competition (see Table 1 for values; $p < 0.001$). The absolute distance covered during full training sessions was greater than competition (see Table 1 for values; $p < 0.001$ by Tukey CI test).

Table 2 shows that sprint and high-intensity running distance (above approximately 6.4 and 5.3 $m \cdot s^{-1}$, respectively) was lower in full pitch practice and tactical/technical drills compared with competition (see Table 2 for values; $p <$ 0.001 by Tukey CI test). Running drills produced greater sprint distance than competition but lower high-intensity running distance (see Table 2 for values; $p < 0.001$ by Tukey CI test). Small-sided games produced similar sprint distance than competition but lower high-intensity running distance (see Table 2 for values; $p < 0.001$ by Tukey CI test).

Table 3 shows that running, SSGs, full pitch, and tactical/technical drills all produced less acceleration efforts than competition (see Table 3 for values; $p < 0.001$ by Poisson rate distribution). However, the mean full training session data show more accelerations than competition (see Table 3 for values; $p < 0.001$ by Poisson rate distribution). There were significantly more decelerations in running, SSGs, and

Table 1. Distance covered by players during training and competition.*

	Absolute (m)	Relative ($m \cdot min^{-1}$)	Drill (per 70 min)
Competition	5868 (5718–6018)	78 (76–81)	5405 (5337–5617)
Running	426 (414–438)†	84 (82–87)	5964 (5796–6132)‡
SSGs	967 (889–1046)†	74 (71–77)	5207 (4787–5632)
Full pitch practice	1016 (940–1092)†	78 (71–85)	5471 (5062–5880)
Tactical/technical	493 (372–615)†	28 (23–33)†§	1816 (1371–2266)†
Full training session (mean)	7318 (6875–7761)‡	67 (65–69)‖	4768 (4575–4961)†

*SSG = small-sided game. Data are given as mean and 95% confidence intervals. The mean data for a full training session is the average distance over the 4 sessions (the sum of running, SSGs, full pitch practice, and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity).
†Data significantly less than competition, $p < 0.001$.
‡Data significantly greater than competition, $p < 0.001$.
§Data significantly less than all other comparisons, $p < 0.001$.
‖Data significantly less than competition, $p \leq 0.05$.

Table 2. Distance covered and relative time spent in sprinting/high-intensity running during training and competition.*

	Absolute (m)	Drill (per 70 min)	Relative time (%)
Competition			
S	114 (102–126)	105 (94–116)	0.2 (0.1–0.3)
HI	457 (444–470)	421 (409–433)	1.2 (1.1–1.4)
Running			
S	146 (139–153)†	2044 (1951–2140)†	2.0 (1.8–2.2)†
HI	135 (123–147)†	1890 (1722–2058)†	1.0 (0.6–1.4)
SSGs			
S	107 (87–126)	576 (470–679)†	0.2 (0.1–0.2)
HI	250 (173–326)‡	1346 (931–1755)†	1.1 (1.0–1.3)
Full pitch practice			
S	76 (60–93)‡	409 (321–498)‡	0.2 (0.0–0.3)
HI	163 (144–183)‡	877 (775–985)†	1.1 (0.9–1.4)
Tactical/technical			
S	19 (13–26)‡	70 (48–96)‡	1.1 (0.0–0.2)‡
HI	34 (25–43)‡	125 (94–159)‡	0.5 (0.0–1.2)‡
Full training session (mean)			
S	116 (97–134)	108 (91–124)	2.2 (0.1–0.3)
HI	448 (384–512)	417 (358–477)	1.1 (0.9–1.4)

*S = sprinting; HI = high-intensity running; SSG = small-sided game. Data are given as mean and 95% confidence intervals. Mean data for a full training session is the average distance covered over each session (the sum of running, SSGs, full pitch practice, and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity).
†Data significantly greater than competition, $p < 0.001$.
‡Data significantly less than competition, $p < 0.001$.

full pitch drills than in competition (see Table 3 for values; $p < 0.001$ by Poisson rate distribution).

Table 4 shows that less player load was accumulated during running, SSGs, full pitch, and tactical/technical drills than in competition (see Table 4 for values; $p < 0.001$ by Tukey CI test). However, the mean full training session data show that the full training session accumulated more player load than in competition (see Table 4 for values; $p < 0.001$ by Tukey CI test).

Relative Data

Table 1 also shows that relative distance covered to be similar for running, SSGs, and full pitch drills and competition (see Table 1 for values). The relative distance covered during full training sessions was lower than in competition (see Table 1 for values; $p > 0.05$ by Tukey CI test). Tactical/technical drills had the lowest relative distance compared with all other areas (see Table 1 for values; $p < 0.001$ by Tukey CI test).

The relative time spent sprinting was greater in running practices than competition (see Table 2 for values; $p < 0.001$ by Tukey CI test), not different between competition and full pitch practices or SSGs (see Table 2 for values), lower in tactical/technical drills than competition (see Table 2 for values; $p < 0.001$ by Tukey CI test).

Table 3. Accelerations and decelerations (>2 $m\cdot s^{-2}$) performed during training and competition.*

	Absolute accelerations (number)	Absolute decelerations (number)	Accelerations (per 70 min)	Decelerations (per 70 min)
Competition	20 (17–23)	8 (8–9)	19 (16–22)	8 (8–8)
Running	10 (7–15)‡	19 (10–27)§	140 (98–210)§	266 (140–378)§
SSGs	6 (6–8)‡	34 (30–39)§	32 (32–43)§	183 (161–210)§
Full pitch practice	3 (2–4)‡	19 (17–22)§	16 (11–21)	102 (92–119)§
Tactical/technical	2 (1–4)‡	8 (3–12)	7 (4–15)‡	30 (16–65)§
Full training session (mean)	37 (32–42)§	9 (8–9)	24 (21–28)‖	6 (5–6)

*SSG = small-sided game. Data are given as mean and 95% confidence intervals. The mean data for a full training session is the average distance over the 4 sessions (the sum of running, SSGs, full pitch practice, and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity).
†Data significantly less than competition, $p \le 0.05$.
‡Data significantly less than competition, $p < 0.001$.
§Data significantly greater than competition, $p < 0.001$.
‖Data significantly greater than competition, $p \le 0.05$.

Table 4. Player load accumulated during training and competition.*

	Absolute player load (AU)	Normalized player load (AU) (per 70 min)
Competition	631 (602–661)	589 (562–617)
Running	51 (48–54)†	714 (672–756)‡
SSGs	108 (99–117)†	581 (577–585)
Full pitch practice	106 (98–113)†	571 (527–608)
Tactical/technical	58 (44–71)†	213 (193–237)†
Full training session (mean)	816 (773–858)‡	524 (520–531)‖

*SSG = small-sided game. Data are given as mean and 95% confidence intervals. The mean data for a full training session is the average distance over the 4 sessions (the sum of running, SSGs, full pitch practice, and tactical/technical drills is different because each component did not always contribute to a session or was repeated after an intervening activity).
†Data significantly less than competition, $p < 0.001$.
‡Data significantly greater than competition, $p < 0.001$.
§Data significantly greater than competition, $p \leq 0.05$.
‖Data significantly less than competition, $p \leq 0.05$.

Data Normalized to Match Duration (Drill [Per 70 Minutes])

Table 1 shows that normalized distance covered during SSGs and full pitch practices are all similar to competition (see Table 1 for values). Full training session and tactical/technical drills produced lower normalized distance covered than competition (see Table 1 for values; $p < 0.001$ by Tukey CI test). Running drills produced higher normalized distance covered than competition (see Table 1 for values; $p < 0.001$ by Tukey CI test).

Table 2 shows normalized sprint and high-intensity running distance is greater in running drills, SSGs, and full pitch practices compared with competition (see Table 2 for values; $p < 0.001$ by Tukey CI test). Tactical/technical drills are lower than competition for normalized sprint and high-intensity running distance (see Table 2 for values; $p < 0.001$ by Tukey CI test), whereas full training session values are similar to competition (see Table 2 for values).

Table 3 shows that, when normalized to competition time, running drills and SSGs produce a greater number of accelerations than in competition (see Table 3 for values; $p < 0.001$ by Poisson rate distribution). Normalized mean full training session data show a greater number of accelerations than in competition (see Table 3 for values; $p > 0.05$ by Poisson rate distribution). Tactical/technical drills had the lowest normalized number of accelerations (see Table 3 for values; $p > 0.001$ by Poisson rate distribution). When normalized to competition time running, SSGs, full pitch, and tactical/technical drills all produced a greater number of decelerations than in competition (see Table 3 for values; $p < 0.001$ by Poisson rate distribution).

Table 4 shows that when normalized to competition time, the accumulated player load is greatest during running drills (see Table 4 for values; $p < 0.001$ by Tukey CI test) and lowest for tactical/technical drills (see Table 4 for values; $p < 0.001$ by Tukey CI test).

Discussion

In conditioning for athletic performance, the principle of progressive overload requires consideration of the specific exercises and total work undertaken in a periodized training program. Specificity of training will mean that certain exercises may focus on specific movement patterns, energy systems, or speed of movement and provide an overload to adapt and exceed the physiological demands of the sporting activity. The use of time-motion analysis in competition and training facilitates the suitability of training prescription to be studied in team sports. The aim of the current study was to compare the physiological demand of training and competition in elite field hockey to consider whether current exercise prescription is appropriate. The data presented demonstrate that if all aspects of field hockey training are included for direct comparison with competition, then an appropriate training intensity can be achieved. However, individual components within the training session can show considerable differences in the parameters reported so that interpretation will require to be in the context of a specific session plan. For example, because of movement patterns particular to field hockey (where tackling or "channeling" an opponent can involve repeated lunges), it may appear that there is a discrepancy in the pattern of acceleration following deceleration that might be expected in other sports.

The data available for time-motion analysis in male elite field hockey during competition and training are relatively sparse (especially for studies using GPS and inertial sensor technology). However, the average distance covered during match play by an individual player is approximately 900 m lower in this study (in absolute terms) than previously reported by Lythe and Kilding (15). Although the players in the current study have similar aerobic capacities to elite level field hockey players in other studies (2,13), their predicted maximal oxygen uptake from a multistage fitness test was 3 $ml \cdot kg^{-1} \cdot min^{-1}$ less than in Lythe and Kilding (15). This difference in aerobic capacity would predict that, at constant running pace over 70 minutes, the total distance covered by the players described here should be lower by approximately 850 m (18). Thus, the difference observed will substantially reflect player conditioning rather than extrinsic factors, such as opposition effects, tactics, etc. The relative distance covered by an individual player during competition is substantially lower than previously reported but reflects a different approach to the data analysis (24).

Comparisons of training load with the demands of competition have been reported in a number of team sports (4–6,10,11,17). The only study in field hockey compared SSGs in training with competition in elite female athletes (9) where it was concluded that SSGs were played at a lower intensity than in competition (but that they contained similar movement patterns). This comparison was based on time spent in low-intensity, moderate or high-intensity activities (determined by velocity) during SSGs. However, by their nature, SSGs limit the distance available for players to accelerate to high velocity and will limit their ability to accumulate significant time at higher velocities. Furthermore, if SSGs are being compared with relative times and distances during competition where "rest periods" on the bench have been removed, then any difference may be overestimated.

The rationale for including bench periods in the data reported here is that it reflects a sport-specific activity. These periods are analogous to the rest period between exercise sets in the gym and are relevant to calculation of work-to-rest ratio and influence overall competition intensity. For direct comparison with training data, the recovery periods allowed within specific drills have been included, but the short periods of time between drills were omitted (e.g., when the players stopped to retrieve sticks and put on shin guards not used during running drills). The data omitted were not sport specific and represented a significantly lower proportion of the training time compared with the half-time rest period during competition.

Specificity of training will dictate what exercises are chosen to provide an adaptive stimulus to improve performance, to maintain condition, or even taper toward a specific competition. Therefore, it is essential to consider all aspects of the session when assessing the training impulse in comparison with competition. The present study monitored training load during final preparation for an international tournament and consequently the focus of the exercises was not to provide an adaptive stimulus. Nevertheless, the mean data accumulated for the full training session show that sprint and high-speed running distance were not different from competition and that the total distance covered during training was significantly higher than competition. The relative distance is significantly lower than competition but can be explained, in part, by the longer duration of training and the impact of specific very low–intensity technical/tactical activities incorporated with these data. Traditionally, a high-intensity, low-volume taper has been suggested for activities with an endurance component (20), and analysis of the individual components within these training sessions allow consideration as to whether players accumulate appropriate high-intensity from different components despite reduced durations to limit total volume. "Normalizing" these component drills to the 70-minute match duration has been used to indicate relative intensity; these data demonstrate that running drills, SSGs, and limited duration full pitch matches provide a relative training intensity in excess of that observed during competition.

Distances covered above the threshold for sprinting during SSGs were not significantly different from competition in the data presented here and suggest similar intensity (but reduced volume) to midfielders and strikers when normalized to match duration as reported by Gabbett (9) and average distance covered at high speed per position as reported by Lythe and Kilding (15). The use of team averages to compare competition and SSGs is likely to be more relevant given the lack of position-specific movement in the SSGs. If position-specific differences are relevant to the data presented here, then the team average will be reduced by inclusion of defensive player data. Furthermore, despite the very high volume of low-intensity activity during technical/tactical training, they accumulate the same volume of high-speed running over the whole training session (largely because of the contribution of specific high-intensity running). These data suggest that field hockey training session can provide an adequate stimulus to maintain condition appropriate to the demands of field hockey.

Gabbett (9) suggests that altering the conditions, design, or drill complexity for small-sided games is necessary to provide an appropriate training stimulus for field hockey. The intensity of SSG play is easily manipulated by changing conditions within the game; for example, the dimensions of the pitch, the player numbers, inclusion of goalkeepers, or playing possession games with limited ball contacts before passing (19). The data presented here illustrate playing area sizes and exercise durations that can provide an appropriate training stimulus to maintain conditioning. Increasing the volume of high-intensity activity within a training session should make it possible to apply progressive overload and thereby enhance performance. However, independent of any desired manipulation, the intensity of SSGs will also be limited by the physical and technical capacity of the players involved. It is undeniable that the range of physical and technical ability will be greater in national level teams than in an international team. We speculate that including sub-elite field hockey players in SSGs will cause the exercise "to break down" more often than with exclusively international players and this effect contributes to the reduced intensity observed previously (9). The reduced game time that sub-elite players were likely to obtain during national competition will limit their impact on the measured intensity of game play. The resultant increase in game time for the elite players will lead to the observed increase in distance covered during competition and provides the stimulus for the higher predicted maximal oxygen uptake.

The intensity of training observed during this study has to be considered in context. The players studied are amateur and obtain their physical conditioning during national level competition and training. Consequently, the context of the observed training sessions was during final preparation for international competition with a focus on tactical coaching rather than conditioning. Specific running drills were applied during training to maintain their conditioning (albeit at a lower volume) and so the intensity and volume of training described here are likely to underestimate the potential conditioning stimulus that can be applied. Although absolute predicted aerobic capacity and total distance covered in competition is lower than some previous studies (2,9,13), these data show the players covering a greater distance at high speed and producing more high-intensity accelerations that supports the notion that high-intensity activity differentiate international competition (13). Moreover, these data demonstrate that international players are able to replicate the intensity of competition in SSGs or use alternative drills to increase volume to ensure an appropriate training stimulus.

The data reported here were obtained using a 5-Hz GPS system that provides less accurate data than at 10 Hz, especially during high-speed running (7,23). However, this technology has been validated for team sports (16) and was used in strict accordance with the manufacturer's instructions; satellite number signal strength and horizontal dilution of position were near optimal values (12) and these data sampling frequency is equivalent or better than used in many of the studies cited.

Practical Applications

The data presented here provide evidence that current training regimens for field hockey can provide an appropriate stimulus for exercise prescription when considered in the whole and in context. The progressive overload required to improve performance can be provided in a sports-specific manner by using a range of exercise drills. In prescribing appropriate load during a periodized program, it will be necessary to consider how player interactions during SSGs can influence training intensity. If technical ability limits accumulation of the prescribed high-intensity activity during SSGs, then it may be necessary to fall back on running drills. It is important to remember that the value of SSGs will extend beyond physical preparation and they remain an important component to facilitate physical and technical development. It is also important to recognize the contribution that competitive match play makes to physical conditioning.

References

1. Aughey, RJ. Applications of GPS technologies to field sports. *Int J Sports Physiol Perform* 6: 295–310, 2011.
2. Aziz, AR, Chia, M, and Teh, KC. The relationship between maximal oxygen uptake and repeated sprint performance indices in field hockey and soccer players. *J Sports Med Phys Fitness* 40: 195–200, 2000.
3. Boyd, LJ, Ball, K, and Aughey, RJ. Quantifying external load in Australian football matches and training using accelerometers. *Int J Sports Physiol Perform* 8: 44–51, 2013.
4. Brewer, C, Dawson, B, Heasman, J, Stewart, G, and Cormack, S. Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *J Sci Med Sport* 13: 618–623, 2010.
5. Casamichana, D, Castellano, J, and Castagna, C. Comparing the physical demands of friendly matches and small sided games in semi-professional soccer players. *J Strength Cond Res* 26: 837–843, 2012.
6. Castellano, J, Blanco-Villasenor, A, and Alvarez, D. Contextual variables and time-motion analysis in soccer. *Int J Sports Med* 32: 415–421, 2011.
7. Castellano, J, Casamichana, D, Calleja-Gonzalez, J, San Roman, J, and Ostojic, SM. Reliability and accuracy of 10 Hz GPS devices for short-distance exercise. *J Sports Sci Med* 10: 233–234, 2011.
8. Cummins, C, Orr, R, O'Connor, H, and West, C. Global positioning systems (GPS) and microtechnology sensors in team sports: A systematic review. *Sports Med* 43: 1025–1042, 2013.
9. Gabbett, TJ. GPS analysis of elite women's field hockey training and competition. *J Strength Cond Res* 24: 1321–1324, 2010.
10. Gabbett, TJ, Jenkins, DG, and Abernethy, B. Physical demands of professional rugby league training and competition using microtechnology. *J Sci Med Sport* 15: 80–86, 2012.
11. Gabbett, TJ and Mulvey, MJ. Time-motion analysis of small-sided training games and competition in elite women soccer players. *J Strength Cond Res* 22: 543–552, 2008.
12. Gray, AJ, Jenkins, D, Andrews, MH, Taaffe, DR, and Glover, ML. Validity and reliability of GPS for measuring distance travelled in field-based team sports. *J Sports Sci* 28: 1319–1325, 2010.
13. Jennings, DH, Cormack, SJ, Coutts, AJ, and Aughey, RJ. International field hockey players perform more high-speed running than national level counterparts. *J Strength Cond Res* 26: 947–952, 2012.
14. Johnston, T, Sproule, J, McMorris, T, and Maile, A. Time-motion analysis and heart rate response during elite male field hockey competition versus training. *J Hum Movement Stud* 46: 189–203, 2004.
15. Lythe, J and Kilding, AE. Physical demands and physiological responses during elite field hockey. *Int J Sports Med* 32: 523–528, 2011.
16. MacLeod, H, Morris, J, Nevill, A, and Sunderland, C. The validity of a non-differential global positioning system for assessing player movement patterns in field hockey. *J Sports Sci* 27: 121–128, 2009.
17. Montgomery, PG, Pyne, DB, and Minahan, CL. The physical and physiological demands of basketball training and competition. *Int J Sports Physiol Perform* 5: 75–86, 2010.
18. Paliczka, VJ, Nichols, AK, and Boreham, CA. A multi-stage shuttle run as a predictor of running performance and maximal oxygen uptake in adults. *Br J Sports Med* 21: 163–165, 1987.
19. Rampinini, E, Impellizzeri, FM, Castagna, C, Abt, G, Chamari, K, Sassi, A, and Marcora, M. Factors influencing physiological responses to small-sided soccer games. *J Sports Sci* 25: 659–666, 2007.
20. Shepley, B, MacDougall, JD, Cipriano, N, Sutton, JR, Tarnopolsky, MA, and Coates, G. Physiological effects of tapering in highly trained athletes. *J Appl Physiol (1985)* 72: 706–711, 1992.
21. Spencer, M, Lawrence, S, Rechichi, C, Bishop, D, Dawson, B, and Goodman, C. Time-motion analysis of elite field hockey, with special reference to repeated-sprint activity. *J Sports Sci* 22: 843–850, 2004.
22. Spencer, M, Rechichi, C, Lawrence, S, Dawson, B, Bishop, D, and Goodman, C. Time-motion analysis of elite field hockey during several games in succession: A tournament scenario. *J Sci Med Sport* 8: 382–391, 2005.
23. Varley, MC, Fairweather, IH, and Aughey, RJ. Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *J Sports Sci* 30: 121–127, 2012.
24. White, AD and MacFarlane, N. Time-on-pitch or full-game GPS analysis procedures for elite field hockey? *Int J Sports Physiol Perform* 8: 549–555, 2013.