Time-on-Pitch or Full-Game GPS Analysis Procedures for Elite Field Hockey?

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**Purpose:** The current study assessed the impact of full-game (FG) and time-on-pitch (TOP) procedures for global-positioning-system (GPS) analysis on the commonly used markers of physical performance in elite field hockey. **Methods:** Sixteen international male field hockey players, age 19–30, were studied (yielding 73 player analyses over 8 games). Physical activity was recorded using a 5-Hz GPS. **Results:** Distance covered, player load, maximum velocity, high-acceleration efforts, and distance covered at specified speed zones were all agreeable for both analysis procedures ($P > .05$). However, percentage time spent in 0–6 km/h was higher for FG (ES: –21% to –16%; $P < .001$), whereas the percentage time in all other speed zones (1.67–3.06 m/s, 3.06–4.17 m/s, 4.17–5.28 m/s, and > 6.39 m/s) and relative distance (m/min) were higher for TOP (ES: 8–10%, 2–7%, 2–3%, 1–1%, 0–1%, respectively; $P < .001$). **Conclusions:** These data demonstrate that GPS analysis procedures should be appropriate for the nature of the sport being studied. In field hockey, TOP and FG analysis procedures are comparable for distance-related variables but significantly different for time-dependent factors. Using inappropriate analysis procedures can alter the perceived physiological demand of elite field hockey because of “rolling” substitutions. Inaccurate perception of physiological demand could negatively influence training prescription (for both intensity and volume).

**Keywords:** time–motion analysis, pacing, physiological demand

Time–motion analysis studies using video analysis and global positioning systems (GPS) have provided valuable data on the physical demands of a variety of team sports. The advent of GPS technology for team sports has provided sports practitioners with more detailed information than previously obtained through video analysis. Athletes’ distance covered in high- and low-velocity movements, time spent at these speeds, their high-acceleration movements, and work-to-rest ratios can all be collected during competition and training. This type of information can be used to set appropriate training zones to elicit the response sought by coaches in each training session or phase of training.

Gabbett provided data from a study that used GPS technology to elucidate the difference in intensity of competition and game play to better understand how training can be used to increase performance. Large differences in a range of measured parameters were shown between elite-level competition and training, with training at a lower intensity than game play. This phenomenon is only visible through time–motion analysis, and, as the author alludes to, there can be discrepancies in reporting data from time–motion analysis studies. While this statement relates to the “description of locomotor activities,” it is evident that the processes used to categorize these activities may also create discrepancies. This will be important when coaches use the information generated to dictate appropriate training intensities to replicate competitive performance.

The current practice for GPS analysis has essentially been derived from soccer. The procedures used follow methods derived from time–motion analysis (using notational observations or video analysis). These methods were developed specifically for the technology being used and are still appropriate for soccer, where players are on the pitch for the full game or do not reenter the game after substitution (ie, the time on pitch is that player’s full game). The current study adds to the analysis of physical performance in field hockey by comparing the impact of data-analysis procedures derived from soccer with sport-specific analysis procedures. Comparing data analysis from the available playing time during a full game (FG) with that restricted to time on pitch (TOP) will establish whether physical-performance measures are influenced by the pacing strategies that are used by players in team sports with rolling substitutions.

**Methods**

**Subjects**

Sixteen elite male field hockey players (mean ± SD age 25 ± 4 y, body mass 70.9 ± 6.6 kg, and maximal oxygen consumption 61.0 ± 2.1 mL · kg$^{-1}$ · min$^{-1}$) participated...
in the study. Athletes were all members of the Scottish national hockey team. They 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 (International Four Nations Tournament and EuroHockey Nations Trophy). Consequently, all participants were in peak physical condition and free from injury at the time of the study. GPS analysis was completed as part of the normal squad performance monitoring. The University of Glasgow ethics committee approved all procedures.

**Design**

In the current study, the physiological demands of elite men’s field hockey competition were investigated, and these demands were analyzed by 2 separate analysis procedures. We hypothesized that FG analysis would provide a more detailed picture of elite field hockey than TOP due to the influence of rolling substitutions. Furthermore, we hypothesized that FG analysis would provide a more accurate description of the work-to-rest ratio and physical demands of game play to establish appropriate training interventions for elite field hockey.

**Apparatus**

The Catapult MiniMaxX 5-Hz GPS system was used for all recordings (Catapult Innovations, Melbourne, Australia). This GPS device has been previously shown to be valid for team sports and field hockey. The GPS was worn, per manufacturer’s instructions, within a specifically designed bib with neoprene pouch that holds the unit between the shoulder blades of the wearer. Players wore these from the start of their warm-up to allow familiarization and time for adjustments before playing.

Body weight was measured using a calibrated scale (Seca 899, Vogel & Halke, Hamburg) with participants wearing undergarments. Maximal oxygen consumption (VO2max) was predicted from a multistage fitness test (Australian Sports Commission 20-m shuttle-run test) completed via MP3 playback on an indoor track before the testing period.

**Environmental Conditions**

Games were played in 2 different countries: Scotland and Ukraine. Three games were played in a temperate climate in June (~14°C). The other 5 games were played in a warm climate in August (~19°C). All games were played on water-based Astroturf away from overhead obstructions. Each tournament was played on the same pitch, so only 2 pitches were used for testing: Satellite signal strength (12.3 ± 1.0 and 10.3 ± 1.2, Scotland and Ukraine, respectively) and horizontal dilution of position were strong (1.3 ± 0.4 and 1.0 ± 0.4, Scotland and Ukraine, respectively). Analysis was conducted on the same data set for comparison of methods removing the error of GPS rate.

**GPS Analyses**

Seventy-three game analyses were collected from this group over 8 games. All opposition teams were from Europe and were ranked 2nd to 32nd in the world at the time of testing.

Data were downloaded, analyzed, and reported using Logan Plus v4.4.0 analysis software. GPS data were reported using 2 methods with specific protocols as follows.

**TOP Analysis Procedure.** During the game, the following procedure was used for TOP analysis:

1. Stopwatch started when GPS units are switched on.
2. Written record of GPS time and Greenwich Mean Time (GMT) for start and end of each half.
3. Written record of GPS time and GMT for rotations—at the start and end of bench time.

After the game, the following procedure was used:

1. Full game downloaded to Logan Plus.
2. GPS coordinates used to create pitch (using Map-builder).
4. Time of commencement of game and second half identified on smooth velocity graph and GPS pitch diagram of an individual player. The point at which a player is stationary on the pitch that corresponds to written record of both GPS start time and GMT is selected as the start point.
5. Termination of pitch time for halftime or full time is taken from smooth velocity graph and GPS pitch diagram of 1 player who is on the pitch in last play of the half—preferably the player used in step 4. This is checked using the written record of GPS time and GMT.
6. The start and end points of first and second halves should be noted and reproduced for each individual.
7. Individual player substitutions and enforced bench time removed using methods 4 and 5 above.
8. Repeat step 7 for all players.
9. Rotations reviewed using written record.

**FG Analysis Procedure.** During the game, the following procedure was used for FG analysis:

1. Stopwatch started when GPS units are switched on.
2. Written record of GPS time and Greenwich Mean Time (GMT) for start and end of each half.

After the game, the following procedure was used:

1. Full game downloaded to Logan Plus.
2. GPS coordinates used to create pitch (this is only completed for 1 method, and subsequently the same pitch is used).
3. Pitch selected.
4. Time of commencement of game and second half identified on smooth velocity graph and GPS pitch diagram of an individual player. The point at which a player is stationary on the pitch that corresponds to written record of both GPS start time and GMT is selected as the start point.

5. Termination of pitch time for halftime or full time is taken from smooth velocity graph and GPS pitch diagram of 1 player who is on the pitch in last play of the half—preferably the player used in step 4. This is checked using the written record of GPS time and GMT.

6. The start and end points of first and second halves are saved and used for each individual.

All downloading and reporting of data were carried out immediately postgame by the same observer. The same written record of GPS time and GMT, as well as pitch coordinates, was used for both methods so that the only difference between methods was the inclusion or exclusion of bench time. All physiological parameters (ie, speed zones) were standardized and downloaded and zones were set as km/h before being converted to m/s for publication.

### Statistical Analyses

All data were normally distributed using an Anderson-Darling normality test. Bland-Altman plots (Tukey mean difference test) were used to illustrate the difference between the 2 methods of analysis on the same data set and not as normally used (to measure 2 different methods measuring the same variable). Data were plotted as FG minus TOP using the following equation:

$$S(x,y) = \{(S_1 + S_2)/2, (S_1 - S_2)\}$$

where $S_1 = \text{FG}$ and $S_2 = \text{TOP}$. Limits of agreement were set at 1.96 × SD of the difference between the 2 methods. One-way ANOVA was performed and Tukey confidence interval tests were used for post hoc analysis of continuous data (eg, distance, relative distance, and player load) or Poisson rate/Mann-Whitney tests were used for post hoc analysis of other variables (eg, number of efforts in velocity or acceleration zones). Effect size (ES) was calculated from 95% confidence intervals of difference (FG – TOP). The physical parameters distance covered, relative distance, and player load were analyzed for correlation to estimated VO2max using regression analysis. Statistical significance was taken as $P \leq .05$, and all data are reported as mean and 95% confidence intervals.

### Results

#### Distance Measurements of GPS Data

The procedures applied to analysis of GPS data appear to have little impact on measurements that derive the distance covered by an athlete during competitive game play. Table 1 demonstrates no difference in distance-related measurements from the GPS analysis procedures, with players covering 5824 m (95% CI; 5677–5972 m) using FG analysis procedures versus 5819 (5661–5976 m) using TOP analysis procedures ($P > .05$). Similarly, there was no difference in maximum velocity (7.58 m/s [7.47–7.67] vs 7.58 m/s [7.47–7.67], $P > .05$) or the commercial-software-derived parameter of player load (645 AU [622–668] vs 631 AU [606–656], $P > .05$).

The number of efforts or distance covered in standardized relative intensity domains was also unaffected by the analysis procedures used in this study, with Tables 1 and 2 demonstrating no difference in efforts or distance covered during jogging (1.67–3.06 m/s), low-speed running (3.06–4.17 m/s), moderate-speed running (4.17–5.28 m/s), and sprinting (>6.39 m/s). During competitive game play, there was no significant correlation between distance covered (either relative or absolute) or player load and predicted VO2max from the multistage fitness test ($R^2$ values 22.2%, 33.7%, and 27.5%; $P > .05$).

### Table 1  Activity Profile Produced by Time-on-Pitch (TOP) and Full-Game (FG) Analysis Procedures

<table>
<thead>
<tr>
<th>Method of GPS Analysis</th>
<th>FG</th>
<th>TOP</th>
<th>Difference (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total distance (m)</td>
<td>5824 (5677–5972)</td>
<td>5819 (5661–5976)</td>
<td>−219 to 208</td>
</tr>
<tr>
<td>Relative distance (m/min)</td>
<td>78 (76–80)</td>
<td>124 (120–128)*</td>
<td>41–50</td>
</tr>
<tr>
<td>Player load accumulation (arbitrary units)</td>
<td>645 (622–668)</td>
<td>631 (606–656)*</td>
<td>−48 to 20</td>
</tr>
<tr>
<td>Efforts &gt;15 km/h (4.17 m/s)</td>
<td>70 (66–73)</td>
<td>70 (67–74)</td>
<td>−4 to 6</td>
</tr>
<tr>
<td>Efforts &gt;19 km/h (5.28 m/s)</td>
<td>28 (27–30)</td>
<td>28 (27–30)</td>
<td>−2 to 2</td>
</tr>
<tr>
<td>Efforts &gt;23 km/h (6.39 m/s)</td>
<td>7 (7–8)</td>
<td>7 (7–8)</td>
<td>−1 to 1</td>
</tr>
<tr>
<td>Acceleration efforts &gt;2 m/s²</td>
<td>16 (14–18)</td>
<td>18 (16–20)</td>
<td>−1 to 5</td>
</tr>
<tr>
<td>Maximum velocity (m/s)</td>
<td>7.58 (7.47–7.67)</td>
<td>7.58 (7.47–7.67)</td>
<td>−0.5 to 0.5</td>
</tr>
<tr>
<td>Work:rest ratio</td>
<td>0.24 (0.22–0.25)</td>
<td>0.55 (0.50–0.62)*</td>
<td>0.26–0.38</td>
</tr>
</tbody>
</table>

* $P < .001$. 
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Time-Dependent Measurements of GPS Data

Obviously, training intensity and volume will be dictated by the time taken to complete an activity or the relative duration spent in an intensity domain during that activity. The average duration of competitive match play during the analyses described here was 74 minutes (74–76), but individual players were on the pitch for only 48 minutes (46–51 min), or 65% (59–71%) of available game time.

The effects of different GPS analysis procedures are illustrated in Figure 1. Panel (a) demonstrates that measurements of distance are unaffected by the analysis procedure employed, but there are differences when assessing important time-related measurements. Traditional TOP analysis procedures resulted in a higher relative distance than in analysis of GPS data using procedures that account for all available game time (124 m/min [120–128] vs 78 m/min [76–80], P < .0001). Table 1 further demonstrates that the work-to-rest ratio is higher with TOP analysis (0.55 [0.50–0.62] vs 0.24 [0.22–0.25], P < .0001).

Figure 2 further illustrates the impact of the GPS analysis procedures on the relative proportion of time that the players spend in relative intensity domains during the analysis period. At all speeds the proportion of time spent at the specified speed was higher by the traditional TOP procedure, as seen by the ES (P < .001).

Discussion

The data presented here show that using different GPS analysis procedures can significantly influence commonly used measurements of physical performance and work-to-rest ratios. In general, it is accepted that distance covered during a game will be directly related to the intermittent physical capacity of the sport,8–12 and, as such, hockey players with higher aerobic capacity are likely to cover greater distances during the time they are on the pitch. In support of this assertion, Lythe and Kilding13 demonstrated that elite hockey players with a mean peak oxygen uptake of 65 mL · kg⁻¹ · min⁻¹ covered around 6800 m during competitive game play (compared with 5800 m in this study where the players are predicted to have a lower mean aerobic capacity). However, in the current study the distance covered (both relative and absolute) and player load did not correlate with predicted VO₂max. This may be due to the indirect test used or relatively small participant numbers. Nevertheless, since the main aim of this study was to compare effects of the analysis procedures this finding will have little impact.

Field hockey is an intermittent sport characterized by short periods of very high intensity interspersed with low-intensity activity and periods of inactivity (both on the pitch and on the bench during unlimited substitutions). Thus, the energy demands of hockey can be further analyzed by breaking down movements on the pitch into different intensity (speed) zones.4,13 As with total distance covered, the distances traveled in different intensity zones were not significantly affected by the data-analysis procedures used in this study. Thus, FG analysis provides valid information in this respect to understand the physiological demands of the game.

The data-analysis procedures described here do, however, produce significant differences when considering distances traveled relative to TOP. This is self-evident in relation to the significantly different work-to-rest ratios when including periods off the pitch show much higher recovery periods and suggest a lower relative workload during game play. Furthermore, the proportion of time spent in each of the intensity zones was significantly reduced by inclusion of all available game time in the analysis procedure. These differences are further emphasized when considering the average distance covered during each minute of the analysis period (“relative distance”). The nature of the analysis procedure employed will therefore have a significant impact on the inferences that can be made on player performance or the physiological demands of competition that have to be addressed in training.4

Classic time-motion analyses of team sports have employed TOP analysis because the video footage is generally restricted to the playing surface, so it is unsurprising that the TOP procedure has been adopted in

<table>
<thead>
<tr>
<th>Distance (%)</th>
<th>Time (%)</th>
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<tbody>
<tr>
<td>0–6 km/h (0–1.67 m/s)</td>
<td>−3 to 2</td>
</tr>
<tr>
<td>6–11 km/h (1.67–3.06 m/s)</td>
<td>−1 to 1</td>
</tr>
<tr>
<td>11–15 km/h (3.06–4.17 m/s)</td>
<td>−2 to 1</td>
</tr>
<tr>
<td>15–19 km/h (4.17–5.28 m/s)</td>
<td>−2 to 2</td>
</tr>
<tr>
<td>19–23 km/h (5.28–6.39 m/s)</td>
<td>−0.3 to 1</td>
</tr>
<tr>
<td>&gt;23 km/h (&gt;6.39 m/s)</td>
<td>−0.3 to 0.3</td>
</tr>
</tbody>
</table>

*P < .001.
subsequent GPS analysis to allow direct comparison with the existing data despite data being available from beyond the playing surface. From this analysis procedure, field hockey usually ranks high in terms of relative distance, with values as high as 140 m/min; it was 124 m/minute in the current study.\textsuperscript{13–15} This is higher than is generally reported in other team sports; for example, in soccer relative distance is generally reported as 100 to 120 m/minute.\textsuperscript{16} These higher values are recorded despite the fact that a hockey player’s aerobic capacity is generally lower than in an equivalent level of soccer and that the game is played on a smaller pitch than in soccer and does not seem to be influenced by the impact of the hockey “stance” on speed over the ground.

The data from studies that use TOP analysis have led to the suggestion that hockey training is not intense enough to reflect the physiological demands of competition.\textsuperscript{4} However, the FG analysis procedure described here...
measures relative distance at around 80 m/min and may limit the impact of the previous data due to the inherent pacing strategies employed by the players during competitive play (where they work at a higher intensity for their allotted rotation before resting and then returning to play). This artifact of the analysis procedure is further emphasized if data are expressed in relation to the playing position rather than the individual player (e.g., Jennings et al. report average distances of nearly 9800 m during international competition).

If rest values are removed from analysis by restricting data to just TOP, a skewed impression of the true physiological demands will be obtained. As a consequence, training based on such analysis will exceed the true demands of competition and increase the risk of injury and overtraining. In essence, FG analysis will give an indication of appropriate training volume even if the appropriate training intensity is difficult to predict from the data currently available.

Furthermore, this skewed impression of game intensity is likely to reflect pacing strategies used in field hockey game play and so may also affect other team sports even when the game is subject to restricted substitutions. While time–motion analysis is not ideal for assessing pacing strategies during competitive game play, it does appear that data from FG analysis may allow some insight into potential pacing strategies where TOP does not. For example, it could be argued that use of tactical substitutions in soccer is relatively commonplace in the last 20 to 30 minutes of game play, so the total TOP for the players being substituted will be reduced. If the players knew that the intention was to remove them from play, their pacing strategy would be based on a shorter playing period. Consequently, the relative distance recorded during the TOP would be greater than that recorded for a player expecting to play the whole game. It may also be the case that the decision to replace a player was based on a rehabilitation strategy from a previous injury, and using relative distance recorded during the TOP analysis might suggest a greater level of preparedness than is actually the case (increasing the risk of recurrent reinjury).

**Limitations**

The findings presented here are limited by some methodological issues and differ in some respects from other published literature. First, the use of 5-Hz GPS technology has been shown to be less reliable than the 10-Hz systems currently available (particularly in identifying high-speed efforts). In an observational study or intervention this could result in less accurate data being reported, but in this study, where the same data were used for both analysis procedures, any error due to low-frequency data recording is removed. However, this limitation should be acknowledged when considering the
data in relation to the physical performance of elite field hockey players. Second, Castellano et al. have shown that contextual variables such as being home or away can affect the resulting work-rate profiles of players. In the current study this was not accounted for in the initial study design, but as the same data set is used for comparison this error is also nullified. Finally, the Yo-Yo IR2 intermittent endurance test has been shown to be better correlated to measures of physical performance in intermittent team sports9–12 and may have provided a more appropriate prediction of VO₂max. We recognize the multistage fitness test is not the most appropriate test for these athletes but were constrained to use data from this test during the study.

**Conclusion, Practical Applications**

The data presented here emphasize the importance of adapting GPS analysis procedures to the specific circumstances of the game or an individual player’s activity within that game. It is unequivocal that hockey is an intermittent high-intensity sport characterized by fast passages of play. However, the speed of the ball movement does not necessitate a higher-intensity physiological demand on the players during the game, and it is likely that traditional time–motion analysis procedures will overestimate these demands. Analysis of GPS data in relation to the full playing time may allow appreciation of pacing strategies used during game play and alter our impression of the training intensity and volume required to elicit an appropriate physiological adaptation or training response.

**References**