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Short Communication

Speed profiles in wheelchair court sports; comparison of two
methods for measuring wheelchair mobility performance

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Speed profiles in wheelchair court sports; comparison of two methods for measuring wheelchair mobility performance

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Abstract

Wheelchair mobility performance is an important aspect in most wheelchair court sports, commonly measured with an indoor tracking system or wheelchair bound inertial sensors. Both methods provide key wheelchair mobility performance outcomes regarding speed. In this study, we compared speed profiles of both methods to gain insight into the level of agreement, for recommendations regarding future performance measurement. Data were obtained from 5 male highly trained wheelchair basketball players during match play. Players were equipped simultaneously with a tag on the footplate for the indoor tracking system (~8 Hz) and inertial sensors on both wheels and frame (199.8 Hz). Being part of a larger study on 3 vs 3 player game formats, data were collected in several matches with varying field sizes, but activity profiles closely resembled regular match play. Both systems provide similar outcomes regarding distance covered and average speed. Due to differences in sampling frequency and sensor location (reference point) on the wheelchair (for speed calculation), minor differences were revealed at low speeds (<2.5 m/s). Since both systems provide complementary features, a hybrid solution as proved feasible in this study, could possibly serve as the new gold standard for mobility performance measurement in wheelchair basketball or wheelchair court sports in general.

Key words: wheelchair basketball, activity profiles, wheelchair mobility performance, inertial sensors, indoor tracking.

Introduction

Quantitative assessment of an athlete's individual wheelchair mobility performance is needed to evaluate game performance, improve wheelchair settings and optimize training routines (Mason et al., 2013). Next to sport specific mobility performance outcomes, speed is one of the key performance indicators, relevant to all wheelchair sports (Burton et al., 2010, Rhodes et al., 2015 & van der Slikke et al., 2016a). Based on a semi-structured interview of nine elite athletes, Mason et al. (2010) identified speed as one of the key performance indicators, important for optimizing wheelchair configuration. Fuss et al. (2012) emphasises the benefits of standard speed measurements in high-performance sports with decreasing costs of technology required. On court wheelchair mobility performance research, is often based on methods that either rely on wheelchair mounted or global reference sensors. Wheelchair bound systems essentially measure wheel rotational speed to calculate forward speed, with data loggers based on reed-switches (Tolerico et al., 2007), potentiometers (Velocometer, Moss et al., 2003) or inertial sensors (Pansiot et al., 2011 & van der Slikke et al., 2015a). If sensors are placed in a fixed global position, wheelchair speed is measured with either laser technology (Ferro et al., 2016) or radio frequency based technology (Rhodes et al., 2014). This technical note describes the comparison between two common systems for performance measurement in court sports, namely the inertial sensor based wheelchair mobility performance monitor (WMPM, van der Slikke et al., 2015a) and the global reference based indoor tracking system (ITS, Rhodes et al., 2014). Inertial sensor based methods like the WMPM allow for easy and accurate measurement of wheelchair mobility performance, but provide no information about absolute field position. Indoor tracking systems provide positional data, enabling tactical team analyses, but lack the option to calculate higher order outcomes like acceleration, due to sample frequency restrictions. In this study, we compared outcomes of both methods regarding speed, to gain insight into the level of agreement between devices.

Methods

Participants & instrumentation

Five male, highly trained wheelchair basketball players (age: 20 ± 1 years; playing experience: 7 ± 2 years, IWBF classification: 1.0, 2.0, 3.0, 3.5 & 4.5) volunteered to participate in the study. Their wheelchair mobility performance was monitored using an ITS (Ubisense, ~ 8 Hz) with a tag positioned on the footplate and simultaneously with three inertial sensors (Shimmer3, 199.8 Hz) on wheels and frame (WMPM) of their own customised sports wheelchairs. Since the objective was to compare existing technologies, procedures and settings used for ITS and WMPM were in line with previous research.

Measurements and setup

Being part of a larger study on wheelchair basketball game innovations (Mason et al., 2017), measurements (6 times 10 min.) were performed during different 3 versus 3 game formats (full court, half court and a modified court length of 22 m). Six ITS sensors were located around the perimeter of a regulation-size wheelchair basketball court (28 x 15 m). The sensors were positioned at each of the four corners of the court, with two additional sensors positioned at the half-way line. Each sensor was mounted on an extendable tripod, elevated approximately 4 m high. The digital signal processing of the ITS was originally optimised for position accuracy, using a 3-pass sliding-average filter with a window width proportional to the tag frequency (Rhodes et al., 2014). In the ITS processing for this study, a five point (~ 0.625 Hz) sliding average filter was applied to the raw position data of the tag. The tag was positioned at the footplate to ensure best reception by the sensors, as described by Perrat et al. (2015). For the wheelchair mobility profile, speed is derived from the filtered position data. Note that the outcomes of the ITS describe the motion of the tag mounted on the footplate, whereas the WMPM describes the movement of the wheelchair frame centre in-between both main wheels, so the reference points on the wheelchair differ (Figure 1). For the WMPM speed calculation is based on wheel rotation derived from the wheel sensors, with additional skid correction algorithm (van der Slikke 2015b). Heading direction is based on the inertial sensor mounted to the frame (van der Slikke 2015a). Due to the shared frequency bandwidth

between multiple player tags in the ITS, the sample frequency varied slightly around 8Hz. Sample timestamps were utilized to resample up to the WMPM frequency (linear interpolation, Interp1, Matlab). Given the absence of hardware synchronisation options, a cross-correlation of speed signals was used for post synchronisation of systems (Li et al., 1999).

Data processing

For each of the six measurements per player (10 min. match play), distance covered, speed and time in six fixed speed zones (see Table 1) was calculated. The speed zone thresholds are enclosed in the ITS method, originally based on the research regarding wheelchair rugby (Rhodes et al., 2015) and wheelchair tennis (Sindall et al., 2013).

The single tag per wheelchair for the ITS does not allow for determination of heading direction of the wheelchair, so no distinction between forward and backward movement is made. The WMPM does differentiate between directions, but to allow for proper comparison with the ITS, *absolute* values of speed were used. To gain insight in the relationship between ITS and WMPM across speeds, the average value of both systems categorised by 0.05 m/s increments, were plotted against each other.

Although the WMPM reference point at the frame centre seems preferable over a reference point at the foot plate, the ITS position outcome does not allow for recalculation of an alternative point on the wheelchair frame, since heading direction is unknown. It was however possible to re-calculate WMPM outcomes to a foot plate reference point and with filtering similar to the ITS procedure. The WMPM heading direction and the measured distance between rear axle and foot plate was used to calculate the speed of the footplate reference point (see Appendix I). This speed signal was low-pass filtered (0.5 Hz, 2nd order butterworth) and used to calculate the alternative outcomes, named WMPM2. This is not the preferred outcome of the WMPM, but does allow for the most optimal comparison of calculated displacement and speed.

Table 1

Average speed and distance related outcomes of the five athletes in six measurements. Data of the indoor tracking system (ITS) are shown in the middle, the Wheelchair Mobility Performance Monitor (WMPM) outcomes are shown on the left and the adjusted WMPM2 shown on the right. Columns in-between show the average differences and standard deviations (SD) of the differences between methods. The lower part shows the percentage time spend in the different speed zones, as adopted from Mason et al. (2014).

		<u>WMPM</u>	<u>difference</u>	<u>SD</u>	<u>ITS</u>	<u>difference</u>	<u>SD</u>	<u>WMPM2</u>
<u>Distance</u>		<u>837.8</u>	<u>-2.6%</u>	<u>3.2%</u>	<u>882.3</u>	<u>0.1%</u>	<u>3.3%</u>	<u>883.4</u>
<u>Speed (m/s)</u>	<u>average</u>	<u>1.30</u>	<u>-2.6%</u>	<u>3.2%</u>	<u>1.37</u>	<u>0.1%</u>	<u>3.3%</u>	<u>1.38</u>
	<u>RMSE</u>		<u>0.41</u>	<u>0.060</u>		<u>0.33</u>	<u>0.072</u>	
	<u>0 - 0.5</u>	<u>22.4%</u>	<u>13.7</u>	<u>5.1</u>	<u>8.7%</u>	<u>5.7</u>	<u>4.5</u>	<u>14.4%</u>
	<u>0.5 - 1.5</u>	<u>37.9%</u>	<u>-15.7</u>	<u>5.9</u>	<u>53.6%</u>	<u>-9.0</u>	<u>5.1</u>	<u>44.6%</u>
<u>Speed Zone</u>	<u>1.5 - 2.5</u>	<u>29.3%</u>	<u>-0.1</u>	<u>3.2</u>	<u>29.4%</u>	<u>2.0</u>	<u>2.8</u>	<u>31.3%</u>
<u>(m/s)</u>	<u>2.5 - 3.0</u>	<u>6.6%</u>	<u>1.0</u>	<u>1.4</u>	<u>5.5%</u>	<u>0.9</u>	<u>1.4</u>	<u>6.4%</u>
	<u>3.0 - 3.5</u>	<u>2.8%</u>	<u>0.7</u>	<u>0.9</u>	<u>2.1%</u>	<u>0.4</u>	<u>0.9</u>	<u>2.5%</u>
	<u>3.5+</u>	<u>1.0%</u>	<u>0.3</u>	<u>0.7</u>	<u>0.7%</u>	<u>0.0</u>	<u>0.7</u>	<u>0.7%</u>

Results

The average distance calculated per 10 min. game time was 882.3 m for the ITS, 837.8 m for the WMPM and 883.4 m for WMPM2 (see Table 1). Differences in calculated distance per 10 min. match play, between ITS and WMPM ranged from -7.6% to 6.4% and between ITS and WMPM2 from -7.6% to 7.3%. The root mean square differences (RMSDs) were calculated based on the comparison between the resampled ITS speed signal versus the WMPM speed (RMSD of 0.41 m/s) and the WMPM2 speed (RMSD of 0.33 m/s). The differences in percentage time spent within the six fixed speed zones varied from 0.1 – 15.7 between ITS and WMPM and 0.0 – 9.0 between ITS and WMPM2 (see Table 1). Figure 2 shows a typical example (20s game play) of the speed of a wheelchair as measured with the different systems. The average ITS corresponding speed per 0.05m/s speed category of the WMPM is shown in Figure 3.

Table 1

Average speed and distance related outcomes of the five athletes in six measurements. Data of the indoor tracking system (ITS) are shown in the middle, the Wheelchair Mobility Performance Monitor (WMPM) outcomes are shown on the left and the adjusted WMPM2 shown on the right. Columns in-between show the average differences and standard deviations (SD) of the differences between methods. The lower part shows the percentage time spend in the different speed zones, as adopted from Mason et al. (2014).

		<u>WMPM</u>	<u>difference</u>	<u>SD</u>	<u>ITS</u>	<u>difference</u>	<u>SD</u>	<u>WMPM2</u>
<u>Distance</u>	-	<u>837.8</u>	<u>-2.6%</u>	<u>3.2%</u>	<u>882.3</u>	<u>0.1%</u>	<u>3.3%</u>	<u>883.4</u>
<u>Speed (m/s)</u>	<u>average</u>	<u>1.30</u>	<u>-2.6%</u>	<u>3.2%</u>	<u>1.37</u>	<u>0.1%</u>	<u>3.3%</u>	<u>1.38</u>
	<u>RMSE</u>	-	<u>0.41</u>	<u>0.060</u>	-	<u>0.33</u>	<u>0.072</u>	-
<u>Speed Zone</u> <u>(m/s)</u>	<u>0 - 0.5</u>	<u>22.4%</u>	<u>13.7</u>	<u>5.1</u>	<u>8.7%</u>	<u>5.7</u>	<u>4.5</u>	<u>14.4%</u>
	<u>0.5 - 1.5</u>	<u>37.9%</u>	<u>-15.7</u>	<u>5.9</u>	<u>53.6%</u>	<u>-9.0</u>	<u>5.1</u>	<u>44.6%</u>
	<u>1.5 - 2.5</u>	<u>29.3%</u>	<u>-0.1</u>	<u>3.2</u>	<u>29.4%</u>	<u>2.0</u>	<u>2.8</u>	<u>31.3%</u>
	<u>2.5 - 3.0</u>	<u>6.6%</u>	<u>1.0</u>	<u>1.4</u>	<u>5.5%</u>	<u>0.9</u>	<u>1.4</u>	<u>6.4%</u>
	<u>3.0 - 3.5</u>	<u>2.8%</u>	<u>0.7</u>	<u>0.9</u>	<u>2.1%</u>	<u>0.4</u>	<u>0.9</u>	<u>2.5%</u>
	<u>3.5+</u>	<u>1.0%</u>	<u>0.3</u>	<u>0.7</u>	<u>0.7%</u>	<u>0.0</u>	<u>0.7</u>	<u>0.7%</u>

Figure2

Figure 3 The ITS speed plotted against the WMPM speed. Per increment of 0.05 m/s the average of all corresponding ITS data points was calculated (80 averages / dots). The graph shows higher values for ITS (above the dashed line) at below average speeds, and slightly lower values at above average speeds (below dashed line), compared to the WMPM.

Discussion

In general, both systems provide quite similar speed data, but the method features do account for some typical deviations. The difference in reference point on the wheelchair (footplate vs. frame centre) affected the calculated speed and distance slightly ($\leq 2.6\%$). In the ITS, turns on the spot (turning without displacement of the frame centre) will cause a displacement equal to the circumference path described by the footplate, whereas the WMPM will not calculate any displacement at the same time. Since the ITS only provides information on tag position and not on heading direction, it is impossible to calculate the speed and distance covered of a different reference point on the wheelchair. To attain a fair comparison, it is however possible to adjust the WMPM outcomes to a reference point near the footplate. Once adjusted, systems provide very similar distance and average speed data ($\leq 0.1\% \pm 3.3\%$), although still individual differences up to 7.6% occur. The RMSD of 0.41 m/s for the WSPM speed and 0.33 m/s for the WMPM2 speed seem acceptable for this type of measurements, where speeds range from 0 - ~5m/s in match play (van der Slikke et al., 2016). Differences in instantaneous speeds as expressed in the RMSD, do not influence the average speeds calculated, but might affect calculated maximal speeds. The position of the reference point causes a very low percentage of time in the lowest speed zone (<0.5 m/s) for the ITS and WMPM2, because when not moving forward, often turns on the spot still cause some speed (see Figure 2, time 124.5 - 126s). The restricted sample frequency of the ITS, requires low-pass filtering with a very low cut-off frequency (~ 0.625 Hz), drawing the speed signal towards the average, so with more time assigned to the corresponding average speed class (0.5 – 1.5 m/s, see Figure 2). The abovementioned effects also show in Figure 3, with ITS values higher than WMPM in speeds below ~ 1.5 m/s, due to the tag position and rotations, and ITS values slightly lower than the WMPM in speeds over ~ 1.5 m/s, due to more severe low-pass filtering. These results provided an insight to what extent research outcomes obtained with both methods are interchangeable. For distance, average speed and

above average speeds zones (> 1.5 m/s), both methods provide similar outcomes. Speed profiles show higher ITS values for below average speeds and slightly lower values for above average speeds, compared to the WMPM.

Although match play settings for the measurements deviated slightly from regular 5 vs 5 match play at regular court settings, the activity profiles did closely resemble the typical elite level performance. The average speed in the measurements was 1.37 m/s (1.3 for the WMPM), which is only slightly lower than reported in literature for elite level wheelchair basketball match play 1.48 m/s (Spörner et al., 2009) and 1.57 m/s (van der Slikke et al., 2016b). Also, peak speeds were a bit lower than reported earlier in elite wheelchair basketball, 2.19 m/s compared to 2.95 m/s (van der Slikke et al., 2016b). The somewhat lower average and peak speed could be explained by the reduced court sizes (half court and modified 22m court length) in part of the measurements. Those dimensions might also have led to an increase in rotations, magnifying the differences between systems due the difference in reference point. Regular match play with higher average speed and less rotations, is expected to positively influence method agreement.

Conclusion

For applied sports research, ease of use and fast turnaround of feedback are crucial in any method. Both measurement systems meet those demands and outcomes proved interchangeable to a great extent. The type of method used for future research is depending on the research question, with a focus on field position (ITS) or acceleration profiles (WMPM). The ITS provides information on field position, so enables wheelchair mobility performance analysis split by game specific characters (e.g. offence-defence, location to the bucket and heat maps). The WMPM provides more detailed kinematic data, allowing for analyses regarding e.g. accelerations, rotations and push characteristics (van der Slikke et al., 2016b). For the most comprehensive approach, this study proved the feasibility of a hybrid solution incorporating both methods, hence providing the best of both worlds and possibly serving as the new standard for mobility performance in court sports.

237

238 **Conflict of interest**

239 None.

240

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Appendix I

The frame centre displacement in the WMPM is based on the average wheel speed derived from wheel rotational speed and wheel circumference (van der Slikke et al., 2015a). This calculation results in a reference point in the middle between both main wheels, thus the middle of the camber bar. To recalculate the speed of a reference point on the footplate, the speed of this point due to rotations with regard to the original reference point, is added. See Equation 1, with the recalculated speed ($Speed_{WMPM2}$, [m/s]) based on the original speed ($Speed_{WMPM}$, [m/s]), the frame rotational speed ($RotSpeed_{WMPM}$, [rad/s]) and the distance between rear axle and footplate (d_{a-f} , [m]).

$$Speed_{WMPM2} = \sqrt{Speed_{WMPM}^2 + RotSpeed_{WMPM}^2 \times d_{a-f}^2} \quad (1)$$