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From big data to rich data: The key features of athlete wheelchair mobility performance

R.M.A. van der Slikke [a,b,*], M.A.M. Berger [a], D.J.J. Bregman [b], H.E.J. Veeger [b,c]

[a] Human Kinetic Technology, The Hague University of Applied Sciences, Johanna Westerdijkplein 75, 2521EN The Hague, The Netherlands
[b] Department of Biomechanical Engineering, Delft University of Technology, The Netherlands
[c] Research Institute MOVE, VU, Amsterdam, The Netherlands

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ABSTRACT

Quantitative assessment of an athlete's individual wheelchair mobility performance is one prerequisite needed to evaluate game performance, improve wheelchair settings and optimize training routines. Inertial Measurement Unit (IMU) based methods can be used to perform such quantitative assessment, providing a large number of kinematic data. The goal of this research was to reduce that large amount of data to a set of key features best describing wheelchair mobility performance in match play and present them in meaningful way for both scientists *and* athletes. To test the discriminative power, wheelchair mobility characteristics of athletes with different performance levels were compared.

The wheelchair kinematics of 29 (inter-)national level athletes were measured during a match using three inertial sensors mounted on the wheelchair. Principal component analysis was used to reduce 22 kinematic outcomes to a set of six outcomes regarding linear and rotational movement; speed and acceleration; average and best performance. In addition, it was explored whether groups of athletes with known performance differences based on their impairment classification also differed with respect to these key outcomes using univariate general linear models. For all six key outcomes classification showed to be a significant factor ($p < 0.05$).

We composed a set of six key kinematic outcomes that accurately describe wheelchair mobility performance in match play. The key kinematic outcomes were displayed in an easy to interpret way, usable for athletes, coaches and scientists. This standardized representation enables comparison of different wheelchair sports regarding wheelchair mobility, but also evaluation at the level of an individual athlete. By this means, the tool could enhance further development of wheelchair sports in general.

1. Introduction

Since wheelchair basketball has reached an increased level of professionalism, there is a need to optimize all factors contributing to team performance, like team interplay and individual athlete performance. The athlete's performance in turn can be subdivided in physical performance, mobility performance and game performance. Physical performance only concerns the athlete (Bloxham et al., 2001), whereas mobility performance is the measure for the combined wheelchair–athlete combination (Mason et al., 2013). Therefore, although mobility performance is established by athlete exertion, it is often expressed in terms of wheelchair kinematics (Mason et al., 2012). Game performance is an overall measure and defined as the true quality of an athlete's contribution to the game (Byrnes and Hedrick, 1994). The present study investigated ways to improve quantification and measurement of *wheelchair mobility performance characteristics*, to enable evaluation of interventions aiming at optimizing wheelchair–athlete interaction.

To date, wheelchair mobility performance is mostly considered and utilized as a concept, instead of a well quantified measure. With regard to activities, mobility performance during a match can be described using systematic observation (de Witte et al., 2015). With more focus on kinematic aspects of mobility performance, Sarro et al. (2010) used video tracking and Rhodes et al. (2015a, 2015b) presented an accurate iGPS system for measuring field position. Still, those systems require to (temporarily) instrument the sports hall and do not allow for calculations of higher order kinematic outcomes due to limited sample frequencies (10 and 16 Hz respectively). Sporner et al. (2009) used a miniature data logger to collect match data of both wheelchair rugby and basketball athletes and claimed the first to provide match data on average speed and distance. Although these systems provide data on aspects of

* Corresponding author at: Human Kinetic Technology, The Hague University of Applied Sciences, Johanna Westerdijkplein 75, 2521EN The Hague, The Netherlands.
E-mail address: r.m.a.vanderslikke@hhs.nl (R.M.A. van der Slikke).

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mobility performance, they lack outcomes related to (rotational) acceleration, which is expected to be important for quantification of wheelchair performance (van der Slikke et al., 2015a).

Recent technical developments allow wheelchair mobility performance to be quantified using an Inertial Measurement Unit (IMU) setup. However, this may result in an abundance of sometimes hard to interpret kinematic data. Usma-Alvarez et al. (2010) used IMUs to determine performance of wheelchair rugby players in a standard agility test while Fuss et al. (2012b) used fractal dimension analysis of frame acceleration to identify activity patterns during wheelchair rugby match play. A newly developed method utilizing IMUs (van der Slikke et al., 2015a) appeared reliable for measuring an extensive set of wheelchair kinematic outcomes, but was not yet applied in actual match play and lacked usability for sports practice given the bulk of outcomes provided.

The aim of this study was to compose an easy to interpret display of key features best representing wheelchair mobility performance. Three subsequent steps were undertaken to meet that aim: 1) reduction of a large number of kinematic outcomes to a set of key kinematic outcomes; 2) seeking a way to display key kinematic features in a concise but clear fashion, usable for coach and athlete; 3) testing if key features discriminate well between athletes of different performance levels. Since mobility performance is known to strongly relate to classification in wheelchair rugby (Rhodes et al., 2015b; Sarro et al., 2010; Usma-Alvarez et al., 2010), it should do so in wheelchair basketball as well, since both games use the same classification principle. Given this assumed performance difference due to classification, the new method was rated accurate if indeed classification appeared to be a significant factor in measured kinematic outcomes.

2. Methods

2.1. Setup and participants

Wheelchair kinematics of wheelchair basketball athletes were measured during 11 premier division competition and friendly international level matches. Twenty-nine athletes were measured with 12 male first division athletes (National NLD), nine female internationals (NLD & GBR) and eight male internationals (NLD, ISR & AUS). Athlete classification was evenly distributed over these three competition level groups (Table 1, Appendix A). This study was approved by the ethical committee of the faculty of Human Movement Sciences: ECB-2014-2. All participants signed an informed consent after being informed on the aims and procedures of the experiment.

2.2. Inertial Measurement Units

The athlete's wheelchair was equipped with three IMUs (X-IO technologies, Fig. 1), one on each rear wheel axis and one on the rear frame bar. The frame sensor was used for measuring forward acceleration as well as rotation of the frame in the horizontal plane. The combined signal of wheel sensor acceleration and gyroscope was used to estimate wheel rotation, which in turn provided frame displacement given the wheel circumference.

Table 1
The distribution of classification and age (years) per competition level group.

Level group		*Mean*	*SD*	Classification						
				1	1.5	2	2.5	3	4	4.5
National Male (NM)	Class	2.5	1.4	3	2	2		1	3	1
	Age	27.9	9.4							
International Male (IM)	Class	2.8	1.1	1	1	3	1	1	1	1
	Age	30	6							
International Female (IF)	Class	2.8	1.3	1	2		2	1	1	2
	Age	28.3	8.8							
Total				**5**	**5**	**5**	**3**	**3**	**5**	**4**

Horizontal frame rotation estimates were used to correct the wheel gyroscope signal for wheel camber angle, as described by Pansiot et al. (2011), Fuss et al. (2012a) and van der Slikke et al. (2015a). Furthermore, a skid correction algorithm was applied to reduce the effect of single or concurrent wheel skidding (van der Slikke et al., 2015b).

2.3. Analysis

2.3.1. Kinematic outcomes

A total of 22 wheelchair kinematic outcomes regarding forward and rotational movement were initially extracted from the IMU based measurement method. To enable genuine comparison independent of match time, average kinematic outcomes were calculated for actual movement time (>0.1 m/s) and rotation time ($>10°$/s) respectively. For all movements of at least 0.5 s, basic kinematic outcomes were calculated: forward frame displacement, speed, acceleration, rotation in the horizontal plane, rotational speed and rotational acceleration. Additionally, combined kinematic outcomes were calculated including rotational kinematic outcomes with minimal forward speed (turn) and rotational kinematic outcomes while driving (curve). Both turn and curve kinematic outcomes were calculated with different boundaries for forward speed (FS): “turn”, FS -0.5 to 0.5 m/s; “turn2”, FS -1.5 to 1.5 m/s (1.5 m/s equals average FS); “curve”, FS 1–2 m/s and “curve2”, 1.5+m/s. For all (rotational) speed related kinematic outcomes, also averages of best ($n=5$) performances were calculated (see Appendix B for a more detailed description of outcomes).

2.3.2. Statistics

Principal Component Analysis (PCA) was used to reduce the number of kinematic outcomes to arrive at independent key factors that describe an athlete's wheelchair mobility performance. The Kaiser–Meyer–Olkin test was used to verify if the dataset of 22 outcomes was suitable for PCA (KMO value >0.5). The PCA was applied with a VariMax rotation to identify components that are not highly correlated. The point of inflexion in the scree-plot was used to make an initial selection for the number of retaining components (Field, 2013). The PCA shows how well each of the 22 kinematic outcomes load ($-1<1$) on those retaining components. For each component, one kinematic outcome was selected, typically the one with the highest loading. In case of a nearly similar loading of several outcomes on a component, also the second or third outcome could be selected based on conceptual reasons. Less complex outcomes, easier to interpret for sports application were preferred over more complex outcomes and a somewhat even distribution between outcomes describing linear or rotational kinematics was aimed at (see Appendix C for application of this concept to the results).

Univariate one-way ANOVA's (General Linear Models) were used to test whether groups of athletes with different performance levels (different classification) also differed with respect to the key outcomes that were identified using PCA. The athlete's classifications ranged from 1–4.5, so the overall group was split in seven classification groups (Table 1, no athletes classified as 3.5). A Holm–Bonferroni correction was applied to correct for multiple testing. In addition, univariate two-way ANOVA's were used to determine whether the differences in the key outcomes between the performance level groups were different for competition levels. If this interaction was not significant ($p>0.05$), results regarding performance level were considered to be independent from competition level.

3. Results

3.1. Kinematic outcomes

Due to high impacts in matches, there was malfunctioning of one of the three sensors in two measurements. One athlete could be measured in a subsequent match, so only the measurement of one international male athlete was lost and the kinematic outcomes of 29 athletes were used in the PCA (Table 1).

Six key kinematic outcomes were selected based on PCA, after the dataset was tested for PCA suitability by the Kaiser–Meyer–Olkin test (0.695, KMO$>$0.5). The PCA scree plot shows a first point of inflexion after four components and a less prominent point of inflexion after six components (Fig. 2). For subsequent analysis, these six components were used. Table 2 shows the three outcomes with the highest load on each PCA component and the final selection of outcomes made. The final set of kinematic outcomes selected for the wheelchair mobility performance comprises: 1) average of the best five rotational speeds in a turn (-1.5 to 1.5 m/s forward speed); 2) average rotational acceleration; 3) average forward acceleration in the first 2 m from standstill; 4)