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Push Characteristics In Wheelchair Court Sport Sprinting

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Abstract

Short sprints are important components of most wheelchair court sports, since being faster than the opponent often determines keeping ball possession or not. Sprinting capacity is best measured during a field test, allowing the athlete to freely choose push strategies adapted to their own wheelchair setting, physical ability, classification and speed changes during a sprint. The key test outcome is sprint duration, but there are various ways to accomplish the same sprint time. So can different push strategies be identified in a wheelchair sport and how do they relate to athlete level/classification and wheelchair configuration? These relationships were investigated by field tests of 30 male wheelchair basketball athletes during a 12 meter sprint in their own wheelchair. A recently developed method for ambulatory measurement was used to calculate wheelchair kinematics [1], providing outcomes on displacement, speed, acceleration and pushes. Additionally maximal isometric push force was recorded and rear seat height was noted. Within the measured athletes, internationals were expected to be faster due to a better physical training status and technique, allowing them to sprint with fewer (but more powerful) pushes. Likewise, athletes of higher classification were expected to be faster due their superior physical capacity, but the effect on the number of pushes used was not that evident. Video analysis was added to validate push detection of the ambulatory measurement system. Mutual correlations and competition level differences of sprint characteristics were calculated. General Linear Models (GLM) were drawn to determine the effect of competition level and classification on sprint time and number of pushes.

In the overall dataset sprint characteristics did not correlate significantly with classification, but if split by competition level, there were significant correlations with sprint time ($r=-0.715$, $p=0.006$) and number of pushes ($r=-0.647$, $p= 0.017$) in the national level athletes. Sprint time, number of pushes and isometric push force differed significantly between national and international level wheelchair basketball athletes. Competition level showed to be a significant ($p<0.05$) factor in univariate GLMs for sprint time and number of pushes, whereas classification did not. The interaction of competition level and classification as a factor in univariate GLMs was significant.

As hypothesized, international level athletes were faster with fewer pushes, even though their higher average seat height was less optimal for propulsion [2]. The interaction effect of competition level and classification in the GLM indicates that the effect of classification on sprint time and number of pushes is different between competition levels. Indeed, in the national level athletes there was a clear relationship between classification and sprint time / number of pushes, but not in internationals. This difference is pointing at a more professional level of wheelchair configuration or better technique of the international athletes regarding sprint performance. Given the correlation between seat height and classification, the seat height of lowly classified athletes seemed optimized for sprinting, whereas seat height of highly classified athletes with already adequate sprinting capacity was optimized for upward reach. Future research based on larger groups with more even distribution over classifications could provide more solid models and reveal more detailed insight in push strategy efficacy. Given the proven reliability of the inertial sensor based method [1] and the proven reliability for push detection in sprinting, this research could well be performed using this easy to use ambulatory method. Although more challenging than well controlled experimental research, the field based setting in this research revealed additional information not only describing the relation between wheelchair setting and performance, but also describing its practical applications if other game demands were taken into account. The results of this approach is believed to assist athletes, coaches and wheelchair experts in decision making concerning wheelchair configuration and athlete training.

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Keywords: Wheelchair kinematics; Wheelchair Basketball; Push detection; Inertial Measurement Unit; Instrumented wheelchair

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1. Introduction

In wheelchair sports, athlete and wheelchair could be considered as one functional unit allowing overall performance improvement by athlete training, wheelchair optimization and perfecting the interaction [2]. The ability to perform a sprint as fast as possible is an important factor in most court sports, since it determines the opportunity to take initiative in the next action. But by optimizing for sprint capacity, there often is a trade-off with other performance aspects, such as upward reach or stability. Therefore athletes and wheelchair experts often optimize wheelchair configuration based on athlete capacity in conjunction with specific roles in the team play. Since it is difficult to weigh those demands and their interaction, more insight in the relationship between athlete/wheelchair characteristics to sprint performance could underpin choices in wheelchair adjustment or athlete training.

Effects of wheelchair configuration on wheelchair performance are well described by publications based on experimental research [3-7] often utilizing an ergometer, treadmill or experimental wheelchair. To include the interaction between athlete and wheelchair configuration, Mason [2] recommends quantitative research with wheelchair athletes to identify optimums in configurations. With that goal in mind one needs research data gathered in circumstances that are close to the specific sport setting, with athletes in their own wheelchairs and in a field based test. This paper describes the relationships found between wheelchair settings and sprint performance based on a 12 meter sprint test of 30 male wheelchair basketball athletes. Within these athletes, internationals were expected to sprint faster and with fewer pushes to cover the same distance, as a result of their superior physical training status and technique, compared to national level athletes. In the same way, higher classified players with more physical capacity were expected to be faster but with an indefinite difference in number of pushes used in the sprint.

2. Methods

2.1. Setup and participants

Thirty elite level wheelchair basketball athletes (see Table 1) performed a series of tests, including a 12 meter sprint in their own sports wheelchair. Athletes were measured in training sessions and during the Euro Cup 4 tournament at Papendal (NL) 2015. On each wheelchair three inertial sensors (Shimmer3, Shimmer Sensing) were mounted, in accordance with the method described by van der Slikke [1, 8]. Custom made clips allowed for easy application on each wheelchair, with one sensor on each wheel hub and one centrally placed on the frame. Acceleration and rotational speed data were collected at 200 Hz and transmitted by BlueTooth to a laptop running Matlab with the Shimmer instrument driver. The sprint tests were performed in regular athlete training facilities. Prior to the sprint test athletes were asked to carry out a warming up and inflate their tires to 7 bar. In addition to the sprint test, maximal isometric forward push force was measured with the footplate of the wheelchair attached with a rope to a force gauge (Mecmesin AFG 1000N) mounted to a measurement plateau on which the wheelchair was stationed. After a trial run, athletes were asked to employ maximal push force for at least 3 seconds in five different hand positions on the rim (-30º; TDC; +30º; maximal forward; self-chosen position). Wheelchair dimensions were measured, including wheel and rim diameter, camber angle, track width and rear seat height.

Figure 1: Sensor mounting locations on the wheelchair

The study was approved by the ethical committee of the Department of Human Movement Sciences (ECB-2014-2) Vrije Universiteit Amsterdam. All participants signed an informed consent after being informed on the aims and procedures of the experiment.

Table 1: Athlete and wheelchair data

					Classification							
Group	**Number**	**Nationality**	**Age (y)**	**Seat height (m)**	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**
National	13	NLD	24.9	0.55	2		1		2	1	5	2
International	17	NLD, GBR, TUR, ESP, SWE, ITA, CYP	26.0	0.61	2	1	1	4	3		2	4
Overall	30		25.6	0.59	4	1	2	4	5	1	7	6

2.2. Push detection

In addition to the previously described method for calculation of wheelchair kinematics [1], a push detection algorithm was developed based on the forward acceleration of the wheelchair. The main forward accelerations were considered to be due to active athlete pushes, so the algorithm was shaped to distinguish those peaks from other fluctuations in the forward acceleration signal. A frequency spectrum (Matlab, “periodogram”) was made with the most prominent frequency over 1.2 Hz assumed to represent the mean push frequency. The forward acceleration was low pass filtered by 1.5 times that frequency and subsequently acceleration peaks were identified (Matlab, “findpeaks” with a minimal peak height and prominence of 0.5 acceleration signal standard deviation and a peak distance of 0.67 times the assumed mean push frequency). Figure 2 shows the pushes detected in a typical example of the forward acceleration in a 12 meter sprint.

Video observed pushes were used as gold standard for comparison with the sensor detected pushes. Three post-measurement synchronized video camera footages were used to register pushes. A push was defined as full hand-rim contact until rim release. So if the final push was followed by braking without rim release, it was discarded.

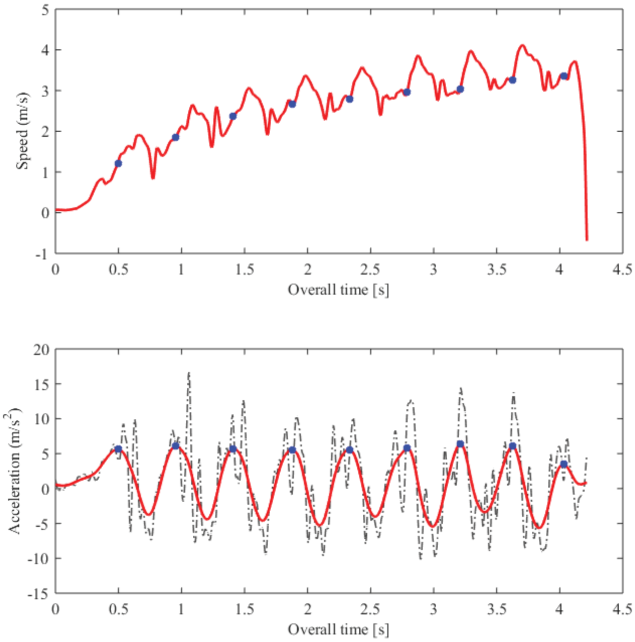

Figure 2: Typical example of the speed (upper graph) and forward acceleration (lower graph) during a 12 meter sprint. The dashed line shows the unfiltered acceleration data and the solid line the filtered data and detected pushes (dots).

2.3. Outcomes

Inertial sensor based wheelchair kinematics were used to calculate sprint specific outcomes. The start time of the sprint was determined by the first moment of speed over a threshold (0.05 m/s) and the stop time of the sprint as the first moment of speed below the threshold after the required displacement. The maximal speed was determined by the maximal speed value in the 12 meter sprint, typically just before braking. The number of pushes was based on the push detection as described in the previous paragraph, with also several derived outcomes calculated like average push time, push frequency and acceleration per push. For maximal isometric force the highest 3 second average of the five pushes on the measurement plateau was taken.

2.4. Statistics

All outcomes were tested with the Kolmogorov-Smirnov test for normal distribution. To rate the reliability of the sensor based push detection, its outcomes were compared to the video observed pushes using the ICC (absolute agreement) method.

Relationships between athlete/wheelchair characteristics and sprint outcomes were determined with a Pearson correlation, except for the correlation with classification which was determined by a Spearman test. Differences in sprint characteristics between competition level outcomes were tested with a T-test. Given the classification differences in measured athletes per competition level, the effect of classification on sprint characteristics was tested by building a univariate General Linear Model (GLM) and determining the influence of each factor on the explained variance.

3. Results

Data were collected without any sensor data reception loss. In 27 cases, measurement circumstances allowed for video analysis and video data were used to register the number of pushes. Isometric maximal force was measured in 29 athletes, with one wheelchair being too wide for the measurement plateau.

All athlete/wheelchair data and sprint characteristics were distributed normally, allowing for parametric statistics except for classification. The only significant Spearman correlation between classification with any of the other characteristics was the correlation with seat height (overall: r=0.555, p=0.001; nationals: r=0.677, p=0.011; internationals r=0.668, p= 0.003). The ICC for video observed and sensor based detected pushes was 0.946, with 3 times (11%) 1 push over detection and in 2 times (7%) 1 push under detection (by 7.97 push on average per 12 meter sprint).

Significant correlations between athlete/wheelchair and sprint characteristics are displayed in Table 2. Most sprint characteristics had high mutual correlations, but a bifurcation could be identified relating to outcome parameters concerning speed/time on the one hand and push related outcomes on the other hand. So for further analysis “sprint time” and “number of pushes” were used, since they correlated moderately (r=0.447, p=0.013) and seemed to measure different aspects of sprint characteristics.

Table 2: Significant (p<0.05) Pearson correlations between sprint characteristics and athlete/wheelchair data within the complete dataset.

Variables			Pearson correlation
Sprint time	x	Nr. of pushes	.447
Sprint time	x	Max. speed	-.856
Sprint time	x	Max. iso force	-.473
Max. speed	x	Nr. of pushes	-.450
Max. speed	x	Seat height	.371
Max. speed	x	Max. iso force	.591
Seat height	x	Max. iso force	.418

Table 3: Differences between mean athlete/wheelchair and sprint characteristics per competition level. With significant differences indicated by the *italic* p value in the right column.

Variable	National		International		T-Test
	Mean	SD	Mean	SD	p
Classification	3.3		3.0		n.a.
Age (y)	24.8	12.1	26.0	7.7	0.510
Seat height (m)	0.56	0.07	0.61	0.07	0.072
Max iso force (N)	470	166	574	90	*0.041*
Sprint time (s)	4.10	0.40	3.67	0.33	*0.003*
Nr. of pushes	8.6	1.0	7.5	1.7	*0.035*

Although competition level groups were not identical in athletes per classification, on average the number of low-high classified athletes was similar (see Table 1 & 3). Age distribution was similar in both groups and although not significant, international athletes appeared to have a higher average seat height (Table 3). Indeed if classification was taken into account as an additional fixed factor, competition level and classification both appeared significant (p<0.05) in the GLM for seat height (Table 4). Measured outcomes showed that significantly more isometric push force was generated by the international compared to national level athletes and that they were faster with fewer pushes on the 12 meter sprint.

GLMs were built for sprint time, number of pushes and maximal isometric push force with the factors competition level and classification (Table 4). Level as a factor produced significant models (p<0.05) for all outcomes, where solely classification produced none. If only main effects of competition level and classification were included in the model, significant models were produced with approximately double the explained variance (R^2) compared to solely level as a factor. The interaction between both factors alone, also showed significant in GLMs for all outcomes.

Table 4: General Linear Model outcomes with significance level (p) of the model, R squared (R^2) and R squared adjusted (R^2 adj.) for the number of explanatory terms.

Variabele	Factor1	Factor2	p	R^2	R^2 adj.
Sprint time	level (2)		0.003	0.268	0.242
Nr. of pushes			0.035	0.149	0.118
Max iso force			0.041	0.145	0.231
Sprint time	class (8)		*0.165*	*0.349*	*0.142*
Nr of pushes			*0.084*	*0.403*	*0.213*
Max iso force			*0.110*	*0.395*	*0.194*
Sprint time	level (2)	class (8)	0.011	0.566	0.401
Nr of pushes			0.027	0.518	0.335
Max iso force			0.027	0.533	0.348
Sprint time	level * class		0.026	0.664	0.427
Nr of pushes			0.008	0.721	0.524
Max iso force			0.050	0.646	0.380
Seat height	level (2)		0.072	0.111	0.079
Seat height	level (2)	class (8)	0.006	0.599	0.446

4. Discussion

In wheelchair sports it is the interaction between wheelchair and athlete that enables propulsion and sporting movements, outlining wheelchair mobility performance [9]. To gain insight in this relationship in the most ecological valid way, this research comprised field testing athletes in their own wheelchair in a competition like setting. Using this method, athletes were tested with their wheelchair settings not just optimized for sprinting, but also with other demands in mind based on sport specific field positions. Sprinting capacity could be described with a variety of properties, such as acceleration from standstill, average speed, maximal speed, number of pushes, push frequency and acceleration per push, but they partly measure the same aspects of the sprint. Based on mutual correlations, two different aspects were acknowledged namely the sprint time as measure for the sprint goal and the number of pushes as a factor of push strategy.

As expected, competition level was an important factor in sprint performance, with international level athletes being faster with fewer pushes on average, despite the (not significantly different) higher average seating position compared to national level athletes. Shorter sprint times with fewer pushes could be achieved with either pushes with increased acceleration (more force) or prolonged acceleration (push force in a longer trajectory) per push. The correlation between maximal isometric push force and sprint time (r=-0.473) supports that part of the increased acceleration per push was due to increased push strength. The magnitude of isometric push force (as measured in this configuration) in turn can be altered by increased physical training (athlete) or changes in wheelchair configuration.

The effect of classification (physical capacity) on sprint performance was clear in the national level group, given the Spearman correlations with sprint time (r=-0.715, p=0.006) and number of pushes (r=-0.647, p= 0.017). Yet in the international level group this relationship was not uncovered, pointing at other aspects that counter acted the sprint performance differences due to classification. Since sprint performance is only *one* game aspect, wheelchair configurations could be set with alternative goals in mind. Given the correlation between classification and rear seat height the effect of classification differences could have been partly undone by lowering the seat for lowly classified athletes with a positive effect on wheelchair sprint performance as described by Mason et al. [2]. So, this correlation could be interpreted as an optimization in wheelchair settings towards sprint performance at the expense of upward reach. This finding is in line with the common practice to allocate lowly classified athletes in a more defensive game role, with most game demands on speeds and less focus on upward reach. In international athletes average seat height is significantly higher (if corrected for classification), so with presumably more focus on upward reach.

No reliable GLMs for sprint outcomes could be built with only classification as a fixed factor (Table 4), but if competition level was added, R squared values for sprint time and number of pushes raise to R^2=0.566 and R^2=0.518 respectively. As a predictor for future measurements, the adjusted R^2 shows an explained variance of 40.1% for sprint time and 33.5% of the number of pushes if classification and competition level were regarded. The construction of this model was affected by two single outliers per classification and competition level. Since the classification of athletes was not evenly distributed over competition level in this dataset, grouping classifications did not improve the GLM. But given the outliers and the model prediction improvement if interaction of competition level and classification is included, it is likely that the GLM improves substantially if the “gaps” in athlete classification in this dataset are filled with additional measurements.

Study results show a high correlation (ICC = 0.946) between the sensor based push detection and video observed pushes, with maximal 1 push miss detection in a 12 meter sprint. It was concluded that the sensor detection could be applied with confidence for distances of at least 12 meter. The complexity of the relationship between wheelchair performance and wheelchair/athlete characteristics requires detailed outcomes to ensure the usability of a field test, pinpointing the need for a reliable ambulatory method [1] for measuring wheelchair mobility performance including push detection.

This field study underpins the challenge of investigating the relationship between athlete, wheelchair setting, their interaction and wheelchair mobility performance. Research with more isolated test settings [3-7] already proved relationships in aspects of wheelchair configuration with performance, but under actual competition conditions the number of influencing factors involved is substantial. Still, already within this limited dataset, trends were where spotted, pointing out the relative importance of factors in optimizing the wheelchair/athlete combination for sprint performance. Enlarging the current data set might allow for better quantification of the influence of those factors, if more solid GLMs could be built. Given the easy to use measurement method with the push detection turning out to be reliable, this is a feasible future goal. With the collected data, also other aspects of wheelchair mobility performance, like maneuverability could be investigated, providing athletes, coaches and wheelchair experts with functional information for their considerations to optimize each athlete/wheelchair for the game demands.

Results show that in general athletes with less physical capacity (low classification) adjust their wheelchair with a relative low seat height, to allow for prolonged and more powerful pushes. Given the absent correlation between sprint time / number of pushes and classification, this adaptation is more effectively done in international level wheelchair basketball athletes and/or in that group other performance goals have higher priority.

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