Mobility Performance

in wheelchair basketball

Annemarie de Witte

Promotoren	*prof. dr. H.E.J. Veeger*
	prof. dr. L.H.V. van der Woude
Copromotoren	*dr. M.J.M. Hoozemans*
	dr. M.A.M. Berger
Leescommissie	*prof. dr. T.W.J. Janssen*
	prof. dr. Y.C. Vanlandewijck
	prof. dr. H.J. Stam
	dr. R.J.K. Vegter
	dr. S. de Groot

Photo cover: Marc Hollander Photography (www.marchollander.nl)

Nothing is impossible, the word itself says,

I'm possible

-Audrey Hepburn-

Chapter 1 General introduction

During a wheelchair basketball game, an athlete has to perform optimal in their wheelchair. The interaction between wheelchair and athlete is decisive for this. A basketball sports wheelchair can be adjusted in many ways and all adjustments have a potential effect on the performance. In the search for the optimal basketball sports wheelchair and the optimal adjustment to the athlete, information about all wheelchair movements and athlete actions during a wheelchair basketball game is necessary. These wheelchair movements and athlete actions, called mobility performance, are essential to understand wheelchair basketball. Therefore, the focus of this thesis is:

Mobility Performance

in wheelchair basketball

1.1 Wheelchair basketball

Wheelchair basketball was first played by USA World War II veterans in 1945. Independently, in 1948 British war veterans started playing wheelchair netball at Stoke Mandeville Hospital in Great Britain. When in 1956 an USA team entered the International Stoke Mandeville Games, the forerunner of the Paralympic Games, there was a further burst of interest. In 1960, wheelchair basketball was one of the eight sports at the inaugural Paralympic Games in Rome, Italy. Nowadays, wheelchair basketball is one of the most popular Paralympic sports.

Wheelchair basketball is very similar to basketball. Most of the rules are the same to those in able bodied basketball, the basket is at equal height and the field has the same dimensions. Wheelchair basketball is a fast-paced game played by two teams of five players in a hand-rim wheelchair. Every team consists of five players and at most seven substitutes. Wheelchair basketball is open to athletes with a permanent physical impairment in the lower limb(s) which can be objectively verified. Impairments may include (lower) limb amputations, cerebral palsy and spinal cord injuries. For instance, players with severe spasms can participate in wheelchair games although they may be able to walk. Not all players in a team have the same type of impairment. Yet, to have a fair competition, teams must consist of players who, on average, have a comparable limitation due to their impairment. To assess the level of impairment, an internationally accepted classification system is used in which eight classes are defined – ranging from 1.0 to 4.5 – with 1.0 being the most limiting impairment. During a game for the five players on court the sum of classification points may not exceed 14 (43).

1.2 Performance in wheelchair basketball

In recent years, wheelchair basketball performance has improved incredibly. This is due to improvements in the physical performance and conditioning of athletes, propulsion technique, tactical awareness and substantial developments in the design and configurations of the basketball wheelchairs (53). As can easily be understood, performance in wheelchair basketball is dependent on a lot of different aspects and most of these aspects interact with each other. For example, when the wheelchair configuration changes, the propulsion technique also changes, which in turn impacts individual game play.

Performance in wheelchair basketball can be analyzed at multiple levels (Figure 1). Winning or losing the game, is dependent on the performance of the team as a whole. *Team performance* is the result of all underlying elements of performance and is highly dependent on the performance of the five different active players on the field. The ability of individuals to work together productively as a team is vitally important to the success (74).

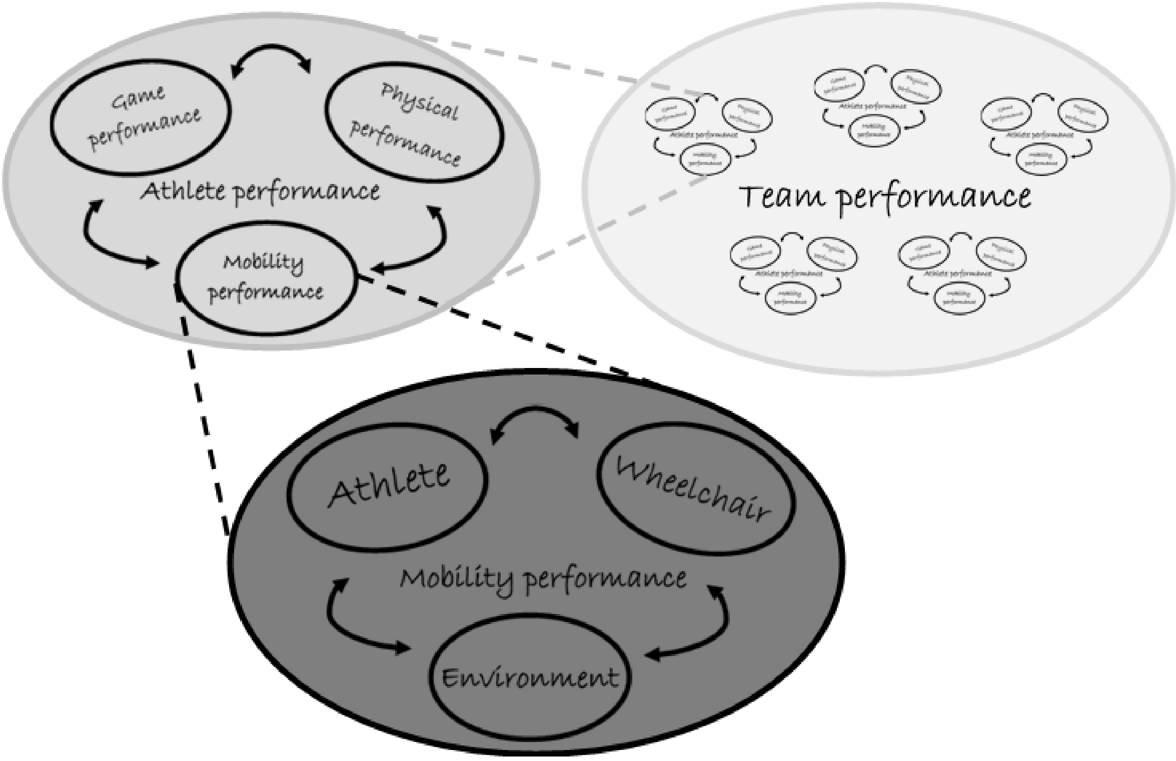


Figure 1. Team performance in wheelchair basketball is defined as the combined athlete performance of five athletes on the field. Individual athlete performance consists of individual game, physical and mobility performance. Focusing on mobility performance in wheelchair basketball, means focusing on the interaction between the athlete, the wheelchair and the environment.

The second level after team performance is *athlete performance* (Figure 1). Athlete performance is the individual performance of an athlete during a wheelchair basketball game. Individual athlete performance is also dependent on several performance aspects such as physical condition, ball skills and the interaction with their wheelchair. Athlete performance can be divided into three performance aspects: 1*) physical performance*; 2) *game performance* and 3) *mobility performance*.

Physical performance is the physical capacity of an athlete to perform and is often quantified in measures such as heart rate, power output, oxygen consumption and lactate level (8). The diversity of individual impairments results in a variety of physiological capabilities. As a short example of physical performance, the average heart rate during a wheelchair basketball match was 163 ± 11 beats/min and the average oxygen uptake 2.26 ± 0.06 L-min (20). Physical performance also includes the mental capacity of an athlete. The second aspect is *game performance*, defined as the true quality of a player's contribution to the game in terms of scored points, offensive rebounds, blocked shots and throws completed. A commonly used method to determine game performance is the Comprehensive Basketball Grading System (11). For example, Gomez et al. (36) stated that the field-goals percentage and the free-throws rate are the most important factors in men's games, and the field-goals percentage and offensive rebounding percentage in women's games. Men take on average 68.6 shots per game versus 65.4 for women and the shot accuracy was for men 39.5% and for women 27.1% (100,101). Finally, *mobility performance* is defined as what the athlete does (or can do) with a wheelchair (54). An athlete handles the wheelchair mainly by using arms and trunk resulting in wheelchair-athlete activities such as driving forward or backward, rotating and blocking. Mobility performance in wheelchair basketball is dependent on the athlete, the wheelchair and the environment, the latter being a general term that encloses aspects like the opponents, floor surface or team composition. Athletes control their wheelchairs through physical actions that cause movements of their wheelchairs in the environment. All three aspects interact with each other continuously (Figure 1). For example, when a wheelchair setting changes, the propulsion technique of the athlete will change, leading to different actions on the field (environment). Another example is for instance the requirements of a field position that lead to certain wheelchair-athlete actions and these actions may be improved by changes in the wheelchair settings.

Systematic research is fundamental to understand wheelchair basketball performance, and its optimization at both the technical and at the individual level, as well as their interaction. The last years, much research has been done into the physical performance of wheelchair basketball athletes (37,76,107). Knowledge about physical performance can be used to e.g. improve training schemes to enhance the athlete physical performance. When focusing on game performance, the trainer's knowledge about e.g. tactical and ball skills is very decisive. Different training methods can be used and evaluated to enhance game performance. The third aspect to improve, is the mobility performance. It takes into account the individual capacities of the athlete, the possibilities of the material, and the requirements of the environment and the continuous interaction between them. The wheelchair design, wheelchair adjustment to the athlete and driving techniques to move around in the environment, are essential for optimal results. When the wheelchair changes, its orientation to the athlete changes and, therefore, the driving technique changes. For wheelchair basketball athletes, the individual adjustment of the wheelchair to their impairment, supplemented with the requirements of the environment, is of great importance and determines performance. For example, to throw the ball in the basket, sitting as high as possible is advantageous. However, when you sit higher, it is more difficult to deliver propulsion on the hand rim as a consequence of the larger shoulder-wheel distance, especially when you have limited trunk function. It enhances scoring opportunities, but the mobility performance is influenced. The challenge is to find the optimum in the wheelchair-athlete-environment interaction to enhance performance. So far, knowledge about the wheelchair-athlete interaction is predominantly based on daily life situations and not focused on the wheelchair basketball practice. Knowledge about the effect of wheelchair adjustments will lead to a better wheelchair-athlete interaction which improves mobility performance and, therefore, team performance. In the search for the optimal wheelchair-athlete-environment configuration, acquiring knowledge of how athletes handle their wheelchairs during matches, is essential. Therefore, the focus of this thesis is on mobility performance in wheelchair basketball.

1.3 Mobility performance in wheelchair basketball

Defining and quantifying mobility performance

Knowledge of how athletes handle their wheelchairs during matches is essential to determine mobility performance in wheelchair basketball and is lacking in current literature. To understand the important role of mobility performance to game play as well as its impact on wheelchair design and fitting for individual players, game mobility performance of elite players must be described. Information about how many times and how long players perform movements like driving forward, rotation and blocking provides insight in the requirements of a wheelchair basketball team in match play. Time-motion analysis techniques can be used to determine the time spent performing various activities and provide insight in the mobility performance during wheelchair basketball (8).

Regarding mobility performance in wheelchair basketball, research is very limited. Coutts (18) estimated that during a wheelchair basketball game, 64% of the game would be spent in propulsive actions and 36% in braking activity. However, this analysis was based on a 6 minutes exhibition game. Bloxham et al. (8) evaluated the time players spent performing various game activities during a wheelchair basketball World Cup game. Players spent almost half the game time resting (48.3%), 8.9% sprinting, 23.5% gliding, 18.2% contesting for ball possession, 0.6% sprinting with ball possession and 0.3% shooting. Unfortunately, this study was based on only six male members of the Canadian team. Furthermore, in both studies not all possible wheelchair-athlete actions were included. Besides the missing activities, like driving backward and blocks, and the very small sample size (n=6), also information about wheelchair handling is lacking. An extensive and complete time-motion analysis to define and quantify mobility performance in wheelchair basketball is necessary to get a clear and full picture of actual mobility performance during games.

Simulating mobility performance

Time-motion analyses can be used to provide insight in mobility performance during wheelchair basketball. However, extensive and complete time-motion analysis is very time-consuming. Furthermore, the results are influenced by the continuously changing environment. Each game has unique circumstances depending on, for example, the opponent, floor surface or team composition. To assess and monitor mobility performance in a controllable setting, the mobility performance during a match must be simulated. Simulation can be done in several ways. One option is laboratory-based experimentation, for example with a wheelchair ergometer or with a wheelchair on a treadmill. Another option is a more practical field-based approach. This thesis focuses entirely on the latter practical approach. A standardised field-based test founded on extensive wheelchair basketball match observations and analyses is assumed to be informative and helpful to simulate mobility performance in wheelchair basketball (38,98). An important issue to be addressed is the validity and reliability of such a field-based test in order to be able to deduce “true” improvements in mobility performance of athletes when observing performance during repeated testing (38). There are field-based tests for wheelchair court sports. However, they assess mainly other aspects of performance, such as athlete performance (heart rate and oxygen uptake), game performance (ball skills) and only limited parts of mobility performance, while they are not based on a structured reflection of the game (4,23,26,35,39,108).

A generally accepted valid and reliable mobility performance test for wheelchair basketball based on extensive game observations, is not available yet. Such a wheelchair basketball specific test can potentially be used to detect strengths and weaknesses of players in mobility performance and to monitor progress in mobility performance over time. Furthermore, a wheelchair test simulating wheelchair basketball mobility performance can be used to examine the impact of different wheelchair configurations on mobility performance (53). To allow this, the test must be sensitive to change in mobility performance when the configuration of a wheelchair is changed.

Predicting and optimizing mobility performance

Several aspects influence mobility performance and one aspect can have more effect than another one. To give direction to the many aspects that are potential 'game changers' or determinants of performance and its underlying hierarchy, it is useful to perform predictive analyses on basis of a wide array of potential determinants. Such a study should investigate which athlete, wheelchair and athlete-wheelchair interaction characteristics are the best predictors of mobility performance and the results can contribute to decide which characteristics should be investigated in order to optimize mobility performance in wheelchair basketball. At the moment, it is not really known which of those characteristics have the most impact on mobility performance. Slight adjustments to the way in which each characteristic is configured will affect the wheelchair propulsion and, therefore, the mobility performance (53). The majority of investigations to wheelchair-athlete characteristics have been conducted with an extremely biased focus on aspects of mobility performance in daily life propulsion and not in a wheelchair basketball context. However, wheelchair-athlete adjustments assumed to have a significant impact on mobility performance as a whole. Mason et al. (53) recommended practical research procedures and precautions to further improve understanding of mobility performance. This enhances the possibility to make results directly applicable and usable to wheelchair basketball. The effect of wheelchair-athlete interaction settings should be measured under the most ecologically valid conditions i.e. in a standardized situation which realistically reflects mobility performance in wheelchair basketball with wheelchair basketball players of different classifications.

1.4 Research context

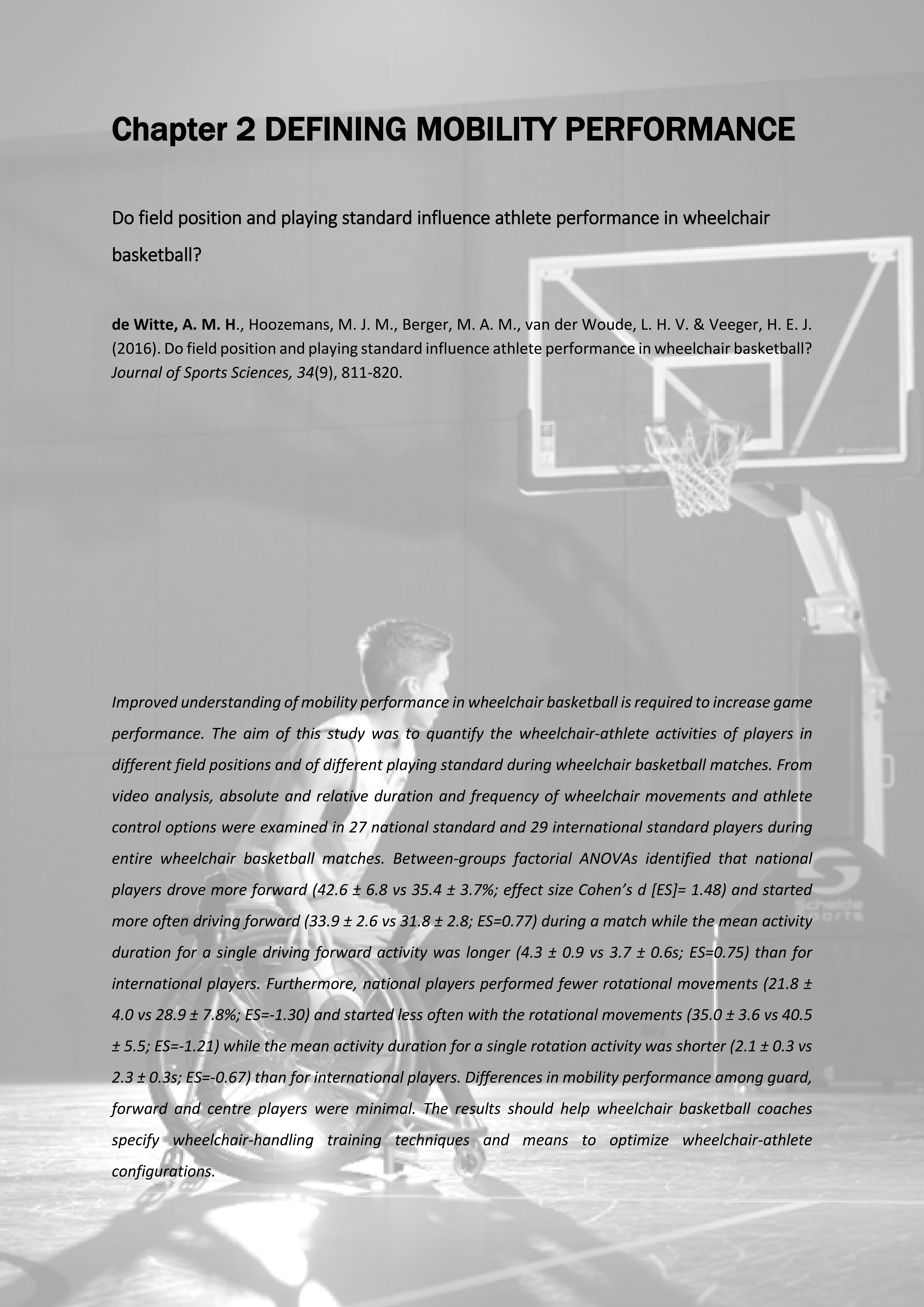
This thesis is the result of a unique collaboration between the knowledge institutes The Hague University of Applied Sciences, Vrije Universiteit Amsterdam, TU Delft and University of Groningen, together with professionals in sport practice from NOC*NSF, the Dutch Basketball Federation (NBB), rehabilitation centers Sophia Rehabilitation and Reade and Motion Matters. Within this research project, a second approach which focused on the technical part of wheelchair kinematics resulted in a thesis as well (82). The practice-based approach of this thesis required a multidisciplinary approach in which researchers, wheelchair technicians, coaches and athletes act together. The research questions in this program, are in general derived from "real life" situations and focus on a structural interaction between education and research within and between applied and regular universities. Being one of the conditions for funding by RAAK-PRO, the new knowledge must contribute to professional practice, education as well as to theoretical understanding of a common problem.

1.5 Thesis aim

An extensive understanding of mobility performance during wheelchair basketball is necessary. Therefore, the aims of this thesis are to *define, quantify, simulate, predict* and *optimize* mobility performance in wheelchair basketball.

In this thesis, the different aims are discussed sequentially. In **Chapter 2**, the athlete and wheelchair aspects related to mobility performance during matches are *defined*. An overview of all the wheelchair-handling activities during wheelchair basketball matches is described, with the main focus on differences between field positions and playing standard. **Chapter 3** describes and *quantifies* to what extent mobility performance is influenced by game state (offense/defense) and ball possession and to what extent the effects of game state and/or ball possession are different for the field positions. Chapters 4 and 5 are directly focused on the development process of the wheelchair mobility performance (WMP) test. **Chapter 4** describes the development, the reliability and validation process of the field-based WMP test that *simulates* mobility performance capacity and which closely mimics the wheelchair mobility skills required in real wheelchair basketball matches. **Chapter 5** validates the WMP test for measuring changes in wheelchair-athlete configuration. **Chapter 6** provides insight in athlete, wheelchair, and athlete-wheelchair interaction characteristics which can *predict* mobility performance in wheelchair basketball and finally **Chapter 7** gives the first results of research in changing a few, of the many possible, wheelchair adjustments to (potentially) *optimize* mobility performance.

A summary and discussion of the general findings is presented in **Chapter 8**. Practical implications, suggestions for future research and possibilities for applications in other sports are also presented in this last chapter.



Chapter 2 DEFINING MOBILITY PERFORMANCE

Do field position and playing standard influence athlete performance in wheelchair basketball?

de Witte, A. M. H., Hoozemans, M. J. M., Berger, M. A. M., van der Woude, L. H. V. & Veeger, H. E. J. (2016). Do field position and playing standard influence athlete performance in wheelchair basketball? *Journal of Sports Sciences, 34*(9), 811-820.

Improved understanding of mobility performance in wheelchair basketball is required to increase game performance. The aim of this study was to quantify the wheelchair-athlete activities of players in different field positions and of different playing standard during wheelchair basketball matches. From video analysis, absolute and relative duration and frequency of wheelchair movements and athlete control options were examined in 27 national standard and 29 international standard players during entire wheelchair basketball matches. Between-groups factorial ANOVAs identified that national players drove more forward (42.6 ± 6.8 vs 35.4 ± 3.7%; effect size Cohen's d [ES]= 1.48) and started more often driving forward (33.9 ± 2.6 vs 31.8 ± 2.8; ES=0.77) during a match while the mean activity duration for a single driving forward activity was longer (4.3 ± 0.9 vs 3.7 ± 0.6s; ES=0.75) than for international players. Furthermore, national players performed fewer rotational movements (21.8 ± 4.0 vs 28.9 ± 7.8%; ES=-1.30) and started less often with the rotational movements (35.0 ± 3.6 vs 40.5 ± 5.5; ES=-1.21) while the mean activity duration for a single rotation activity was shorter (2.1 ± 0.3 vs 2.3 ± 0.3s; ES=-0.67) than for international players. Differences in mobility performance among guard, forward and centre players were minimal. The results should help wheelchair basketball coaches specify wheelchair-handling training techniques and means to optimize wheelchair-athlete configurations.

2.1 Introduction

In wheelchair basketball, performance is determined by individual capabilities of athletes and their wheelchair in combination with the requirements of the game. An athlete's physical performance and his/her interaction with the wheelchair determine mobility performance, which in turn influences match and team performance. Figure 1 shows a schematic overview of the various performance aspects in wheelchair basketball. The individual performance of an athlete can be indicated as physical performance (8), which is often quantified in measures such as heart rate or oxygen consumption. Furthermore, what an athlete does (or can do) with a wheelchair can be referred to as mobility performance (54). Mainly by using their arms and upper body, wheelchair athletes control their wheelchair for activities such as driving forward or backward, rotating and blocking. Mobility performance is therefore determined both by capabilities of an athlete, as well as the design and configuration of a wheelchair. Finally, game performance in wheelchair basketball can be defined as the true quality of an athlete's contribution to the game, such as offensive rebounds, blocked shots and throws completed (11). All athlete performance aspects vary widely because of the diversity of disabilities. Therefore, all athletes are graded based on functional capabilities on a 1-4.5 scale (4.5 being characterized as maximal functional ability).

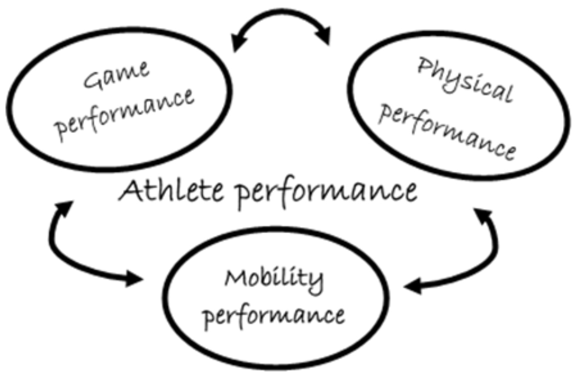


Figure 1. Overview of performance aspects in wheelchair basketball. The interaction between game, mobility and physical performance defines athlete performance in wheelchair basketball.

Several performance aspects have been studied, such as game performance (62,78). Vanlandewijck et al. (101) videotaped wheelchair basketball matches and analysed 59 elite-standard female players. They identified a clear relationship between game performance and classification. Players with a high-point classification tend to perform better for the majority of variables that determine the quality of game performance than low-point classification players. Field-goal percentages and free-throw rates were the most important factors for game performance in men's games (36). Physiological characteristics of athletes in wheelchair basketball matches have been investigated in several studies. Croft et al. (20) concluded that wheelchair basketball players have greater aerobic capability than wheelchair tennis players of a similar playing experience. Furthermore, Bloxham et al. (8) studied external power output, peak VO2 and peak heart rate in wheelchair basketball matches and concluded that 20 ± 15% of match time was played at an intensity above that of the ventilatory threshold. In contrast, only one study has investigated mobility performance (8). They investigated the time elite-standard wheelchair basketball players spent performing wheelchair handling activities during a wheelchair basketball match and reported that players moved 23.5 ± 7% of the time over the court with light or no arm strokes. However, their conclusions were based on a small sample (six participants), and only a limited number of wheelchair-athlete activities was included.

The performance characteristics of athletes and their wheelchair are influenced by field position and playing standard. Vanlandewijck et al. (100) and Wootten et al. (106) demonstrated a strong relationship between the classification, field position and game performance at international standard. The majority of classification 1 players played as guards (83%), whereas the majority of classification 4 players played as centres (93%) (101). For female basketball, Rodriguez-Alonso et al.

(70) reported that physical performance demands increased with higher playing standard and differed for field positions. This means that knowledge of how athletes handle their wheelchair (mobility performance) during a game, as well as their physiological capabilities, also depends on field position and playing standard.

In recent years, overall performance in wheelchair sports has improved for reasons that include general increases in understanding of factors that underpin physical fitness of wheelchair athletes, (propulsion) technique and functional adjustments to the wheelchair (53). Further increases in wheelchair basketball performance can be achieved by, for instance, optimization of the design and configuration of the wheelchair. For this, acquiring knowledge of how athletes handle their wheelchairs during matches, i.e. mobility performance, is essential. Therefore, the aim of this study was to quantify mobility performance expressed as wheelchair-athlete activities in matches for field position (guard, forward, centre) and playing standard (national and international) and determine whether the positions and playing standards can be distinguished in terms of wheelchair-athlete activities. Additionally, a sub-aim of this study was to confirm the relationship between a player's field position and his/her classification.

2.2 Methods

2.2.1 Participants

Twenty-seven male wheelchair basketball players of national standard and twenty-nine male players of international standard participated. National standard players competed in the Dutch first division competition and the international standard players were national team members of Australia (n=6), Great Britain (n=3), The Netherlands (n=8), Italy (n=5) and Canada (n=7). Distributions of classification and field position are given in Table I (classifications of 1-1.5 is category 1, classifications 2-2.5 in category 2, classifications of 3-3,5 in category 3, and classifications 4-4.5 in category 4). Ethics approval was obtained from the Faculty of Human Movement Sciences, VU University Amsterdam.

Table I. Distribution and mean (± *s*) classification of participants for position (guard, forward and centre) and playing standard (national and international).

Classification		1	2	3	4	Mean (± s)
National *	Guard (N=8)	4	2	1	1	2.1 (1.1)
	Forward (N=12)	3	5	2	2	2.5 (1.0)
	Centre (N=7)	0	0	0	7	4.1 (0.2)
International *	Guard (N=10)	3	5	2	0	2.0 (0.8)
	Forward (N=12)	3	2	2	5	2.9 (1.3)
	Centre (N=7)	0	1	0	6	4.0 (0.7)

*Significant association (p<0.05) between field position and classification (Chi-square). Value of Cramer's V for national standard=.575 and international standard=.494.

2.2.2 Assessment of player and wheelchair activities

Dutch wheelchair basketball coaches from the first division and the national team were interviewed to obtain clearly described and defined activities of the wheelchair and the way it is handled by an athlete (control options) during wheelchair basketball (Table II). The wheelchair-athlete activities are the basis of the assessment of athlete and wheelchair activities by systematic observation from video footage.

2.2.3 Video registration

Players were filmed for entire matches, including all breaks in play and bench-time (total match time), with two high definition video cameras (Casio EX-FH100, 1280*720, 20-240mm) with fixed fields of vision. Camera positions varied depending on location, and were placed at a distance between 5 and 10 m from the court, at an elevation of 3-5 m from the ground. Each of the cameras was focused on one half of the court, with a small overlap between the two videos in the centre of the court. Video footage from the two cameras was synchronised using free available software (Kinovea 0.8.15, France). This allowed the players to be seen for the entire match at all times. Four matches at national standard during the Dutch first division competition at the end of the season 2013-2014 were recorded. Video recordings of five international standard matches were made at the Easter Tournament of Wheelchair Basketball in Belgium in April 2014.

2.2.4 Video analysis

The video data were analysed by four trained observers using the Dartfish 7.0 TeamPro (1218) software package and observation scheme of Table II. To assess inter-observer reliability, all observers independently analysed the same representative video clip of a match. To test intra-observer reliability, the same video clip was analysed two weeks later. An ICC between 0.40 and 0.75 is considered as a moderate to good observer reliability for these types of comparison (77). After training, the ICC for inter-observer reliability for relative activities was 0.61 (95% Cl:0.60-0.63) and the ICC for intra-observer reliability was 0.96 (95% Cl:0.73-0.99).

2.2.5 Data analysis

Video data were used to calculate total match time for each team, which included offense, defense and when the game clock was stopped. For each player that was observed, absolute playtime was determined which included time playing on court and excluded bench time. Absolute as well as relative playtimes, as a proportion of total match time, were calculated. Furthermore, the individual wheelchair activities and athlete control options (Table II) were observed and the following measures were calculated:

- *Absolute duration of activities (min):* duration spent on a given movement activity while the player is active on court.
- *Relative duration of activities (% of absolute playtime):* time spent on a given movement activity as a proportion of the absolute playtime.
- *Frequency of activities (number):* occasions when an activity was started while that activity was preceded by another activity, without control options.
- *Relative frequency of activities (% of total frequency):* occasions when an activity was started while it was preceded by another activity as a proportion of the total number of changes from one activity to another, without control options.
- *Mean duration of activities (s):* mean duration of an activity (without control options), calculated as total duration of an activity divided by its frequency.

In consultation with coaches, three groups were defined based on field position: 1) guards, including shooting guards and point guards, 2) forwards, including power forwards and small forwards and 3) centres. A second distinction was made based on playing standard (national and international).

Table II. Descriptors of wheelchair-athlete activities used during observation of wheelchair basketball athletes.

Wheelchair activity	Control option	Definition	Comment
Standing still	1 hand	No/small movements of the wheelchair performed with one hand on the rim	< Half propulsion stroke from initial position
	2 hands	No/small movements of the wheelchair performed with two hands on the rim	
	Otherwise	No/small movements of the wheelchair performed with no hands on the rim	
Driving forward	1 hand	Forward movement of the wheelchair performed with one hand on the rim	> Half propulsion stroke from initial position
	2 hands	Forward movement of the wheelchair performed with two hands on the rim	
	Otherwise	Wheelchair moves forward without athlete action	
Driving backward	1 hand	Backward movement of the wheelchair performed with one hand on the rim	> Half propulsion stroke from initial position
	2 hands	Backward movement of the wheelchair performed with two hands on the rim	
	Otherwise	Wheelchair moves backward without athlete action	
Rotate	Clockwise	Rotational movements of the wheelchair, performed clockwise (turn right)	Turn must be >45°
	Counter clockwise	Rotational movements of the wheelchair, performed counter clockwise (turn left)	
Brake	2 hands	Slowing down the wheelchair with two hands	--
	Otherwise	Slowing down the wheelchair otherwise	--
Block	--	Collision with another wheelchair	--

2.2.6 Statistical analysis

Data were analysed using a between-groups factorial ANOVA (3 × 2 (Position [guard, forward, centre] × Playing standard [national, international])). Results with *p*-values *<0.05* were considered statistically significant. A Shapiro-Wilks test, as well as z-values of the skewness and kurtosis, tested for normality of distributions before analysis. Also, histograms, q-q plots and boxplots of the data were visually inspected. The assumption of normality was not violated. Homogeneity of variance was checked using Levene's test. When the assumption of homogeneity of variances was violated, the significance threshold was set to *p<0.01* (66). In case of a main effect, pair-wise comparisons were made using Tukey's post-hoc tests. Cohen's *d*'s (14) were determined as a measure of effect size [ES] for playing standard (national vs international) and for field position (guard vs forward; forward vs guard; guard vs centre). The (absolute) magnitude of the ES was classified as large (≥0.80), moderate (0.50-0.79) or small (<0.50) (15). A Chi-square test determined whether the observed frequency distribution of numbers of players for each of the classifications of field position differed from expected frequencies. All statistical analyses were performed using IBM SPSS statistics (IBM Corporation, Armonk, New York, USA).

2.3 Results

2.3.1 Total match and playtime (min)

The mean total match time for national standard players was less than that of international standard players (82±3 vs 93±7min; ES=-2.02).

The frequency distribution of classification for the national standard differed from the international standard (Table I). Guards had the lowest classification (mean category national=2.1 vs international=2.0), forwards moderate classification (national=2.5 vs international=2.9) and centres had the highest classification (national=4.1 vs international=4.0).

Field positions were linked to different playtimes both in absolute and in relative terms (Table III). For absolute playing time, international standard players did not play longer or shorter than national standard players (44±15 vs 49±15min; ES=0.27). However, when expressed as a percentage of total playing time, internationals played 12 percentage points [pp] less than nationals (60±20 vs 48±16%; ES=0.67).

Table III. Mean (± *s*) absolute (minutes) and relative (%) playtime for position (guard, forward and centre) and playing standard (national and international).

Playtime	National				International				Effect size [ES]	
	All players	Guard	Forward	Centre	All players	Guard	Forward	Centre	Playing standard[1]	Position[2]
Absolute (minutes)	48.5 (15.3)	41.7 (7.6)	46.8 (19.3)	59.1 (8.6)	44.0 (15.0)	42.0 (16.4)	45.9 (18.0)	43.7 (6.8)	0.27	GF -0.33 FC -0.34 CG 0.91
Relative (%)	59.7 (20.1)	50.8 (10.8)	58.4 (25.3)	72.2 (11.8)	47.5 (16.5)	45.3 (18.0)	49.7 (19.0)	47.0 (10.2)	0.67*	GF -0.37 FC -0.26 CG 0.77

[1]ES between group means; national-international
[2]ES between group means; GF (guard-forward); FC (forward-centre); CG (centre-guard)
*Differences (p<0.05) between national and international standard.

2.3.2 Absolute durations of activities (min)

Differences among field positions during "standing still" occurred (Table IV). Post-hoc tests showed that centre players spent 5 min longer standing still than guards (ES=1.20) and centres stood still 0.5 min longer with one hand on the rim than forwards (ES=-0.83). Furthermore, there were main effects of playing standard. International standard players spent 5 min less driving forward (ES=0.82) and 4 min less driving forward with two hands than national standard players (ES=0.78). Similarly, internationals spent less time on braking activities (0.7±0.4 vs 1.2±0.7min; ES=0.97) than nationals.

2.3.3 Relative activity durations

There was no interaction between position and playing standard and no main effect of position for relative duration for any movement activities (Table V). However, differences in standing still, driving forward and rotation between forwards and centres were accompanied by moderate (absolute) effect sizes (ES=0.49–0.86). A main effect for playing standard occurred for 50% of the comparisons. International standard players drove 7 pp shorter forward than national standard players (ES=1.48). Within driving forward, national standard players used the control option one hand on the rim 1 pp more than international standard players (ES=0.72). Most of the time, all players used two hands on the rim during driving forward. However, international standards drove more forward with two hands on the rim than national standards (92±6 vs 90±8%; ES=0.34). Additionally, internationals spent also 7 pp more time on rotation movements (ES= -1.30) and 1 pp less on braking activities than nationals (ES=0.92).

2.3.4 Frequencies

The mean absolute frequency that a player changed wheelchair movements was 881±342 times during a match for national standard players and 798±278 times for international standard players (ES=0.27). The interaction among field position and playing standard for the absolute frequency of standing still is attributable to the differences in absolute play time (Table VI). National centre players had a greater frequency of standing still than international centre players (p=0.03). Moreover, internationals started 7 times "drive backward" less than nationals (ES=0.61) and the brake frequency was 22 times lower (ES=0.96). In addition, post-hoc tests showed that guards brake considerably less often (-40) than centres (ES=0.91).

For international standard players, 32±3% of the started activities was driving forward, this is 2 pp less than national standard players (ES=0.77) (Table VII). For the activity "brake", the relative frequency was 2 pp less for international than national standard players (ES=1.26). The relative frequency for the start of a rotation movement was notably higher for internationals than nationals (41±6 vs 35±4%; ES=-1.21). However, while international standard players had a lower relative frequency for driving forward, the mean activity duration is 0.5s lower than national standard players (ES=0.75). In contrast, for rotation activities, internationals had a higher relative frequency and they performed rotational movements 0.2s longer than nationals (ES=-0.67) (Table VIII).

Table IV. Mean (± *s*) absolute duration (min) of wheelchair-athlete activities during a match for position (guard, forward and centre) and playing standard (national and international).

Action	Control	National			International			Effect size [ES]	
		Guard	Forward	Centre	Guard	Forward	Centre	Playing standard[1]	Position[2]
Standing still	Overall	13(5)	12(6)	21(6)	12(6)	14(7)	15(4)	0.17	GF -0.18 FC -0.91 CG 1.20[#]
	1 hand	1(1)	0(0)	1(1)	0(0)	0(0)	0(0)	0.80**	GF 0.15 FC -0.83[†] CG 0.61
	2 hands	11(4)	11(6)	16(5)	11(6)	13(7)	14(4)	-0.04	GF -0.14 FC -0.55 CG 0.81
	Otherwise	1(1)	1(1)	3(2)	1(1)	1(1)	1(1)	0.32	GF -0.15 FC -0.60 CG 0.78
Driving forward	Overall	18(5)	21(10)	23(4)	16(7)	16(6)	15(2)	0.82*	GF -0.26 FC -0.09 CG 0.45
	1 hand	0(0)	0(0)	1(1)	0(0)	0(0)	0(0)	0.71*	GF 0.05 FC -0.36 CG 0.30
	2 hands	16(5)	19(8)	20(4)	15(6)	14(5)	14(2)	0.78*	GF -0.24 FC -0.03 CG 0.34
	Otherwise	1(1)	2(2)	3(2)	1(1)	1(1)	1(1)	0.44	GF -0.29 FC -0.17 CG 0.48
Driving backward	Overall	1(1)	1(1)	1(1)	1(0)	1(1)	1(0)	0.41	GF -0.13 FC -0.07 CG 0.24
	1 hand	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0.39	GF 0.18 FC -0.57 CG 0.42
	2 hands	1(1)	1(1)	1(1)	1(0)	1(1)	1(0)	0.37	GF -0.13 FC -0.05 CG 0.22
	Otherwise	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0.44	GF -0.10 FC 0.19 CG -0.13
Rotate	Overall	9(2)	11(5)	12(1)	12(6)	14(6)	11(4)	-0.47	GF -0.28 FC 0.13 CG 0.21
	Clockwise	4(1)	5(3)	5(1)	6(3)	7(3)	5(2)	-0.39	GF -0.33 FC 0.25 CG 0.15
	Counterclockwise	5(1)	5(2)	6(1)	7(3)	7(3)	6(2)	-0.48	GF -0.20 FC -0.03 CG 0.26
Brake	Overall	1(1)	1(1)	1(1)	1(1)	1(0)	1(0)	0.97**	GF -0.25 FC -0.29 CG 0.48
	2 hands	1(1)	1(1)	1(1)	1(1)	1(0)	1(0)	0.97**	GF -0.25 FC -0.31 CG 0.49
	Otherwise	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0.56	GF -0.13 FC 0.30 CG -0.27

Note: summative differences are caused by rounding off.
[1]ES between group means; national-international
[2]ES between group means; GF (guard-forward); FC (forward-centre); CG (centre-guard)
[#] Differences (p<0.05) between field position: guard < centre.
[†] Differences (p<0.05) between field position: forward < centre.
* Differences (p<0.05) between national and international standard.
**Differences (p<0.01) between national and international standard.

Table V. Mean (± *s*) relative duration (%) of wheelchair-athlete activities during a match for position (guard, forward and centre) and playing standard (national and international).

Action	Control	National			International			Effect size [ES]	
		Guard	Forward	Centre	Guard	Forward	Centre	Playing standard[1]	Position[2]
Standing still	Overall	31(11)	27(9)	35(7)	29(9)	30(6)	35(7)	-0.14	GF 0.18 FC -0.86 CG 0.59
	1 hand	1(1)	1(1)	2(1)	0(0)	0(0)	1(1)	0.83**	GF 0.12 FC -0.63 CG 0.49
	2 hands	26(10)	23(10)	28(9)	26(9)	27(5)	31(7)	-0.29	GF 0.12 FC -0.56 CG 0.40
	Otherwise	3(3)	3(2)	4(2)	3(4)	3(2)	3(2)	0.11	GF 0.14 FC -0.49 CG 0.26
Driving forward	Overall	42(9)	45(5)	40(6)	37(4)	35(4)	34(2)	1.48**	GF -0.12 FC 0.49 CG -0.35
	1 hand	1(1)	1(1)	1(2)	0(0)	0(0)	0(0)	0.72*	GF 0.02 FC -0.23 CG 0.20
	2 hands	38(10)	41(4)	34(5)	34(5)	32(4)	32(3)	1.18**	GF -0.08 FC 0.63 CG -0.48
	Otherwise	3(2)	3(3)	4(3)	2(2)	3(3)	2(2)	0.28	GF -0.15 FC -0.07 CG 0.23
Driving backward	Overall	2(1)	2(1)	2(1)	2(2)	2(1)	1(1)	0.16	GF 0.25 FC 0.06 CG -0.30
	1 hand	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0.29	GF 0.22 FC -0.52 CG 0.27
	2 hands	2(1)	1(1)	2(1)	2(1)	2(1)	1(1)	0.12	GF 0.26 FC 0.09 CG -0.34
	Otherwise	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0.30	GF 0.08 FC 0.17 CG -0.22
Rotate	Overall	21(2)	23(5)	20(2)	29(10)	30(6)	26(8)	-1.30**	GF -0.12 FC 0.54 CG -0.33
	Clockwise	10(3)	11(3)	9(1)	14(6)	15(4)	12(3)	-0.95**	GF -0.13 FC 0.61 CG -0.37
	Counterclockwise	11(2)	12(3)	11(2)	15(5)	16(3)	14(4)	-1.26**	GF -0.08 FC 0.33 CG -0.21
Brake	Overall	3(2)	3(1)	2(1)	1(1)	2(1)	2(1)	0.92**	GF -0.15 FC -0.01 CG 0.16
	2 hands	3(2)	2(1)	2(1)	1(1)	2(1)	2(1)	0.89**	GF -0.15 FC -0.02 CG 0.17
	Otherwise	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0.49	GF -0.10 FC 0.31 CG -0.44

Note: summative differences are caused by rounding off.
[1]ES between group means; national-international
[2]ES between group means; GF (guard-forward); FC (forward-centre); CG (centre-guard)
* Differences (p<0.05) between national and international standard.
**Differences (p<0.01) between national and international standard.

Table VI. Mean (± *s*) absolute frequencies (times) of occasions an activity movement was started during a match for position (guard, forward and centre) and playing standard (national and international).

Action	National			International			Effect size [ES]	
	Guard	Forward	Centre	Guard	Forward	Centre	Playing standard[1]	Position[2]
Total	734(211)	834(398)	1130(242)	753(293)	850(35)	774(145)	0.27	GF -0.30 FC -0.34 CG 0.80
Standing still	138(53)	134(56)	226(57)	119(48)	143(63)	135(29) #	0.44	GF -0.20 FC -0.70 CG 0.95
Driving forward	252(68)	289(141)	363(68)	246(103)	267(107)	242(35)	0.43	GF -0.27 FC -0.23 CG 0.64
Driving backward	19(10)	16(15)	29(15)	11(8)	16(10)	12(6)	0.61*	GF -0.13 FC -0.35 CG 0.52
Rotate	250(67)	302(150)	383(65)	308(133)	348(141)	304(82)	-0.13	GF -0.33 FC -0.15 CG 0.62
Brake	39(25)	45(26)	68(31)	21(18)	30(17)	32(13)	0.96**	GF -0.36 FC -0.50 CG 0.91†
Block	37(22)	49(35)	61(34)	47(22)	46(25)	48(20)	0.05	GF -0.18 FC -0.25 CG 0.49

Note: summative differences are caused by rounding off.
[1]ES between group means; national-international
[2]ES between group means; GF (guard-forward); FC (forward-centre); CG (centre-guard)
Interaction effect (p<0.05) between field position and playing standard.
* Differences (p<0.05) between national and international standard.
**Differences (p<0.01) between national and international standard.
† Differences (p<0.05) between field position: guard < centre.

Table VII. Mean (± *s*) relative frequencies (%) of total percentage of occasions an activity was started during a match for position (guard, forward and centre) and playing standard (national and international).

Action	National			International			Effect size [ES]	
	Guard	Forward	Centre	Guard	Forward	Centre	Playing standard[1]	Position[2]
Standing still	19(3)	17(4)	20(3)	16(4)	17(3)	18(3)	0.40	GF 0.15 FC -0.65 CG 0.46
Driving forward	34(3)	34(2)	32(3)	33(4)	31(2)	31(2)	0.77*	GF 0.16 FC 0.40 CG -0.49
Driving backward	2(1)	2(1)	2(1)	2(1)	2(1)	2(1)	0.38	GF 0.14 FC -0.19 CG 0.05
Rotate	34(3)	36(4)	34(3)	41(6)	41(5)	39(6)	-1.21**	GF -0.14 FC 0.39 CG -0.22
Brake	5(3)	6(2)	6(2)	3(2)	3(2)	4(1)	1.26**	GF -0.25 FC -0.29 CG 0.51
Block	5(2)	6(3)	5(2)	6(2)	5(2)	6(2)	-0.26	GF 0.10 FC -0.06 CG -0.04

Note: summative differences are caused by rounding off.
[1]ES between group means; national-international
[2]ES between group means; GF (guard-forward); FC (forward-centre); CG (centre-guard)
* Differences (p<0.05) between national and international standard.
**Differences (p<0.01) between national and international standard.

Table VIII. Mean (± *s*) activity duration (seconds) during a match for position (guard, forward and centre) and playing standard (national and international). The duration is calculated as the absolute activity time divided by the activity frequency.

Action	National			International			Effect size [ES]	
	Guard	Forward	Centre	Guard	Forward	Centre	Playing standard[1]	Position[2]
Standing still	6.1(3.0)	5.7(2.6)	5.5(1.2)	6.3(2.0)	5.9(0.9)	7.0(1.7)	-0.25	GF 0.18 FC -0.23 CG 0.01
Driving forward	4.3(1.1)	4.5(0.8)	3.9(0.4)	3.9(0.7)	3.6(0.6)	3.7(0.4)	0.75*	GF 0 FC 0.38 CG -0.36
Driving backward	3.1(1.0)	3.0(0.9)	2.5(0.2)	3.4(1.2)	3.0(0.8)	2.7(0.5)	-0.14	GF 0.28 FC 0.55 CG -0.80
Rotate	2.2(0.3)	2.2(0.4)	1.9(0.2)	2.3(0.3)	2.4(0.3)	2.2(0.2)	-0.67*	GF -0.02 FC 0.69 CG -0.73
Brake	1.5(0.3)	1.6(0.4)	1.3(0.2)	1.5(0.4)	1.5(0.4)	1.5(0.3)	0	GF -0.05 FC 0.49 CG -0.43

Note: summative differences are caused by rounding off.
[1]ES between group means; national-international
[2]ES between group means; GF (guard-forward); FC (forward-centre); CG (centre-guard)
* Differences (p<0.05) between national and international standard.

2.4 Discussion

In this study we quantified mobility performance of wheelchair basketball players and investigated differences in wheelchair-athlete activities between field positions (guard, forward, centre) and playing standard (national and international). National standard players drove more forward (+7 pp), started driving forward more often (+2 pp) and performed longer driving forward actions during a match than international standard athletes (+0.5 s). International standards performed more rotational movements (+7 pp), started rotation more often (+6 pp) and performed rotational actions longer than national standards (+0.2 s). Also, internationals performed fewer braking activities and started driving backward less often than nationals. Additionally, some differences in wheelchair-athlete activities were observed among field positions. In absolute duration, centres stood still more than guards and forwards and performed more braking activities.

2.4.1 Comparisons based on field position

We hypothesized that mobility performance would be different for playing standard and field position in a game. The players in centre position drive mostly near the basket and with their body domination they perform movements in that area, while guards contribute more to the organization of matches (45). This might be reflected in the activity standing still. For both playing standards, centre players spent more absolute duration standing still during a match than guard and forward players. There were moderate to large effect sizes for relative duration between forward and centres, and between guard and centre players. National standard centres had also a greater absolute frequency of the activity standing still. There were no notable differences among a guard, forward and centre player for any of the other wheelchair-athlete activities, both for nationals and internationals. Aspects of mobility performance in wheelchair basketball have been investigated (8,18,79). Coutts (18) estimated that 64% of the time was spent in propulsive actions and 36% in braking activity. Propulsive actions were classified as positive accelerations and negative accelerations were considered indicative of braking activity. This conclusion was, however, based on only two players without a specific field position during a portion of an exhibition match (6 min). Bloxham et al. (8) reported that six players (also without a specific field position) spent 23.5 ± 7% driving across the court with light or no arm strokes during a match. In this study, the percentage braking was considerably lower and the percentage driving was considerably higher than in previous studies. A comparison with this study is not reliable because of differences in number of participants, characteristics of participants and the methods used. Furthermore, in contrast to the previous studies, the intra- and inter-observer reliability scores confirm internal validity of the used observation method and descriptions. In addition, the participants in the present study were a representative sample of wheelchair basketball players and all players were measured during entire wheelchair basketball matches.

There is a strong relationship between the field position of a player and functional classification. Earlier research identified that the majority of classifications 1 and 1.5 players play as guards, whereas the majority of classifications 2 and 2.5 play as a forwards. Almost all classification 4 and 4.5 players play as centres (100,101,106). In the present study, approximately the same distribution was found for players in the national competition, although international forwards had a slightly higher classification (2.9). This might be attributable to a difference in gender between the studies, only male wheelchair basketball players participated in the present study whereas Vanlandewijck et al. (101) based his results on female wheelchair basketball players. Previous research has further shown a relationship between field position and game performance. Skucas et al. (78) showed that centre players were better in game performance (e.g. shooting accuracy) and performed more actions per minute in a game than guard and forward players. Field position can influence game performance but, in contrast to our expectations, there is no association with mobility performance in wheelchair basketball matches in this study. All players, regardless of field position, handle their wheelchair in the same way.

In the present study, mobility performance was assessed by video observation. This did not allow us to calculate speed, accelerations and covered distances for all players. These variables could optionally differ among the field positions while the wheelchair-athlete activities showed no differences. However, these variables are currently being investigated with inertial sensors placed on both wheel axles and the frame centre of the wheelchair in a study as recommended by van der Slikke et al. (86). Likewise, differences between game aspects such as ball possession and offense/defense situations are not included in this study. Probably, these aspects are field position dependent because of specific roles. Therefore, to obtain a complete overview, it is important to analyse the influence of these game aspects on mobility performance. Moreover, each player has a custom-made wheelchair adapted to his/her functional capabilities. As a result, differences on mobility performance are reduced in advance. Specific information on the settings of a wheelchair in combination with the functional capabilities of the player can determine mobility performance. Information on kinematics, game aspects and wheelchair-athlete settings are necessary to get a complete overview of position-specific mobility performance in wheelchair basketball games and should be included in future research.

2.4.2 Playing standard comparisons

National and international standard players differed in duration and frequency of wheelchair-athlete activities, especially for the activities driving forward, rotation and braking. The internationals played about 48% of total match time while nationals played 60%. This is probably because of the number of available players in a team. International teams had approximately 11 team players in contrast to 8

players in national teams. In wheelchair basketball there is an unlimited substitution rule. As there are always five players active during a match the total number of team members affects play time.
The presented results indicate that international standard players are more agile than national standard players. The former performed more and longer rotational movements on the field and fewer and shorter driving forward movements. Interpretation of national standard data should be done carefully. Sport performance is the product of several factors, such as functional potential and skill. National teams involve players who have recreational interest as well as those who aspire to become an elite-player. The national standard will develop less optimal skill proficiency than the international standard (100). The data suggest that rotational movements are important to enhance mobility and therefore game performance because these movements are connected with game performance. Players use a lot of small and big rotational movements to prepare themselves to receive or throw the ball. Rotational movements are used to circumvent the opponent in a one-to-one duel to get in a free position. The difference in playing standard could explain the difference in (wheelchair-mobility) skills, and therefore rotational movements.

The most effective way to perform movement is to exert force at the pushrim with two hands. Furthermore, response time for changing a movement is shorter when there is direct contact with the rims and finally, a stationary wheelchair is more stable when the hand on the rim blocks the wheels. As a result, collisions with other wheelchairs can be absorbed. In this study, during forward driving, over 90% of the time players used two hands. However, nationals drove 1.4% of the time with one hand on the rim, in contrast to 0.3% for internationals (p=0.01). There is also a notable difference for standing still with one hand on the rim. International standard players performed this action 5% of the time standing still while national standard players performed it 2%. These results probably suggest that international players are more effective in propulsion in wheelchair handling and that the international wheelchair-athlete combination is more stable during standing still.

The presented variations in mobility performance between playing standards could be attributable to differences in physiological capabilities. In wheelchair basketball large differences in experience and practice within and between teams are common. National players practice only 1 or 2 days a week, whereas international players have daily practices all year (36). In addition, aspects such as (core) stability and reach are not involved in this study but will influence control options in wheelchair-athlete activities because of limited trunk function. Finally, decision-making abilities of international standard players are likely to be greater than those of the national standard, which could allow for improved wheelchair positioning and movement activities and therefore different activity profiles.

2.4.3 Limitations and practical implications

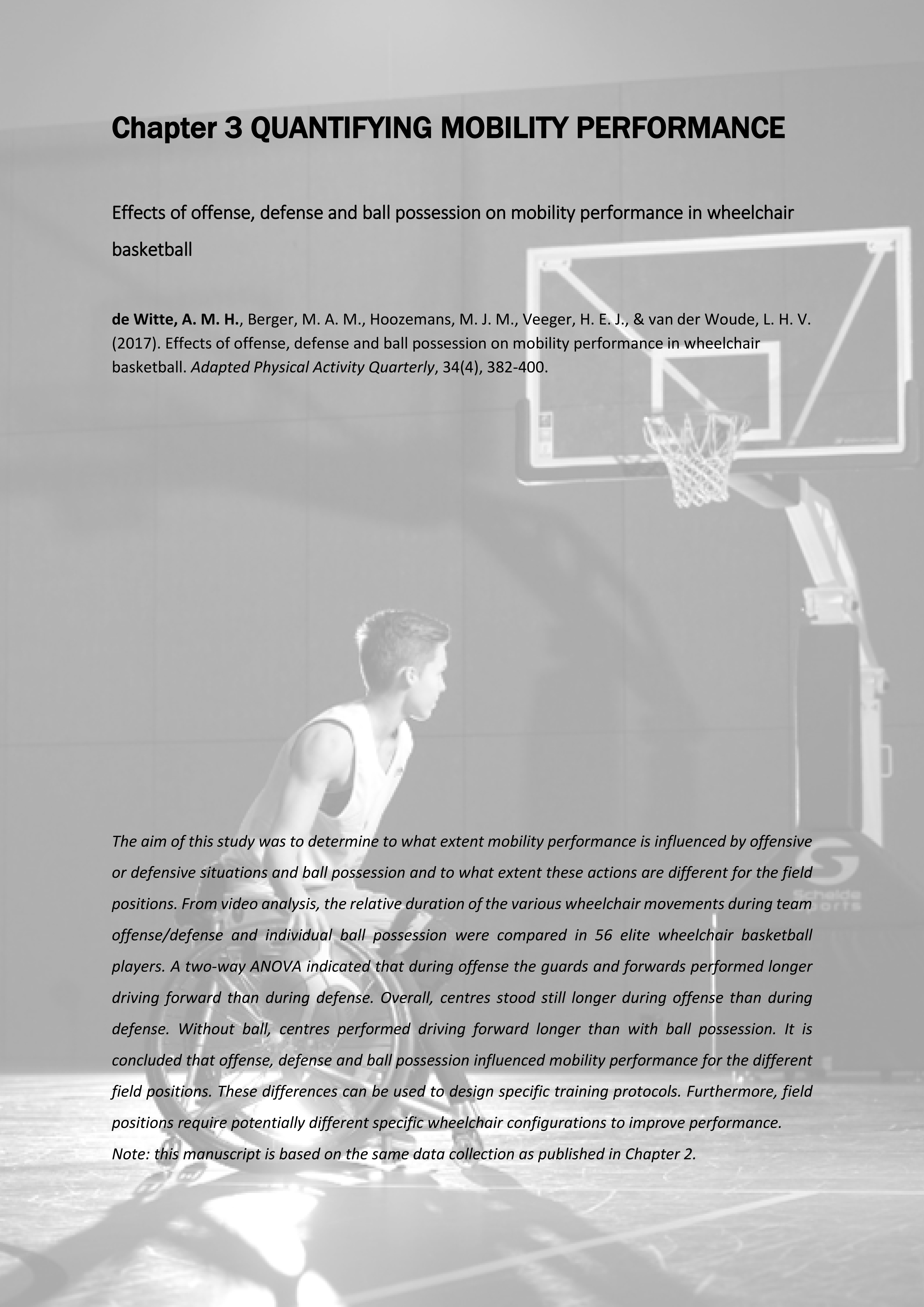
There are several aspects that could influence mobility performance that are not included in this research. An ideal analysis of mobility performance should also comprise actual wheelchair kinematic data (86), influence of game aspects on mobility performance, specific knowledge of wheelchair settings and configurations and physical (performance) aspects such as (core) stability and reach. We intend to extend our research along these lines and measure all these aspects synchronously in the near future.

It is essential that wheelchair mobility training should prepare players to cope with the most common wheelchair-athlete activities of wheelchair basketball activities (10). The practical implication of the presented results is that wheelchair-handling training can be the same for all field positions in a team irrespective of playing standard. However, the focus on training differ between playing standards. The difference in standard could be used by national basketball coaches to highlight the wheelchair-activities of internationals. This could assist teams to aspire a higher playing standard. Specifically, national teams have to focus more on rotational movements and more on the control option “two hands on the rim” within all wheelchair-movement activities. Coaches should advise players to keep moving to respond quickly to changing situations such as rebounds or opponent actions. The design of training practices should focus on rotational movements and one-to-one duels, especially for national standard teams.

The results are also important for the optimization of wheelchairs and wheelchair-athlete configurations. To optimize wheelchair-athlete settings and improve performance, requirements for performance activities in each field position should be similar. This implies that all players should have the same wheelchair requirements for rotation, driving forward e.g., independent of field position and that configuration is mostly dependent on playing standard and athlete.

2.5 Conclusion

The results of this study suggest that while playing standard influences mobility performance, there are no notable differences in wheelchair-athlete activities among guard, forward and centre players. National standard players drive more forward and start this activity more often than international standard players. In contrast, international standard players rotate more and start rotational activities more often. These findings provide important information to increase performance in wheelchair basketball. Results can be used to specify wheelchair-handling training and for optimization of wheelchair-athlete settings. Future research on kinematics, (physical) performance and game aspects need to provide additional information for a complete overview of mobility performance.



Chapter 3 QUANTIFYING MOBILITY PERFORMANCE

Effects of offense, defense and ball possession on mobility performance in wheelchair basketball

de Witte, A. M. H., Berger, M. A. M., Hoozemans, M. J. M., Veeger, H. E. J., & van der Woude, L. H. V. (2017). Effects of offense, defense and ball possession on mobility performance in wheelchair basketball. *Adapted Physical Activity Quarterly*, 34(4), 382-400.

The aim of this study was to determine to what extent mobility performance is influenced by offensive or defensive situations and ball possession and to what extent these actions are different for the field positions. From video analysis, the relative duration of the various wheelchair movements during team offense/defense and individual ball possession were compared in 56 elite wheelchair basketball players. A two-way ANOVA indicated that during offense the guards and forwards performed longer driving forward than during defense. Overall, centres stood still longer during offense than during defense. Without ball, centres performed driving forward longer than with ball possession. It is concluded that offense, defense and ball possession influenced mobility performance for the different field positions. These differences can be used to design specific training protocols. Furthermore, field positions require potentially different specific wheelchair configurations to improve performance.

Note: this manuscript is based on the same data collection as published in Chapter 2.

3.1 Introduction

Wheelchair basketball is a Paralympic sport characterized by fast paced defensive and offensive actions that include specific wheelchair manoeuvres like starting, stopping, and turning (105). Next to the functional abilities of the athlete, the movement dynamics of the wheelchair, specifically those actions related to handling the wheelchair and the ball, are crucial to both individual and team performance. Individual performance, and therefore team performance, can be optimized by (1) the athlete; (2) the wheelchair design such as wheel camber and anti-tip castor positioning, and (3) the wheelchair-athlete interface configurations which essentially will determine the efficiency of power transfer from the athlete to the wheelchair (93). Performance in wheelchair basketball can be determined by three elements that continuously interact: physical performance (athlete capabilities), mobility performance (wheelchair-athlete interaction) and game performance (athlete basketball tactics and skills) (31). Game performance in wheelchair basketball can be defined as the true quality of a player's contribution to the game, such as the percentage of successful offensive rebounds, steals and free throws (11,100). The physical properties and capabilities of an athlete, often measured with indicators such as heart rate, oxygen uptake and blood lactate, determine the physical performance (8). Finally, what the athlete does (or can do) with a wheelchair can be referred to, as mobility performance (54).

Specific athlete training schedules mainly affect physical and game performance. In addition, changes in the wheelchair design and therefore, wheelchair-athlete interface configuration have most impact on mobility performance. To optimally adjust wheelchair configurations to the benefit of individual wheelchair basketball players, not only lab and field-based experiments are required, but also a thorough insight into mobility performance during wheelchair basketball games itself (54,55,93).

Regarding mobility performance during wheelchair basketball games, research is very limited (8,18,31). Based on a 6 minute exhibition game, Coutts (18) estimated that 64% of the time was spent in propulsive actions and 36% in braking activity. Propulsive actions were classified as positive accelerations and negative accelerations were considered indicative of braking activity. Bloxham et al. (8) reported the time that elite wheelchair basketball players spent performing various wheelchair handling activities during a World Cup game. They stated that players moved across the field with light or no arm strokes for 24 ± 7% of the time. De Witte et al. (28) showed significant differences in player activities during wheelchair basketball games between national and international standard players. National players drove relatively more forward while international players performed more rotational movements during the game. Recently, van der Slikke et al. (89) measured accelerations for wheelchair basketball players during games with inertial sensors. International standard players showed higher rotational and linear accelerations compared to national standard players.

The studies above showed differences in mobility performance between players in general, but important aspects like functional classification, game related aspects and field position are not taken into account. All players are awarded from 1 (minimal functional potential) to 4.5 points (maximal functional potential) on an ordinal functional level scale. During international competition, the sum of points of the five players on court may not be greater than 14 points (43). Earlier research has shown that functional classification and field position are closely related. The majority of classification 1 and 1.5 players play as guards, the majority of classifications 2 and 2.5 play as forwards and classifications 4 and 4.5 mostly play the centre position (31,100,101,106). When looking at the specific qualities that are required for the different field positions, this is a logical relationship (61,72). Therefore, this study focused mainly on field position in order to found the specific qualities in wheelchair basketball. Centres play mainly in the lane under the basket and have high seat positions and they need optimal trunk control while guards have high manoeuvrability and excellent ball skills. Nowadays, based on experience of coaches and players, the guards and forwards typically choose for wheelchair configurations favouring manoeuvrability and acceleration, whereas centres will prefer a higher sitting height to play in the bucket (98). To improve the wheelchair configurations, players have to find the best compromise between the level of their impairment (classification level) and their field position

In previous research we observed no differences in mobility performance between field positions during both active and non-active playtime together (31). This was somewhat surprising since each field position has its own responsibilities on court, especially during the game situations offense and defense (71). For example, during offensive situations, the guards are floor leaders and are responsible for preserving ball possession. Moreover, during offensive situations, guards had the highest percentage of ball possession (between 23-44%) compared to other positions (65). During defensive situations, guards are primarily responsible for making opposing guards as ineffective as possible. Previously, de Witte et al. (31) analysed total playing time, even when the game-clock was stopped. Since players remain active during this period, these movements may have caused differences between field positions to be minimal. It is therefore plausible that although overall field positions do not differ in mobility performance, differences may become apparent when game situations are compared. Further analysis of the extensive dataset collected by de Witte et al. (2016) (31) allowed us to get a more in depth view of mobility performance in wheelchair basketball in terms of game situation and ball possession.

Therefore, the purpose of this study was to examine differences in the mobility performance between wheelchair basketball players of different field positions and to determine whether mobility performance is influenced by game situation (offense and defense) and/or ball possession, and whether these actions are different for the field positions guard, forward and centre.

3.2 Methods

3.2.1 Participants

Several sports clubs of the Dutch first division competition and the participating teams in the Easter Tournament of Wheelchair Basketball in Blankenberge (Belgium, 2014) were approached for participation in the present study. Of all teams and players that were informed - the number of which was not registered - fifty-six trained male wheelchair basketball players volunteered to participate in the study during competitive games. Twenty-seven players competed at national standard in the Dutch first division and 29 players played at international standard (Australia (n=6), Great Britain (n=3), The Netherlands (n=8), Italy (n=5) and Canada (n=7)). In consultation with the coaches, three groups were defined based on field position: 1) guards (n=18), including shooting guards and point guards, 2) forwards (n=24), including power forwards and small forwards, and 3) centres (n=14). The distribution of field position within categories is presented in Figure 1. Players in classifications 1 and 1.5 are categorized in category 1, classifications 2-2.5 in category 2, classifications of 3-3.5 in category 3, and classifications 4-4.5 in category 4. The local Ethical Committee of the Department of Human

Movement Sciences, Vrije Universiteit Amsterdam, approved the research project. Players participated on a voluntary basis and after signing an informed consent.

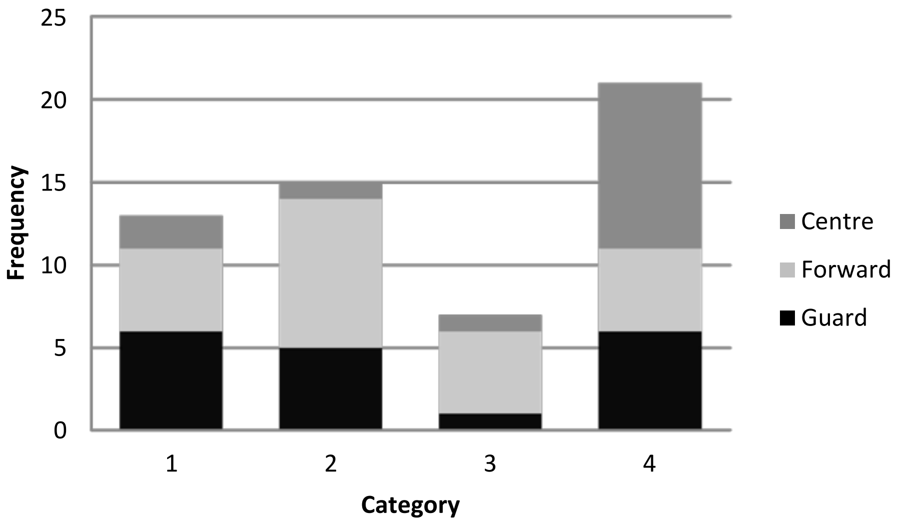


Figure 1. Distribution (n=56) of field position within classification categories. Players in classifications 1 and 1.5 are categorized in category 1, classifications 2-2.5 in category 2, classifications of 3-3.5 in category 3, and classifications 4-4.5 in category 4.

3.2.2 Time-and-motion analysis

Mobility performance was determined using video analysis. Players were filmed and observed during one entire match using an approach previously described by de Witte et al. (31). In brief, video footage was collected during four entire games in the Dutch first division competition and five games at the Easter Tournament of Wheelchair Basketball in Blankenberge (Belgium, 2014) using two High Definition video cameras (Casio EX-FH100, 1280*720, 20-240mm) with fixed fields of vision. Measurement time was accurate to 0.03s (29Hz). Based on interviews with coaches, all possible wheelchair-handling activities and athlete control options, which determine mobility performance, were defined and are described in Table I (31). These descriptors are the basis of the assessment of wheelchair and athlete activities by systematic observation, by four trained observers using Dartfish 7.0 TeamPro (Fribourg, Switzerland). A single observer observed the activities of one player during an entire game. Intraclass correlation coefficient (ICC) for intra-observer reliability was 0.96 (95% Cl 0.73-0.99) and the ICC for inter-observer reliability was 0.61 (95% Cl 0.60-0.63), an ICC between 0.40 and 0.75 for these types of analyses is considered as a moderate to good observer reliability (77).

Table I. Descriptors of wheelchair-athlete activities used during observation of wheelchair basketball athletes.

Wheelchair activity	Control option	Definition	Comment
Driving forward	1 hand	Forward movement of the wheelchair performed with one hand on the rim	> Half propulsion stroke from initial position
	2 hands	Forward movement of the wheelchair performed with two hands on the rim	
	Otherwise	Wheelchair moves forward without athlete action	
Driving backward	1 hand	Backward movement of the wheelchair performed with one hand on the rim	> Half propulsion stroke from initial position
	2 hands	Backward movement of the wheelchair performed with two hands on the rim	
	Otherwise	Wheelchair moves backward without athlete action	
Rotate	Clockwise	Rotational movements of the wheelchair, performed clockwise (turn right)	Turn must be >45°
	Counter clockwise	Rotational movements of the wheelchair, performed counter clockwise (turn left)	
Standing still	1 hand	No/small movements of the wheelchair performed with one hand on the rim	< Half propulsion stroke from initial position
	2 hands	No/small movements of the wheelchair performed with two hands on the rim	
	Otherwise	No/small movements of the wheelchair performed with no hands on the rim	
Brake	2 hands	Slowing down the wheelchair with two hands	--
	Otherwise	Slowing down the wheelchair with a handling other than hand-rim contact	--

Note: table retrieved from de Witte et al. (31).

3.2.3 Data analysis

Wheelchair-handling activities and athlete control options were only calculated during active playtime. Active playtime was defined as the time that a player was active on the court and with the game clock running. Due to unlimited substitutions in wheelchair basketball, the total absolute active playtime was different for each player. Data for all players who participated in the game were analyzed, regardless of active playing time. To validly compare game situations and the effect of ball possession, it is important to analyze the player's relative duration of wheelchair-handling activities to rule out the differences between players in action. Thus, for each player, the percentages of performing wheelchair-athlete activities and the athlete control options during active playtime were determined and defined as relative duration of activities.

During active playtime the team can be in an offensive or defensive situation. An offensive situation is defined as the game situation in which someone from the team has ball possession and the team had the objective to score, whereas a defensive situation is defined as the state when the opponent has ball possession. For each of those two game situations the relative duration of activities were calculated as a proportion of the duration of the game situation within active playtime.

This study quantified ball possession as the percentage of active playtime that an individual player held the ball. The relative duration of the wheelchair-handling activities and control options during ball possession was calculated as a proportion of the active playtime that a player performed activities during ball possession or without the ball.

3.2.4 Statistical analysis

The relative duration of all variables was calculated for each athlete and presented as the mean (± standard deviation) and complemented with the 95% confidence intervals (CI) for the mean differences. Data were analyzed using a two-way mixed design analysis of variance with "field position" as between-subject factor [guard, forward, centre]. The within-subject factor was in the first analysis "game situation" [offense, defense] and in the second analysis "ball possession" [with ball, without ball], respectively. The assumptions of normality and homogeneity of variance within the data were respectively checked with the Shapiro-Wilks test and Levene's test. The main effects for ball possession and game situation were tested, as well as the interaction between these factors and field position. When a significant interaction ($p<0.05$) was observed, t-tests with Bonferroni correction were used to examine the interaction effect with a main focus on the differences in mobility performance within field positions. Additionally, Cohen's *d* effect size (ES) and their 95% CI were calculated for all pairwise comparisons within field positions (guard vs. guard; forward vs. forward; centre vs. centre) (Cohen, 1992). The (absolute) magnitude of the ES was interpreted as follows: <0.2 (trivial), 0.2 to <0.6 (small), 0.6 to <1.2 (moderate), 1.2 to <2.0 (large), and ≥2.0 (very large) (Hopkins et al., 2009). IBM SPSS statistics version 22 was used for all statistical analyses (IBM Corporation, Armonk, New York, USA).

3.3 Results

The mean active playing time for guards was 21 ± 7 min, forwards played 23 ± 9 min and centres played 26 ± 7 min of 40 minutes game time. Offense and defense were equally divided over playing time for all field positions (50 ± 2%). During the game, guards had the highest percentage ball possession (21 ± 15%) when compared to forwards (16 ± 12%) and centres (18 ± 8%). Figures 2 and 3 summarize the differences between game situation and ball possession for the main activities.

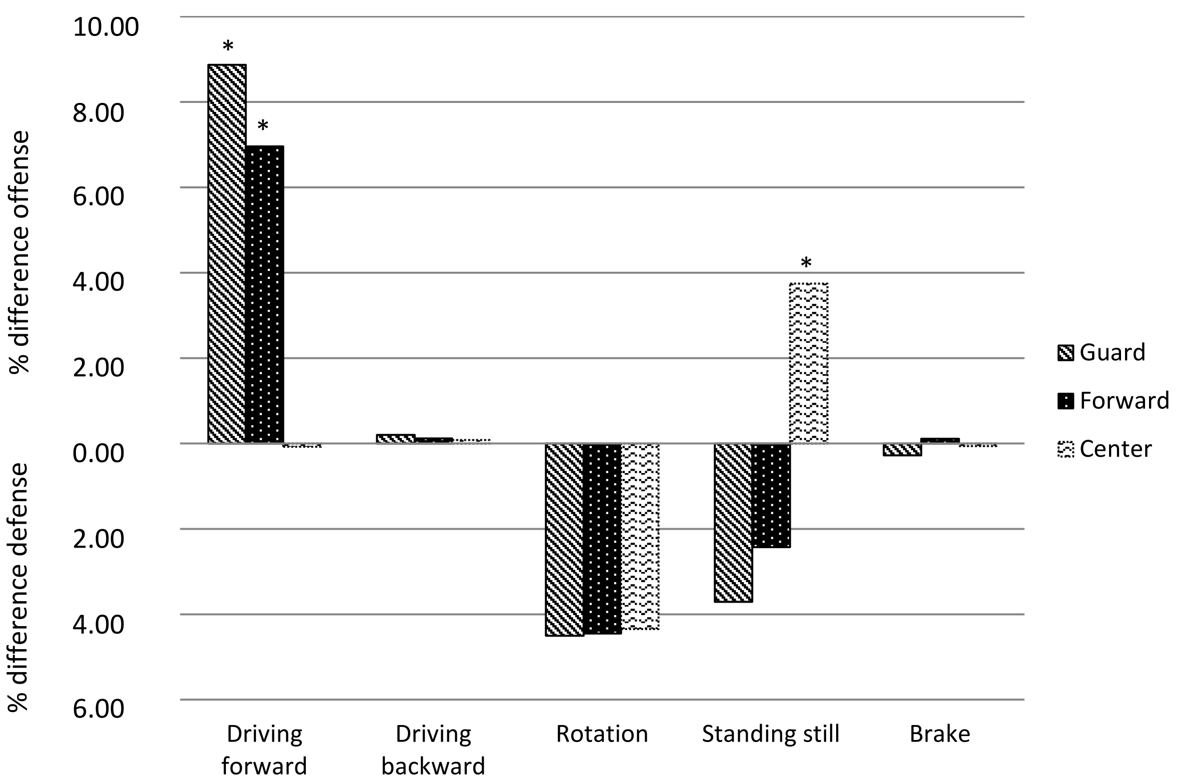
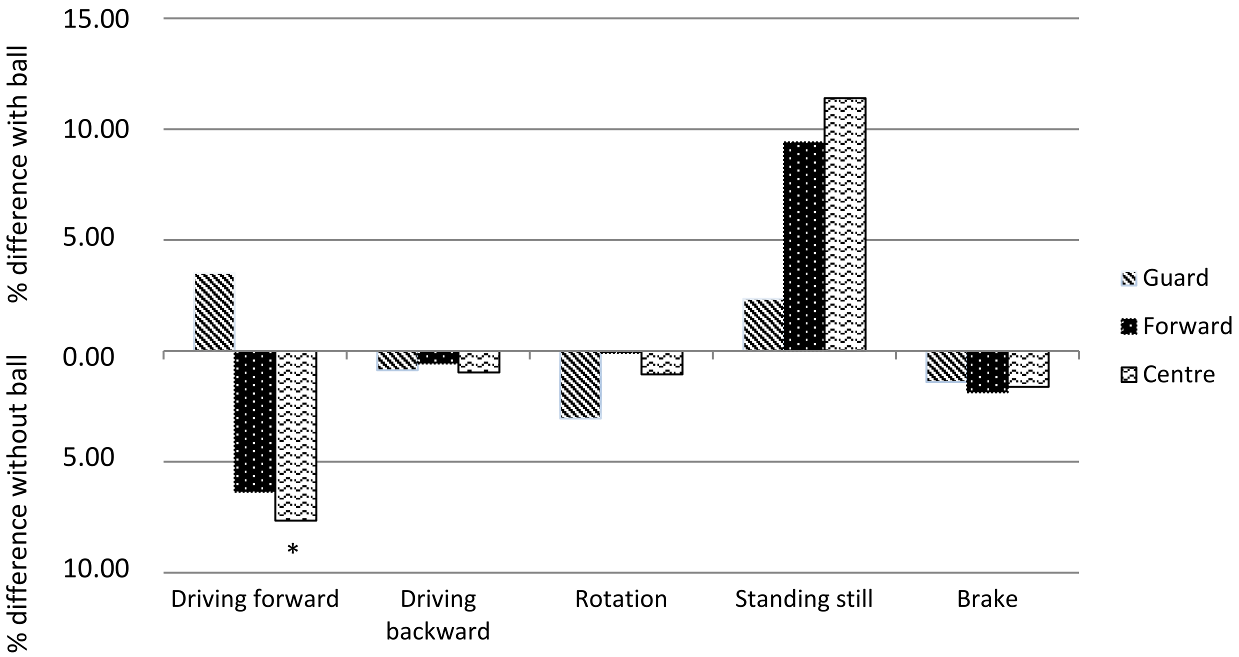


Figure 2. Differences in mean relative duration (%) of wheelchair-athlete activities between offense and defense situation. Deviation from the axis means that the activity is performed longer during offense/defense than the other game situation.
*Significant difference between offense and defense (*P*<0.05).

Figure 3. Differences in mean relative duration (%) of wheelchair-athlete activities between ball possession and no ball possession. Deviation from the axis means that the activity is performed longer during ball possession than no ball



possession.
*Significant difference between ball possession (*P*<0.05).

3.3.1 Game situation

Means and standard deviations for all wheelchair-athlete activities and control options during game situations are shown in Table II. Two-way mixed design analysis of variance revealed a significant main effect for game situation for rotational movements (p<.01), both clockwise and counter clockwise. During defense, all field positions performed on average 4 percentage points (pp) more rotational movements than during offense. Moreover, during defense all field positions stood still 4pp longer with two hands on the rim (p<.01) and during offense all field positions stood still longer without hands on the rim than during defense (p<.01). The magnitude of the effect sizes of these three pairwise comparisons was large (ES≥1.34).

Furthermore, there was a significant interaction between game situation and field position for driving forward in general (p=.001) and driving forward with the athlete control options “otherwise” (p=.044) and “two hands” (p=.006). During offensive situations, guards and forwards performed driving forward activities more than during defensive situations (guards 51 ± 8 vs. 43 ± 6%; ES=1.19; forwards 48 ± 10 vs. 41 ± 6%; ES=0.86) while centres showed no differences between offense and defense and the effect sizes was trivial (44 ± 6 vs. 44 ± 4%; ES=-0.01). Furthermore, only guards performed driving forward without hand rim propulsion (control option “otherwise”) less during defensive situations than during offensive situations (3 ± 2 vs. 2 ± 2%; ES=0.55).

There was also an interaction between game situation and field position for the activity standing still overall (p=.018). During offense, centres stood still 4 pp longer than in a defensive situation (23 ± 7 vs. 20 ± 6%; ES=0.58) while the guard and forward showed no differences (guards 15 ± 6 vs. 19 ± 8%; ES=-0.56; forwards 17 ± 7 vs. 20 ± 7%; ES=-0.35). The magnitudes of the effect sizes of these three comparisons were small (<0.6).

3.3.2 Ball possession

Ball possession had a major impact on wheelchair-athlete mobility performance: in 12 of the 18 activities a main effect for ball possession was seen. Players with ball possession stood still longer and they showed fewer moving activities than without ball possession. There was a remarkable difference for turning clockwise. During ball possession, players performed on average 2 pp fewer rotations clockwise than without ball possession with a small effect (12 ± 7 vs. 14 ± 4%; ES=-0.36).

An interaction effect between ball possession and field position was only observed for the activity driving forward (p=.017) (Table III). Follow-up analyses showed that centres with ball possession drove less forward than without ball possession (38 ± 12 vs. 45 ± 5%; ES=0.84) whereas guards and forwards showed no differences between possession and driving forward (guards 50 ± 10 vs. 46 ± 7%; ES=0.42; forwards 38 ± 16 vs. 45 ± 7%; ES=-0.52). The magnitudes of the effect sizes ranged from small (>0.2) to moderate (<1.2).

Table II. Mean (± *s*) relative duration (%) of wheelchair-athlete activities with 95% confidence intervals (CI) of mean differences during a game for position (guard. forward and centre) during game situations (offense and defense) complemented with Cohen's d effect sizes with 95% CI. For each activity the overall percentage is presented, as well as the distribution of the control options. The relative duration is calculated as a proportion of the duration of a game situation.

Action	Control	Guard					Forward					Centre				
		Mean (± standard deviation)		95% CI Mean difference	Effect Size	95% CI Effect size	Mean (± standard deviation)		95% CI Mean difference	Effect Size	95% CI Effect size	Mean (± standard deviation)		95% CI Mean difference	Effect Size	95% CI Effect size
		Offense	Defense				Offense	Defense				Offense	Defense			
Driving forward	Overall*	51(8)	43(6)	3.84 - 13.90	1.19^	0.46 - 1.87	48(10)	41(6)	2.27 - 11.65	0.86^	0.26 - 1.44	44(6)	44(4)	-4.28 - 4.12	-0.01	-0.76 - 0.73
	1 hand#	1(1)	0(1)	-0.18 - 0.97	0.47	-0.20 - 1.12	1(1)	0(0)	-0.05 - 0.99	0.53	-0.06 - 1.09	1(2)	0(1)	-0.89 - 1.56	0.21	-0.53 - 0.95
	2 hands*	48(9)	40(7)	2.16 - 13.15	0.94	0.24 - 1.61	44(9)	38(6)	1.90 - 11.11	0.82	0.22 - 1.40	40(7)	40(5)	-4.12 - 4.94	0.07	-0.67 - 0.81
	Otherwise*	3(2)	2(2)	-0.26 - 2.45	0.55^	-0.13 - 1.20	3(3)	3(3)	-1.68 - 1.75	0.01	-0.55 - 0.58	3(8)	4(3)	-5.25 - 4.04	-0.10	-0.84 - 0.64
Driving backward	Overall	2(1)	1(1)	-0.59 - 0.99	0.17	-0.48 - 0.82	2(1)	2(2)	-0.74 - 0.98	0.08	-0.49 - 0.65	2(1)	1(1)	-0.61 - 0.76	0.09	-0.66 - 0.83
	1 hand	0(0)	0(0)	-0.04 - 0.01	-0.48	-1.13 - 0.19	0(0)	0(0)	-0.04 - 0.05	0.08	-0.48 - 0.65	0(0)	0(0)	-0.08 - 0.10	0.07	-0.68 - 0.80
	2 hands	2(1)	1(1)	-0.59 - 0.94	0.16	-0.50 - 0.81	2(1)	2(2)	-0.77 - 0.91	0.05	-0.52 - 0.61	1(1)	1(1)	-0.59 - 0.66	0.04	-0.70 - 0.78
	Otherwise	0(0)	0(0)	-0.03 - 0.11	0.42	-0.25 - 1.07	0(0)	0(0)	-0.03 - 0.11	0.37	-0.21 - 0.93	1(1)	0(0)	0.77 - 2.02	1.73	0.82 - 2.54
Rotate	Overall#	27(9)	32(10)	-10.88 - 1.87	-0.48	-1.13 - 0.19	28(8)	33(8)	-9.21 - 0.30	-0.54	-1.11 - 0.04	26(7)	30(6)	-9.66 - 0.96	-0.64	-1.38 - 0.14
	Clockwise#	12(5)	15(7)	-6.90 - 1.07	-0.50	-1.15 - 0.18	13(6)	16(5)	-5.37 - 0.57	-0.47	-1.03 - 0.11	12(4)	15(3)	-5.53 - -0.32	-0.87	-1.62 - -0.07
	Counter-clockwise#	15(6)	17(5)	-5.30 - 2.13	-0.29	-0.94 - 0.37	15(5)	17(5)	-4.93 - 0.88	-0.41	-0.97 - 0.17	14(4)	15(4)	-4.63 - 1.81	-0.34	-1.08 - 0.42
Standing still	Overall*	15(6)	19(8)	-8.19 - 0.76	-0.56	-1.21 - 0.12	17(7)	20(7)	-6.48 - 1.63	-0.35	-0.91 - 0.23	23(7)	20(6)	-1.30 - 8.79	0.58^	-0.20 - 1.32
	1 hand	1(2)	1(1)	-0.95 - 1.29	0.10	-0.55 - 0.75	1(1)	1(1)	-0.84 - 0.58	-0.11	-0.67 - 0.46	2(3)	2(1)	-1.35 - 1.70	0.09	-0.66 - 0.83
	2 hands#	11(4)	18(7)	-10.33 - -2.04	-1.01	-1.68 - -0.30	13(7)	18(7)	-8.61 - -0.46	-0.65	-1.22 - -0.06	16(6)	17(6)	-5.82 - 3.65	-0.18	-0.91 - 0.57
	Otherwise#	3(2)	0(1)	1.11 - 3.38	1.34^	0.59 - 2.03	3(2)	1(1)	1.45 - 2.97	1.69^	1.01 - 2.32	5(2)	1(1)	3.45 - 5.85	3.01^	1.86 - 3.99
Brake	Overall	3(2)	3(2)	-1.68 - 1.13	-0.13	-0.78 - 0.52	3(2)	3(2)	-0.94 - 1.16	0.06	-0.51 - 0.62	3(2)	3(1)	-1.29 - 1.16	-0.04	-0.78 - 0.70
	2 hands	3(2)	3(2)	-1.75 - 1.01	-0.18	-0.83 - 0.47	3(2)	3(2)	-0.95 - 0.88	-0.02	-0.59 - 0.54	3(2)	3(1)	-1.22 - 1.12	-0.03	-0.77 - 0.71
	Otherwise	0(0)	0(0)	-0.01 - 0.20	0.60	-0.08 - 1.26	0(1)	0(0)	-0.15 - 0.45	0.29	-0.29 - 0.85	0(0)	0(0)	-0.05 - 0.08	0.23	-0.52 - 0.97

Notes: summative differences are caused by rounding off

*Significant interaction between game situation and field position (P<0.05)

Significant main effect of game situation (P<0.05).

^Significant difference between offense and defense (P<0.05).

Table III. Mean (± *s*) relative duration (%) of wheelchair-athlete activities with 95% confidence intervals (CI) of mean differences during a game for position (guard, forward and centre) during ball and no ball possession complemented with Cohen's d effect sizes with 95% CI. For each activity the overall percentage is presented, as well as the distribution of the control options. The relative duration is calculated as a proportion of the duration of ball and no ball possession.

Action	Control	Guard					Forward					Centre				
		Mean (± standard deviation)		95% CI Mean difference	Effect Size	95% CI Effect size	Mean (± standard deviation)		95% CI Mean difference	Effect Size	95% CI Effect size	Mean (± standard deviation)		95% CI Mean difference	Effect Size	95% CI Effect size
		With ball %	Without ball%				With ball %	Without ball%				With ball %	Without ball%			
Driving forward	Overall*	50(10)	46(7)	-2.22 - 9.25	0.42	-0.25 - 1.07	38(16)	45(7)	-13.42 - 0.72	-0.52	-1.09 - 0.06	38(12)	45(5)	-14.68 - -0.61	-0.84^	-1.59 - -0.05
	1 hand#	3(6)	0(0)	-0.31 - 5.17	0.60	-0.08 - 1.25	2(5)	0(0)	-0.05 - 3.85	0.57	-0.02 - 1.13	2(3)	1(1)	-0.88 - 3.13	0.44	-0.33 - 1.17
	2 hands#	43(13)	44(8)	-8.41 - 6.04	-0.11	-0.76 - 0.55	32(14)	41(7)	-16.02 - -3.11	-0.86	-1.44 - -0.26	32(15)	42(5)	-18.15 - -1.09	-0.88	-1.62 - -0.08
	Otherwise#	4(6)	2(2)	-0.60 - 5.16	0.54	-0.14 - 1.19	4(6)	3(3)	-1.17 - 3.83	0.31	-0.27 - 0.87	3(3)	3(3)	-1.97 - 2.62	0.11	-0.63 - 0.85
Driving backward	Overall#	1(1)	2(1)	-1.68 - -0.04	-0.71	-1.37 - -0.03	1(2)	2(1)	-1.52 - 0.38	-0.35	-0.91 - 0.23	1(1)	2(1)	-1.65 - -0.29	-1.10	-1.86 - -0.28
	1 hand	0(0)	0(0)	-0.02 - 0.00	-0.47	-1.12 - 0.20	0(0)	0(0)	-0.05 - 0.09	0.16	-0.41 - 0.72	0(1)	0(0)	-0.13 - 0.46	0.43	-0.33 - 1.17
	2 hands#	0(1)	2(1)	-1.73 - -0.60	-1.41	-2.10 - -0.65	1(2)	2(1)	-1.62 - 0.30	-0.40	-0.96 - 0.18	0(1)	2(1)	-1.68 - -0.65	-1.75	-2.57 - -0.84
	Otherwise	0(1)	0(0)	-0.16 - 0.78	0.45	-0.22 - 1.10	0(0)	0(0)	-0.05 - 0.19	0.33	-0.25 - 0.89	0(0)	0(0)	0.00 - 0.00	NaN	NaN
Rotate	Overall	27(15)	30(9)	-5.05 - 9.75	-0.25	-0.44 - 0.87	30(12)	30(7)	1.17 - 17.63	-0.01	0.07 - 1.23	27(9)	28(6)	2.96 - 19.85	-0.13	0.23 - 1.81
	Clockwise#	11(8)	14(5)	-0.14 - 6.79	-0.50	-0.03 - 1.31	14(8)	15(5)	0.35 - 4.02	-0.13	0.10 - 1.26	11(6)	13(3)	-0.12 - 5.70	-0.48	-0.04 - 1.49
	Counter-clockwise	16(9)	16(5)	-12.76 - -4.61	0.04	-2.14 - -0.68	17(9)	16(4)	-11.61 - -2.42	0.12	-1.46 - -0.28	15(6)	14(4)	-9.77 - 2.86	0.23	-1.16 - 0.34
Standing still	Overall#	20(15)	18(5)	3.06 - 12.43	0.22	0.39 - 1.80	28(19)	18(6)	6.17 - 22.15	0.66	0.41 - 1.61	32(14)	20(6)	7.42 - 16.72	1.05	1.06 - 2.86
	1 hand#	4(7)	1(1)	-11.34 - 5.26	0.65	-0.90 - 0.41	3(4)	1(1)	-5.69 - 5.51	0.69	-0.58 - 0.56	4(5)	1(1)	-7.29 - 5.18	0.74	-0.87 - 0.61
	2 hands#	7(7)	16(5)	-7.72 - 1.19	-1.44	-1.15 - 0.18	9(9)	16(6)	-4.69 - 2.99	-0.89	-0.69 - 0.44	14(10)	17(5)	-5.88 - 1.41	-0.43	-1.21 - 0.29
	Otherwise#	9(10)	1(1)	-4.75 - 5.33	1.12	-0.62 - 0.69	15(19)	1(1)	-3.15 - 4.72	1.03	-0.45 - 0.68	14(8)	2(1)	-2.69 - 5.03	2.02	-0.52 - 0.97
Brake	Overall#	1(2)	3(2)	-2.85 - 0.06	-0.65	-1.30 - 0.04	1(2)	3(2)	-3.07 - -0.66	-0.90	-1.48 - -0.29	2(2)	3(2)	-2.88 - -0.36	-1.00	-1.75 - -0.19
	2 hands#	1(1)	3(2)	-3.30 - -1.12	-1.37	-2.06 - -0.62	1(2)	3(2)	-3.10 - -1.28	-1.39	-2.00 - -0.74	2(2)	3(1)	-2.87 - -0.47	-1.08	-1.84 - -0.26
	Otherwise	0(0)	0(0)	0.00 - 0.00	NaN	NaN	0(0)	0(0)	0.00 - 0.00	NaN	NaN	0(0)	0(0)	0.00 - 0.00	NaN	NaN

Notes: summative differences are caused by rounding off
*Significant interaction between ball possession and field position ($P<0.05$).
Significant main effect of ball possession ($P<0.05$).
^Significant difference between ball possession and no ball possession ($P<0.05$).

3.4 Discussion

The purpose of this research was to determine whether mobility performance is influenced by offensive and defensive game situations and/or ball possession, and whether the effects of these actions differed between field positions. Game situation and ball possession influenced mobility performance for the three field positions in a different way. During offense, guards performed 9 percentage points (pp) more driving forward activities and forwards performed 7 pp more driving forward activities than during defense. Moreover, centres stood still 4 pp longer during offense than during defense and without ball possession, centres performed 7 pp more driving forward activities than with ball possession. All field positions performed on average more rotational movements and stood still longer with two hands on the rim during defensive states. In the case of ball possession, almost all dynamic wheelchair-activities are influenced.

3.4.1 Game-related aspects

During offensive situations, a team has ball possession and tries to score. The individual ball possession differed between the field positions; guards had the highest percentage ball possession, followed by centres and forwards. This is similar with running basketball where guards also have more ball possession compared to the other players (65). In running basketball as well as in wheelchair basketball, this position requires the ability to facilitate the team during a play and therefore the guards have the most ball possession (71).

During defense, guards stood still longer than during offense while centres stood still longer during offense. This can be explained by defensive basketball strategies. Most defensive schemes in wheelchair basketball are designed to block an opponent's chair from getting into the restricted area. This means that a guard during defense must focus more on stopping an opponent driving to the basket, rather than on locating the ball (80). Centres play mainly in the lane under the basket, both in offensive and defensive situations, to shoot from inside the lane and grasp rebounds (101). As a result, the relative percentage standing still is higher in both situations for centres compared with guards and forwards.

Moreover, guards in an offensive situation drove more forward with two hands on the rim than during a defensive situation. Guards are the floor leaders and are responsible for carrying the ball and generally cover greater distances in offensive situations (71). Greater distances and a higher relative duration are not directly related with each other, kinematic data is necessary to confirm this assumption. The centres primary role in offense is to score from a position close to the basket (80). Guards and forwards led the offense and mostly play the ball to the centres who stood still near by the basket. By doing so, centres with ball possession performed 8 pp less driving forward activities than without ball possession.

Rotational movements are a very important factor of mobility performance. During the game, almost 30% of the wheelchair-handling activities consisted of turning (31). During offense and individual ball possession, there is a striking difference in rotation direction clockwise or counter clockwise. During offensive situations, all field positions performed on average 2 pp more rotations counter clockwise than clockwise. During individual ball possession, the difference in the direction of rotation is even higher (on average 4 pp). This could be explained by the use of the dominant hand. Of all people, about 90% is right-handed and 10% left-handed (95). During situations with more pressure, it is likely that the dominant hand is used or prepared for ball possession. Most of the players use their dominant hand (right) to handle the ball and use their other hand (left) to rotate the wheelchair, which leads to a counter clockwise rotation. For all players during ball possession, it is important to have the opportunity to turn both, clockwise or counter clockwise because opponents might anticipate on the preferred direction that can lead to turnovers. Therefore it is advisable to incorporate drills with rotational movements in both directions during ball possession in training schedules.

Important to note, players are able to change their positions throughout the game. In addition, the interaction between classification level and field position dependent tasks may have obscured some interclass differences between performance variables. Earlier research, showed differences in performance between classification level 1 and the other classifications levels (12,102). Main difference between classification 1 players and the others, are reflected in the inability to have active stability and rotation of the trunk. These functional disadvantages result in lower manoeuvrability and more limited range of action for the classification 1 player. The functional abilities are often necessary in player-to-player offensive and defensive actions during the game (102). In this study, there are significant differences described between game situations and ball possession. These differences are related to the specific tasks associated with field position. It is important for the trainer and coach to know what the specific requirements for (mobility) performance are related to the field positions. The coach is responsible for allocating players over the specific tasks and not violate the classification rules in order to achieve maximal performance. However, one has to be aware that field position versus mobility performance is highly influenced by classification level and vice versa.

3.4.2 Practical implications for wheelchair configurations and recommendations

The observed differences in mobility performance with or without the ball, for the different field positions and game situations can be used to design specific training schedules. Moreover, this information may also be used to improve individual wheelchair configurations and subsequent field performance. Based on this study, guards and forwards could benefit more from improved acceleration characteristics of the wheelchair (driving forward) in offensive situations, while centres could benefit more from improved stability (standing still). Rotational movements (manoeuvrability) are not influenced by game situation or ball possession, but take almost 30% of the relative duration during all game phases. Rear wheel camber plays an essential role here (93). Clearly, manoeuvrability should not be negatively affected by any adjustments of the wheelchair mechanics of interfacing. The effects of manipulating wheelchair configurations, on aspects of mobility performance during wheelchair court sports, has received limited attention in scientific research. In the past, some studies investigated seat height parameters within the propulsion cycle in a laboratory setting (58,75,91,94). Lower seat heights have been associated with reductions in push frequency and increasing seat height was reflected in decreased push duration. Therefore, seat height could be a key interface characteristic that may improve the acceleration characteristics of the wheelchair for guards and forwards (as well as reach). Under sport-specific conditions, Walsh et al. (104) assessed maximal effort mobility performance during a combination of different vertical and horizontal seat positions. For-aft position of the wheelchair-athlete combination influences, as with seat height, the centre of gravity and therefore will affect stability (58). Fore-aft position may improve stability characteristics of the wheelchair which could be beneficial for centres. Because the basketball wheelchairs have changed in recent years (i.e. use of anti-tip castors at the backs), one has to wonder whether scientific knowledge is helpful or valid for today’s court sports. Recently, only Mason et al. (54,55) studied effects of sports wheelchair configurations on mobility performance in the context of court sports. Wheels with 18° camber reduced 20m sprint times and enabled greater initial acceleration over the first 2 and 3 pushes in comparison with 24° camber (55). Furthermore, larger 26inch wheels improved the maximal sprinting performance in wheelchair basketball players compared to 24inch wheels (54). Hand-rim and wheel size are related; the diameter of the hand-rim of court sport wheelchairs are typically one inch (0.025 m) smaller than the diameter of the main wheel (57). Knowledge about the effects of wheel size, hand-rim and wheel camber on acceleration performance, could be beneficial for the different field positions. Therefore, the study of the effects of wheelchair configuration on mobility performance during wheelchair basketball matches is warranted.

To increase mobility performance, players have to find the best compromise between wheelchair configurations, in terms of field position and their disability (classification level). When it is considered how many compromises are possible to potentially optimize wheelchair-athlete configurations and consequent performance in wheelchair basketball, it is clear that further research is required. Since the specific qualities for the field positions are known, future research should test the effects of wheelchair configurations on mobility performance in wheelchair basketball. Apart from the wheelchair basketball playing characteristics for different field positions and game situations, the basketball rulings and wheelchair regulations/legalisations should be taken into account when future research is designed. It is important to identify which areas of wheelchair configuration need priority for scientific research. In addition, it must be acknowledged that this study only focused on mobility performance. Wheelchair basketball also includes game performance and physical performance. Future investigations should also explore whether the differences in mobility performances also apply for game and physical performance. The influence of game situation, classification, ball possession and possibly optimisation of wheelchair configurations on game and physical performance should also be examined in future studies.

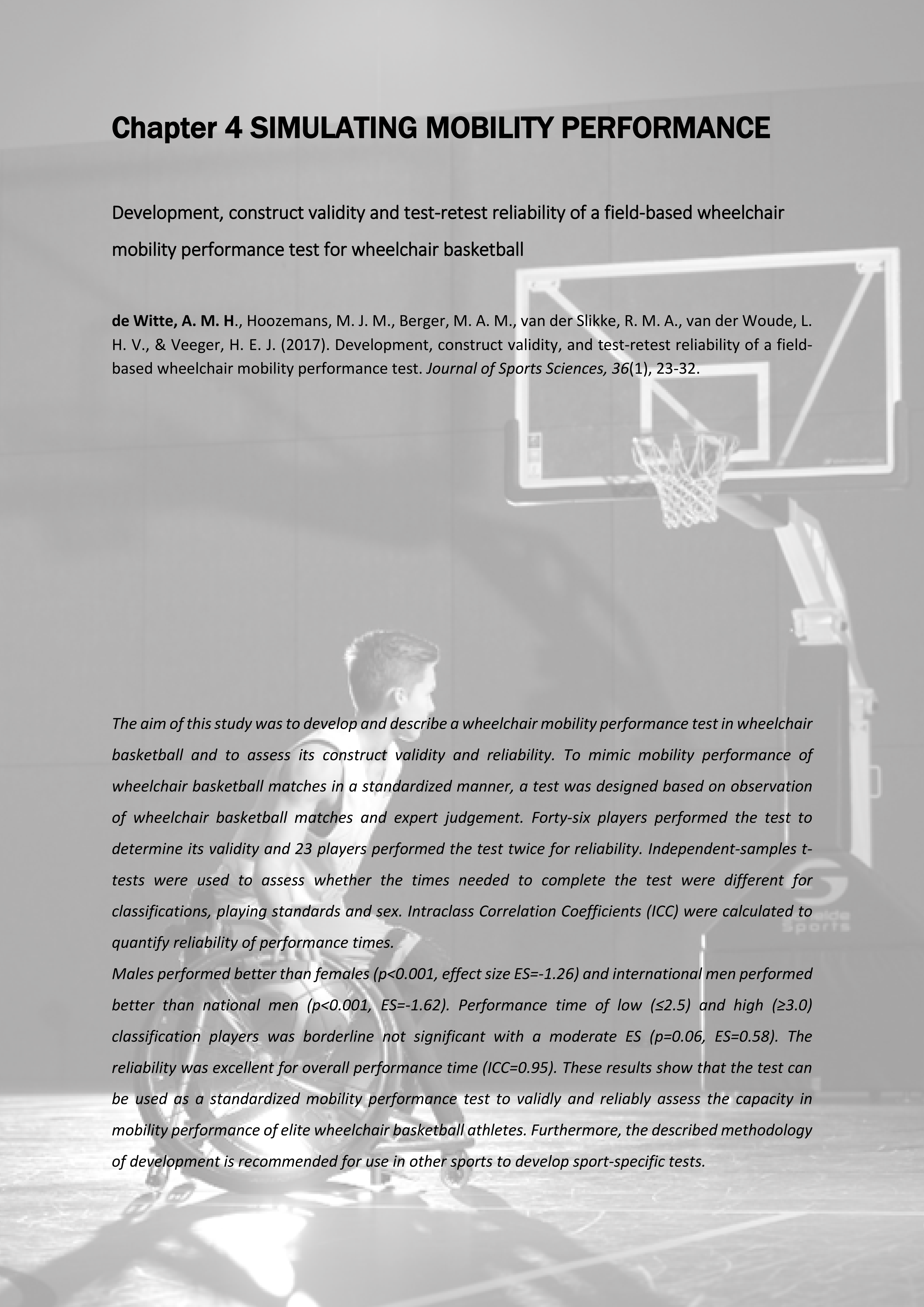
Video analysis lacked quantitative data of distances and acceleration, which is necessary to get a thorough understanding of mobility performance during games. Results of mobility performance during games complemented with kinematic data of wheelchair basketball games (89) could be used to develop a field-based test circuit with the most common wheelchair-handling activities. This field-based test can be used to test the impact of wheelchair configurations on mobility performance with players competing in wheelchair basketball under the most ecologically valid conditions.

3.4.3 Conclusions

It can be concluded that game situation and ball possession influenced mobility performance for the different field positions. The specific tasks associated with field position are reflected in mobility performance. Because guards and forwards lead the offense, they perform more driving forward activities during offense than during defense. Centres stand still longer during offense than during defense because they try to score from the area under the basket. During defense, all field positions perform more rotational movements than during offense. In parallel, ball possession has a high impact on almost all wheelchair-athlete activities. This information can be used to design specific training protocols to improve performance (e.g. increase mobility performance during ball possession) and it can help the coach allocate specific roles to players, taking into account specific individual qualities. Future research is imperative to identify optimal (individual) wheelchair- and interface configurations in terms of their disability and their field position.

3.4.4 Perspectives

Wheelchair basketball is one of the most popular Paralympic sports. Players have become elite in their sport and due to the increased professionalism, there is a need for scientific input. To make adjustments to e.g. training protocols and wheelchair-athlete configurations, it is important to have a comprehensive and thorough understanding of the influence of game related aspects and wheelchair-athlete activities during the game. This study is an important basis for the design of further research that contributes to performance in wheelchair basketball games. In addition, wheelchair experts can take into account the main wheelchair-athlete activities related to the field position in order to make a firm choice between possible configurations.



Chapter 4 SIMULATING MOBILITY PERFORMANCE

Development, construct validity and test-retest reliability of a field-based wheelchair mobility performance test for wheelchair basketball

de Witte, A. M. H., Hoozemans, M. J. M., Berger, M. A. M., van der Slikke, R. M. A., van der Woude, L. H. V., & Veeger, H. E. J. (2017). Development, construct validity, and test-retest reliability of a field-based wheelchair mobility performance test. *Journal of Sports Sciences, 36*(1), 23-32.

The aim of this study was to develop and describe a wheelchair mobility performance test in wheelchair basketball and to assess its construct validity and reliability. To mimic mobility performance of wheelchair basketball matches in a standardized manner, a test was designed based on observation of wheelchair basketball matches and expert judgement. Forty-six players performed the test to determine its validity and 23 players performed the test twice for reliability. Independent-samples t-tests were used to assess whether the times needed to complete the test were different for classifications, playing standards and sex. Intraclass Correlation Coefficients (ICC) were calculated to quantify reliability of performance times.

Males performed better than females ($p<0.001$, effect size ES=-1.26) and international men performed better than national men ($p<0.001$, ES=-1.62). Performance time of low (≤2.5) and high (≥3.0) classification players was borderline not significant with a moderate ES ($p=0.06$, ES=0.58). The reliability was excellent for overall performance time (ICC=0.95). These results show that the test can be used as a standardized mobility performance test to validly and reliably assess the capacity in mobility performance of elite wheelchair basketball athletes. Furthermore, the described methodology of development is recommended for use in other sports to develop sport-specific tests.

4.1 Introduction

In wheelchair court sports, the player, the wheelchair and the environment determine performance. All the activities an athlete does (or can do) with a wheelchair, the wheelchair-athlete activities, can be defined as mobility performance. Key determinants of mobility performance are the abilities of the athlete to accelerate, sprint, brake and turn with the wheelchair (31,52). The actual mobility performance in wheelchair court sports should be assessed during a match, preferably by systematic (video) observation combined with the use of (inertial) sensors (8,31,68,89). These observations and measurements during wheelchair basketball result in, for example, findings that players move across the field with light or no arm strokes for 24% (standard deviation [SD] 7) of the time (8) and that national standard players drive relatively more forward, while international standard players perform more rotational movements during a match (31). Assessing mobility performance is a fundamental requirement for trainers and coaches to, for example, develop training schemes, discuss and improve the athlete's level of performance, detect strength and weaknesses of mobility performance and develop optimal wheelchair configurations. The use of systematic observation and/or sensor technology during matches can thus provide useful information about mobility performance. However, systematic observation is very time-consuming and results of both methods are influenced by the continuously changing environment when participating in a match of wheelchair basketball. Each match has unique circumstances depending on, for example, the opponent, injuries or team composition.

In order to repeatedly monitor athletes' mobility performance, athlete performance on a standardized field-based test is assigned to be informative and helpful (38,98). Currently, there is no generally accepted validated mobility performance test available for wheelchair court sports in general and for wheelchair basketball specifically. To assess and monitor mobility performance in a controllable setting, the mobility performance during a match must be simulated. A simulation or test that is based on field activities – i.e. the match – will result in meaningful information for coaches, players and (embedded) scientists. Field-based tests are generally acknowledged as a feasible way to get an indication of the performance standard of athletes (23). Field-based tests exist for wheelchair court sports, but they assess mainly other aspects of performance, such as game performance (ball skills) and athlete performance (e.g. maximal heart rate or oxygen consumption) and only some parts of mobility performance (4,11,23,26,35,39,108).

Extensive systematic observation and analyses of mobility performance during wheelchair basketball matches have recently been done for wheelchair basketball (31,87). These data were used to develop a standardized and worldwide-accepted wheelchair mobility performance (WMP) test. Feasibility is a precondition in the development process and the test should be easy to take without advanced equipment. To further ensure a high external validity, the test should be performed by wheelchair basketball players in their own sports wheelchair and on a regular wheelchair basketball court. Furthermore, the test should discriminate between different categories of athletes (e.g. sex and playing standard), which is known from the literature that they differ in mobility performance (31,36,87,89,97). Besides valid results, the test should give reliable data to monitor the actual capacity in mobility performance of athletes.

In this context, the goals of the present study were (1) to describe the development of a field-based wheelchair test that assesses mobility performance capacity and which closely mimics the wheelchair mobility skills required in real wheelchair basketball matches, (2) to define the developed field-based test and (3) to assess the construct validity and test-retest reliability of the newly developed field-based WMP test for wheelchair basketball.

4.2 Methods

4.2.1 Test development

The development process had a stepwise character: (1) examine match mobility performance, (2) determine practical test requirements and (3) organize expert meetings to verify the test design.

To examine mobility performance in matches, coaches were interviewed to describe and define wheelchair-athlete activities during wheelchair basketball. The wheelchair activities were assessed by systematic observation of video footage of matches (31). Four matches at national playing standard and five matches at international playing standard were recorded. In total, 56 male wheelchair basketball players were analyzed during an entire match. Time-motion analysis was used for determining the frequency and duration of these athlete and wheelchair activities (31). Based on the results, wheelchair basketball mobility performance was defined in various dominant game-related wheelchair activities (Table I). In order to make a translation from match data to test design, the output was organized into three main categories: separate activities, combined activities and activities with ball possession. For each of these categories the most common wheelchair-athlete activities and distances were determined with inertial sensors (87).

In addition, practical test requirements were formulated for the WMP test based on interviews with coaches and experts: (1) The WMP test should be easy to use without advanced equipment; (2) The WMP test should take place in a realistic environment common to wheelchair basketball, e.g. athletes performed the test in their own sports wheelchairs and on a regular wheelchair basketball court and (3) Fatigue should not be a limiting factor for performance. The observed activities and the requirements were used to draft the first test setup.

An expert meeting with coaches, players and researchers was organized to discuss the first version of the WMP test to increase its content validity, after which “specific skills” were added as a fourth main group. The four main groups contained a total of 15 different wheelchair-athlete activities (Table II). Based on these data a final version of the WMP test was developed which is described in the results section. The development process took place between March 2014 and March 2015.

Table I. Overview of the relative duration (±SD) as a percentage of wheelchair-athlete activities based on video analysis of 56 male wheelchair basketball athletes playing at national and international playing standard (31). The data are complemented with information from data of inertial sensors based on 29 wheelchair basketball players (87).

Wheelchair activities	Outcome video analysis Relative duration % (±SD)	Relative duration during ball possession % (±SD)	Outcome inertial sensors
Standing still	19 (6)	26 (16)	--
Driving forward	45 (6)	42 (12)	Most common: 3 m Maximal: 12 m
Driving backward	2 (1)	1 (1)	--
Rotate	29 (8)	28 (12)	Most common: radius 1.5-2.5 m
Brake	3 (2)	2 (2)	--

Table II. Setup test protocol based on observed wheelchair-athlete activities and distances (for the total test protocol see Appendix I).

Main group	Activity	Distance	Direction
Separate activities	Driving forward	12 m	--
	Rotation	Radius 1.9 m (total circumference of 12 m)	Clockwise/ Counterclockwise
	Rotation on the spot		Clockwise/ Counterclockwise
Combined activities	Driving forward with two stops	3, 3 and 6m = 12 m	--
	Rotation with two stops	90° (3m), 90° (3m), 180° (6m) = 12 m	Clockwise/ Counterclockwise
	Rotation on the spot with stop	90°, 90°	Clockwise/ Counterclockwise
	Combined activities		--
Specific skills	Tik-Tak Box		--
Activities with ball possession	Driving forward	12 m	--
	Rotation	Radius 1.9m (total circumference of 12 m)	Clockwise/ Counterclockwise

4.2.2 Construct validity and test-retest reliability

To evaluate the construct validity and reliability of the newly developed WMP test, experienced wheelchair basketball players were included in different field-based standardized experimental sessions.

4.2.2.1 Participants

For the validity study, 46 players - competing at different playing standards - were included, and for the reliability study, 23 players - competing at a national playing standard (Dutch first division competition) - participated. In the validity group, a distinction was made between men and women competing at an international standard and players competing at a national standard, and a distinction was made between low classification (≤2.5 points) and high classification (≥3.0 points) players. The International Wheelchair Basketball Federation uses a classification system based on the players' functional potential to execute fundamental basketball movements (43). All players are scaled from 1 (minimal functional potential) to 4.5 points (maximal functional potential) on an ordinal functional level scale. The characteristics (classification, basketball experience and age) of the validity and reliability study groups are shown in table III. Players were informed about the procedures before given

Table III. General characteristics of the participants included in the construct validity (n=46) and test-retest reliability (n=23) analyses for classification 1-4.5.

	Classification	n	Experience in years (±SD)	Age in years (±SD)	Mean (±SD) and range of wheel size (cm)	Mean (±SD) and range of elbow angle with hand on the top of the rim (°)	Mean (±SD) and range of wheel camber (°)	Men playing at International standard (n)	Women playing at International standard (n)	Men playing at National standard (n)
Validity study	1-1.5	8	7.2 (4.8)	28.3 (7.1)	62.0 (2.4)	100 (11)	17 (1)	3	3	2
					58 - 64	86 – 122	16 -19			
	2-2.5	11	12.9 (6.9)	28.9 (9.3)	62.8 (2.6)	117 (18)	17 (1)	6	3	2
					59 - 68	77 – 135	15 – 19			
	3-3.5	8	9.1 (3.3)	26.7 (10.0)	64.4 (1.1)	128 (18)	18 (1)	5	3	-
					64 - 67	100 – 162	17 – 21			
	4-4.5	19	8.4 (5.2)	24.7 (8.3)	64.5 (2.0)	136 (18)	18 (1)	7	4	8
					61 - 68	99 – 168	15 – 21			
Reliability study	1-1.5	2	4.0 (0.7)	21.0 (4.2)	61.5 (3.5)	87 (1)	17 (1)	-	-	2
					59 – 64	86 – 88	16 – 17			
	2-2.5	1	9.0	21.0	61.0	110	17	-	-	1
	3-3.5	5	6.4 (1.9)	16.8 (5.1)	60.4 (2.9)	104 (24)	18 (2)	-	-	5
					58 – 64	81 – 136	15 – 20			
	4-4.5	15	6.5 (6.4)	22.8 (10.8)	63.4 (2.5)	129 (16)	18 (1)	-	-	15
					56 - 67	99 - 151	15 – 20			

their written informed consent. This study was approved by the Ethical Committee of the Department of Human Movement Sciences, Vrije Universiteit Amsterdam, the Netherlands.

4.2.2.2 Procedure

Prior to all tests, procedures were explained and the test protocol was demonstrated using a video shown to all participants. Players were asked to refrain from smoking and drinking caffeine or alcohol at least 2 h prior to the WMP test. Before performing the WMP test, players carried out a self-selected warm up. All players performed the WMP test in their own sports wheelchairs, with their own configurations and tires were inflated to 7 bar.

Participants of the validity study performed the WMP test once on the same synthetic soft-top basketball court. Participants were measured while being involved in training sessions and in the Euro Cup 4 tournament (April 2015, the Netherlands).

Participants of the test-retest reliability study performed the same test twice. Participants were tested during their training sessions, on the basketball courts where the teams trained, on two separate days at the same time of the day, with 1 week in between (October/November 2015).

4.2.2.3 Data acquisition and analyses

The WMP test simulated the 15 most common wheelchair-athlete activities during wheelchair basketball (table II). All the standardized activities were carried out in succession, separated by standardized rest periods to avoid fatigue. Two high-definition video cameras (CASIO EX-FH100, 1280*720, 20-240mm) were placed at the side of the test. Each camera was focused on one half of the basketball court with a small overlap between the videos. The outcome of the WMP test was time (s), which was manually recorded from video analysis (Kinovea 0.8.15, available for download at: http://www.kinovea.org). These analyses resulted in 16 performance time values, one for each of the 15 wheelchair-athlete activities (*time activity no. 1 - 15*) and the *overall performance time,* which is the sum of the performance times of the 15 separate activities.

4.2.2.4 Statistical analyses

All statistical analyses were performed using IBM SPSS statistics version 22 (IBM Corporation, Armonk, NY, USA). Descriptive statistics for the *time activities no. 1-15* and the *overall performance time* were presented as mean ± SD. The assumptions of normality were checked with the Shapiro-Wilk test, as well as z-values of the skewness and kurtosis. Also, histograms, boxplots and q-q plots of the data were visually inspected. The assumption of normality was not violated.

Construct validity

To determine the construct validity of the WMP test, three hypotheses were formulated and tested. Hypothesis (1): Players with a high classification (≥3.0 points) are expected to perform better than players with a low classification (≤2.5 points) (89,98). Hypothesis (2): Players playing at an international standard are expected to perform better than players at a national standard (31,89). Hypothesis (3): Men are expected to perform better than women because of sex differences in upper body strength and trunk stability as key determinants of mobility performance (36).

To assess potential differences in the 16 performance time outcomes between classification categories, playing standards and sex, independent samples *t*-tests were used. The means ± standard deviations were completed with mean differences, 95% confidence intervals of the difference and *p*-values. Differences with *p*-values <0.05 were considered statistically significant. In addition, Cohen's *d* effect sizes (ES) were calculated for main effects as outlined by Cohen (14). The (absolute) magnitude of the ES was classified as large (≥0.80), moderate (0.50-0.79) or small (<0.50) (15).

Test-retest reliability

Test-retest reliability of the 16 time performance outcomes was evaluated with Intraclass Correlation Coefficients (ICC(3,1)), Standard Error of Measurement (SEM) and Limits of Agreement (LoA). ICC(3,1) is a two-way mixed single measure of absolute agreement (77). ICC scores ≥0.70 are indicated as satisfactory, values ≥0.75 are considered as good and values ≥0.90 are categorized as excellent reliability (2). The SEM for agreement was calculated with Equation (1).

Equation 1: $SEM_{agreement} = \sqrt{Var_o + Var_{residual}}$

Variance components were obtained from variance component analyses and two components were estimated, variance attributable to observers (Var_o) and residual error ($Var_{residual}$).

The Bland-Altman method was used to examine the differences between the WMP test and retest for the whole group, including the calculation of the mean difference between the test and retest, the SD of the difference and the 95% LoA (7). The LoA95 was calculated with Equation (2).

Equation 2: $LOA95 = Mean_{difference} \pm 1.96 * SD_{difference}$

The differences for the overall performance times were visualized in a Bland-Altman plot, where the individual differences between the test and retest are plotted against the mean of the test and retest.

4.3 Results

4.3.1 Design of the WMP test

The final version of the WMP test for wheelchair basketball consisted of 15 activities with a standardized period of rest between the activities. The WMP test is divided into four main groups. Group (1): Separate activities containing a 12 m sprint, a rotation with a curve (circumference) of 12 m (clockwise/counterclockwise) and a turn on the spot (clockwise/counterclockwise); Group (2): Combined activities containing the same activities as group 1, combined with starts and stops in between; Group (3): Specific skills consisting of a tik-tak box, which means performance of short movements forward and backward alternated with collisions against a stationary object. Group (4) a 12 m sprint and rotation (clockwise/counterclockwise) with a curve (circumference) of 12 m performed with ball possession (dribble) (for the total WMP test protocol and the sequence of the activities, see Appendix I).

4.3.2 Construct validity and test-retest reliability

Time scores of the tik-tak box (activity no. 1) of the WMP test were not included in both the reliability and the construct validity study. The start and stop times of this activity were not clearly visible at the video-analysis, and because of this, the data are not presented and included.

4.3.2.1 Construct validity

To determine the construct validity of the WMP test, three hypotheses were formulated and tested.

Hypothesis 1) Players with a high classification are expected to perform better than players with a low classification. The overall performance time was borderline non-significant between high and low classifications (p=0.06, ES=0.58) but the magnitude of the ES can be interpreted as moderate (Table IV). For time scores on the individual activities, the classification analyses showed significant differences for driving forward movements and turn on the spots, in which high classification players performed the activities faster than low classification players. Significant differences between high and low classifications were observed for the 12 m sprint (mean difference=0.32s; ES=0.92) and for the 3-3-6 m sprint (mean difference=0.55s; ES=0.81). However, for nearly all activities related to rotation (7 out of 10) there was no difference between classification categories.

Hypothesis 2) Players playing at an international standard are expected to perform better than players at a national standard. The WMP test showed a significant difference for playing standard for the overall performance time (p<0.001, ES=-1.62). International men performed the WMP test on average 8.11s faster than the national men (table V). The WMP test showed a significant difference between international men and national men for 13 of the 15 outcomes and showed that international men were faster on all the activities (moderate/large ES: 0.81-1.72). The WMP test showed no differences for three of the four activities that measured turn on the spot (no. 2,6 and 10) (moderate/small ES: 0.71 – 0.22).

Hypothesis 3) Men are expected to perform better than women, both competing at the same playing standard. There was a significant difference between men and women on the overall performance time (p<0.001, ES=-1.26). International men performed the WMP test faster than international women (Table VI). In addition, the WMP test showed differences between international men and international women on all activities with the exception of the activities that measured turn on the spot and 12 m dribble. A striking detail is that international women performed the rotation on the spot activities almost as fast as the international men (small ES: 0.02-0.44).

4.3.2.2 Test-retest reliability

The test-retest reliability analyses results are summarized in table VII. The ICC value for the overall performance time was excellent (ICC=0.95). The LoA95 show that an improvement of 4.20s (5.1%) can be detected as a real improvement on the WMP test. The Bland-Altman plot for test-retest agreement of the overall performance time is shown in figure 1. The mean difference between the WMP test and retest for the overall performance time was 0.57s (±2.14). The variability of the differences between the two measurements seems to be constant over the range of the (mean) performance time scores. The ICC values for the individual activities ranged from 0.25 for the 180^0 turn on the spot (left) (no. 2) to 0.92 for the combination (no. 15). The four activities that measured turn on the spot (no. 2,6,10 and 14) show a low reliability (ICC≤0.62) while the LoA95 for these activities were high (at least 0.3s, 22.0%).

Table IV. Mean (±SD) performance times (s) for each activity and overall performance time (s) of the wheelchair mobility performance test for classification (classification ≤2.5 points and classification >2.5 points) complemented with the mean difference between the classification groups, 95% confidence intervals of the differences and Cohen's d effect sizes.

*Significant effect of classification ($p < 0.05$).

		Classification ≤2.5 points (n=19)	Classification >2.5 points (n=27)	Mean difference	Standard Error difference	95% Confidence Interval of the difference		*p*-values	Effect Size
		Mean (±SD)	Mean (±SD)			Lower	Upper		
Activity 2	180° Turn on the spot (left)	0.93 (0.09)	0.84 (0.08)	0.09	0.02	0.04	0.14	0.00*	1.04
Activity 3	12 m sprint	5.12 (0.42)	4.80 (0.28)	0.32	0.10	0.11	0.53	0.00*	0.92
Activity 4	12 m rotation (right)	5.97 (0.41)	5.90 (0.40)	0.07	0.12	-0.17	0.31	0.57	0.17
Activity 5	12 m rotation (left)	5.95 (0.47)	5.89 (0.39)	0.06	0.13	-0.19	0.32	0.62	0.15
Activity 6	180° Turn on the spot (right)	0.95 (0.13)	0.89 (0.12)	0.06	0.04	-0.01	0.14	0.10	0.50
Activity 7	3-3-6m sprint	7.19 (0.77)	6.64 (0.61)	0.55	0.20	0.14	0.96	0.01*	0.81
Activity 8	3-3-6m rotation (left)	7.66 (0.84)	7.33 (0.61)	0.33	0.21	-0.10	0.76	0.13	0.47
Activity 9	3-3-6m rotation (right)	7.58 (0.80)	7.23 (0.61)	0.36	0.21	-0.06	0.78	0.09	0.51
Activity 10	90°- 90° turn on the spot with stop (left)	1.54 (0.19)	1.38 (0.17)	0.16	0.05	0.05	0.27	0.01*	0.87
Activity 11	12 m dribble	6.03 (0.70)	5.80 (0.68)	0.24	0.21	-0.18	0.65	0.26	0.34
Activity 12	12 m rotation dribble (right)	7.38 (0.91)	7.17 (0.87)	0.22	0.26	-0.31	0.75	0.41	0.25
Activity 13	12 m rotation dribble (left)	7.42 (0.97)	7.27 (0.68)	0.15	0.24	-0.34	0.64	0.54	0.19
Activity 14	90°- 90° turn on the spot with stop (right)	1.41 (0.17)	1.31 (0.15)	0.10	0.05	0.00	0.19	0.05*	0.61
Activity 15	Combination	13.95 (0.95)	13.42 (0.67)	0.53	0.24	0.04	1.02	0.03*	0.67
Overall performance time (Sum activities 2 - 15)		79.25 (6.56)	75.95 (4.97)	3.30	1.72	-0.17	6.77	0.06	0.58

Table V. Mean (±SD) performance times (s) for each activity and overall performance time (s) of the wheelchair mobility performance test for differences in playing standard (international men & national men) complemented with the mean difference between the (international) groups, 95% confidence intervals of the differences and Cohen's d effect sizes.

		International men (n=21)	National men (n=12)	Mean difference	Standard Error difference	95% Confidence Interval of the difference		*p*-values	Effect Size
		Mean (±SD)	Mean (±SD)			Lower	Upper		
Activity 2	180° Turn on the spot (left)	0.87 (0.09)	0.89 (0.12)	-0.02	0.04	-0.10	0.05	0.54	-0.22
Activity 3	12 m sprint	4.76 (0.34)	5.08 (0.45)	-0.32	0.14	-0.60	-0.03	0.03*	-0.84
Activity 4	12 m rotation (right)	5.72 (0.42)	6.16 (0.37)	-0.43	0.15	-0.73	-0.14	0.01*	-1.08
Activity 5	12 m rotation (left)	5.67 (0.38)	6.17 (0.38)	-0.51	0.14	-0.79	-0.23	0.00*	-1.33
Activity 6	180° Turn on the spot (right)	0.90 (0.15)	0.95 (0.15)	-0.05	0.05	-0.16	0.06	0.38	-0.32
Activity 7	3-3-6m sprint	6.57 (0.75)	7.17 (0.73)	-0.60	0.27	-1.15	-0.06	0.03*	-0.81
Activity 8	3-3-6m rotation (left)	7.01 (0.71)	7.88 (0.52)	-0.86	0.24	-1.34	-0.38	0.00*	-1.32
Activity 9	3-3-6m rotation (right)	6.91 (0.56)	7.89 (0.60)	-0.99	0.21	-1.41	-0.56	0.00*	-1.72
Activity 10	90°- 90° turn on the spot with stop (left)	1.41 (0.21)	1.55 (0.18)	-0.14	0.07	-0.29	0.01	0.06	-0.71
Activity 11	12 m dribble	5.66 (0.63)	6.25 (0.67)	-0.59	0.23	-1.07	-0.12	0.02*	-0.92
Activity 12	12 m rotation dribble (right)	6.77 (0.69)	7.91 (0.77)	-1.13	0.26	-1.67	-0.60	0.00*	-1.57
Activity 13	12 m rotation dribble (left)	6.88 (0.73)	7.99 (0.72)	-1.10	0.26	-1.64	-0.57	0.00*	-1.52
Activity 14	90°- 90° turn on the spot with stop (right)	1.28 (0.15)	1.49 (0.17)	-0.21	0.06	-0.32	-0.09	0.00*	-1.34
Activity 15	Combination	13.15 (0.70)	14.17 (0.86)	-1.02	0.28	-1.59	-0.45	0.00*	-1.34
Overall performance time (Sum activities 2 - 15)		73.44 (4.95)	81.55 (5.08)	-8.11	1.83	-11.84	-4.37	0.00*	-1.62

*Significant effect of playing standard ($p < 0.05$).

Table VI. Mean (±SD) performance times (s) for each activity and overall performance time (s) of the wheelchair mobility performance test for differences in sex (international men & international women) complemented with the mean difference between the sex groups, 95% confidence intervals of the differences and Cohen's d effect sizes.

		International men (n=21)	International women (n=13)	Mean difference	Standard Error difference	95% Confidence Interval of the difference		*p*-values	Effect Size
		Mean (±SD)	Mean (±SD)			Lower	Upper		
Activity 2	180° Turn on the spot (left)	0.87 (0.09)	0.89 (0.07)	-0.02	0.03	-0.08	0.04	0.58	-0.20
Activity 3	12 m sprint	4.76 (0.34)	5.04 (0.27)	-0.28	0.11	-0.50	-0.05	0.02*	-0.90
Activity 4	12 m rotation (right)	5.72 (0.42)	6.07 (0.21)	-0.35	0.12	-0.60	-0.09	0.01*	-0.98
Activity 5	12 m rotation (left)	5.67 (0.38)	6.07 (0.29)	-0.40	0.12	-0.65	-0.15	0.00*	-1.15
Activity 6	180° Turn on the spot (right)	0.90 (0.15)	0.90 (0.07)	0.00	0.04	-0.09	0.09	0.95	0.02
Activity 7	3-3-6m sprint	6.57 (0.75)	7.06 (0.52)	-0.49	0.24	-0.97	-0.01	0.05*	-0.73
Activity 8	3-3-6m rotation (left)	7.01 (0.71)	7.83 (0.45)	-0.81	0.22	-1.27	-0.36	0.00*	-1.30
Activity 9	3-3-6m rotation (right)	6.91 (0.56)	7.65 (0.56)	-0.74	0.20	-1.14	-0.34	0.00*	-1.33
Activity 10	90°- 90° turn on the spot with stop (left)	1.41 (0.21)	1.40 (0.14)	0.01	0.07	-0.14	0.15	0.93	0.03
Activity 11	12 m dribble	5.66 (0.63)	5.95 (0.70)	-0.30	0.23	-0.77	0.17	0.21	-0.45
Activity 12	12 m rotation dribble (right)	6.77 (0.69)	7.44 (0.84)	-0.67	0.26	-1.20	-0.13	0.02*	-0.89
Activity 13	12 m rotation dribble (left)	6.88 (0.73)	7.47 (0.51)	-0.58	0.23	-1.06	-0.11	0.02*	-0.89
Activity 14	90°- 90° turn on the spot with stop (right)	1.28 (0.15)	1.34 (0.10)	-0.06	0.05	-0.15	0.04	0.22	-0.44
Activity 15	Combination	13.15 (0.70)	13.88 (0.55)	-0.73	0.23	-1.20	-0.26	0.00*	-1.12
Overall performance time (Sum activities 2 - 15)		73.44 (4.95)	79.21 (3.88)	-5.76	1.63	-9.08	-2.44	0.00*	-1.26

*Significant effect of sex ($p < 0.05$).

Table VII. Descriptive values of 23 national male wheelchair basketball players (mean (s) ±SD) and mean differences for the test-retest complemented with reliability statistics (s): ICC(3,1) absolute agreement, 95% confidence interval of the ICC agreement, SEM and 95% limits of agreement.

		Test 1	Test 2	Mean difference (±SD)	ICC agreement	95% confidence interval of the ICC agreement		SEM agreement	Limits of agreement
		Mean (±SD)	Mean (±SD)			Lower	Upper		
Test2	180° Turn on the spot (left)	0.90 (0.15)	0.90 (0.10)	0.00 (0.15)	0.25	-0.19	0.60	0.10	0.30
Test3	12 m sprint	5.02 (0.36)	5.13 (0.42)	-0.10 (0.34)	0.62	0.29	0.82	0.24	0.66
Test4	12 m rotation (right)	6.33 (0.56)	6.33 (0.49)	0.00 (0.23)	0.91	0.80	0.96	0.16	0.45
Test5	12 m rotation (left)	6.33 (0.54)	6.40 (0.56)	-0.08 (0.31)	0.84	0.66	0.93	0.22	0.61
Test6	180° Turn on the spot (right)	0.93 (0.16)	0.90 (0.13)	0.03 (0.14)	0.55	0.20	0.78	0.10	0.26
Test7	3-3-6m sprint	7.11 (0.61)	6.98 (0.62)	0.14 (0.38)	0.80	0.58	0.91	0.28	0.75
Test8	3-3-6m rotation (left)	8.05 (0.74)	7.92 (0.81)	0.13 (0.36)	0.88	0.74	0.95	0.26	0.70
Test9	3-3-6m rotation (right)	8.06 (0.88)	7.82 (0.72)	0.24 (0.48)	0.79	0.53	0.91	0.37	0.94
Test10	90°- 90° turn on the spot with stop (left)	1.49 (0.26)	1.40 (0.18)	0.09 (0.19)	0.62	0.28	0.82	0.14	0.37
Test11	12 m dribble	6.23 (0.68)	6.19 (0.60)	0.04 (0.45)	0.76	0.51	0.89	0.31	0.88
Test12	12 m rotation dribble (right)	8.29 (1.31)	8.34 (1.20)	-0.05 (0.81)	0.80	0.59	0.91	0.56	1.58
Test13	12 m rotation dribble (left)	8.30 (1.06)	8.24 (1.04)	0.06 (0.74)	0.76	0.52	0.89	0.51	1.44
Test14	90°- 90° turn on the spot with stop (right)	1.40 (0.20)	1.36 (0.16)	0.04 (0.16)	0.62	0.30	0.82	0.11	0.31
Test15	Combination	14.44 (1.30)	14.41 (1.13)	0.04 (0.49)	0.92	0.83	0.97	0.34	0.96
Overall performance time (Sum activities 2 - 15)		82.88 (7.22)	82.31 (6.41)	0.57 (2.14)	0.95	0.89	0.98	0.98	4.20

4.4 Discussion

This study describes the development of a new field-based WMP test to assess the capacity of mobility performance and its construct validity and test-retest reliability. To examine the construct validity, we hypothesized that classification, playing standard and sex will influence the performance on the test. The construct validity tests showed that the WMP test distinguishes sex and playing standards, but did not show differences between low and high classifications on the overall performance time. The test-retest reliability for the overall performance time was excellent and an improvement of 4.2s (5.1%) can be detected relative to the overall performance time. However, the reliability for the activities related with rotation on the spot and the 12 m sprint is low.

4.4.1 Test development

The WMP test which is introduced in this article is a simulation of mobility performance during matches specific to wheelchair basketball. The WMP test can easily be used by trainers, coaches and scientists to gain insight into the capacity of mobility performance of players. The developed WMP test meets the requirements which have been reported in previous studies of wheelchair court sports (38,53,96). The WMP test is based on the most common aspects of mobility performance, the players are tested in their natural environment and they are tested with their own wheelchair configuration. However, mobility performance may change when essential aspects of the sport change, e.g. changes in the basketball rulings or wheelchair regulations. In the case of such changes, the mobility performance needs to be redefined.

4.4.2 Construct validity

Players with a high classification (≥3.0 points) are expected to perform better than players with a low classification (≤2.5 points) (89,97). The key determinants of the classification system are the ability to have active stability and rotation possibilities of the trunk (43). Previous research shows that trunk impairment had impact on wheelchair propulsion, especially in accelerating from standstill (13,96). The overall performance time of the WMP test showed a borderline non-significant difference (p=0.06) and a moderate ES in capacity of mobility performance between low and high classifications. There were significant differences between classification levels on the separate activities related to driving forward movements (no. 3,7 and 15). In contrast, almost all activities related to rotational movements of the wheelchair showed no significant differences, which could mean that classification (trunk impairment) has less influence on rotational movements. Furthermore, the used cutoff point for dichotomizing classification in this study is debatable. Other studies showed differences between classification 1 (and 1.5) point players compared to the other classifications (61,100,102). Currently, there is not a clear relationship between classification and mobility performance. The impact and content of the classification system should be further investigated in future research.

The second hypothesis was that players competing at an international playing standard perform better than players at a national standard. This hypothesis proved to be true for the overall performance time and for 12 of the 14 separate activities with moderate-to-large ES (0.81-1.72). Except three activities related with turn on the spot, players at an international standard perform all the activities faster than national standard players. The difference between national and international playing standard on the overall performance time was 8.11s, which is significantly more than the LoA calculated in the reliability study (4.20s). Although the findings are in line with the hypothesis, the differences may be partly explained by other factors than the actual capacity of the athletes in mobility performance. Possibly, due to the more professional approach, international players may have a more optimized wheelchair configuration compared to national players which might have affected their performance on the test circuit. The activities, which showed no differences between playing standards were again related with turn on the spot. These activities are, in addition to low reliability, not distinctive for playing standards. Turns on the spot are frequent elements of performance during matches and, therefore, important to include in the WMP test. However, time appears not to be a reliable outcome measure for these activities. In order to optimize the test, these activities must be further examined. At the moment, the WMP test is also analyzed with data from inertial sensors using the method of van der Slikke et al. (86) with outcome measures such as velocity and acceleration.

The third hypothesis was that men perform better at the WMP test than women of the same playing standard. Except, again, for the activities related with turn on the spot, the hypothesis proved true. Men did perform all activities faster than women, except for the 12 m sprint with ball possession. The hypothesis is based on differences in upper body strength and trunk stability between men and women (36). However, for the 12 m sprint with ball possession ball-handling skills play an important role. For the rotational movement combined with ball possession the hypothesis was proven. It may be possible that there is a difference in training focus between the international men and women in ball handling. Women may have better ball skills and with this they compensate for their slower performance on the 12 m sprint.

In this study three hypotheses were formulated and tested to determine the construct validity of the WMP test. These hypotheses are chosen based on literature and practical feasibility. Several other variables than classification, gender and sex could have an influence on the mobility performance. Examples of variables which may also could have been used are floor surface and wheelchair configurations aspects such as wheel size, camber and elbow angle. Floor surface can affect performance due to a different rolling resistance and the WMP test should reveal this difference. However, for the present study it was practically difficult to organize to have players perform the test circuit at different floor surface. In addition, it should be mentioned that other variables than mentioned in the hypothesis might have partly affected the differences in mobility performance. In this study we focused primarily on the construct validity of the WMP test and not at variables that best predict performance on the WMP test.

4.4.3 Reliability

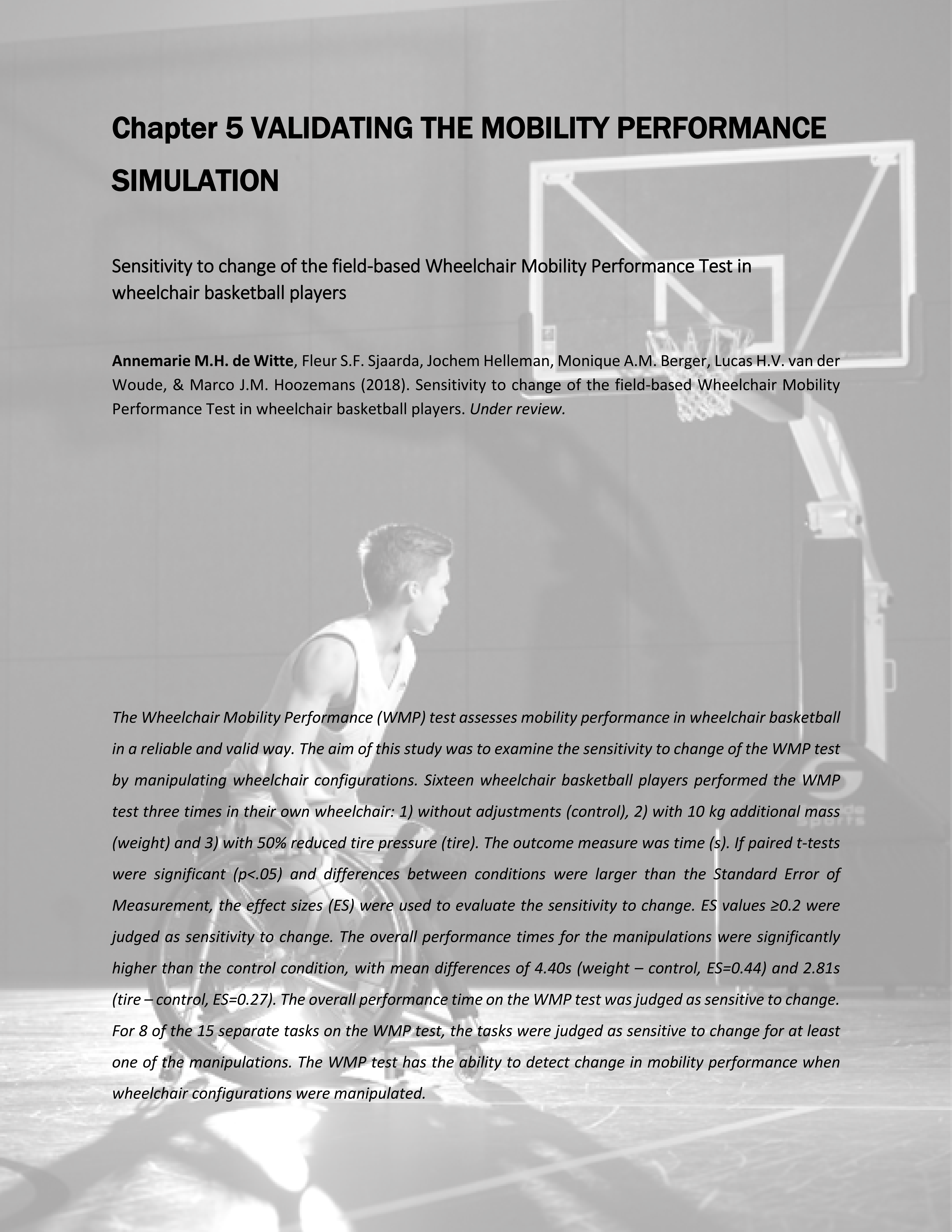
The ICC values of the separate activities of the WMP test ranged between 0.25 and 0.95, and 5 of the 15 outcome measures showed low reliability (<0.70). The ICC of four activities that included a turn on the spot ranged between 0.25 and 0.62. The performance time of these activities is very short compared to the other activities. For example, the average duration for a turn of the spot (left) is 0.90s with SEM of 0.1s. The reason for these lower ICC values could be that the measurement error of these activities is relatively high due to the short performance times. Because of this, performance time may not be an adequate outcome parameter in these four activities. In this study, the reliability between the WMP test and retest on the 12 m sprint time was also low (ICC=0.62). Previous research showed that time over a 15 m sprint cannot be used to assess wheelchair-specific capacity (81). In contrast, de Groot et al. (23)

reported a good reliability score (ICC 0.80 – 0.84) for a 5 mm sprint test. These differences in reliability could be explained by the differences in handling the timing of deceleration to stop. In our study the players had to stand still at the end of the 12 m while in the study of de Groot et al. (23) the players were allowed to drive over. The potential large variation between and within participants in timing of starting to decelerate and the level of braking (hand) forces needed to stand still at 12 m may have resulted in a relatively large variation of performance time and thus a low reliability score. The ICC of the 12 m sprint with stops is 0.80 and well in line with the study of de Groot et al. (23). The 12 m sprint with stops is in this case divided in three short sprints of 3, 3 and 6 m, and thus comparable in distance with the (single) 5 m in the study of de Groot et al. (23). Although the total distance of the sprints with an without stops is the same, the inclusion of starts from stand still and stops seems to affect reliability. However, the design of the 12 m sprint as part of the WMP test, including the acceleration and deceleration phases, is in our opinion an essential element of mobility performance, also considering the results of the observations of wheelchair basketball matches (31).

4.4.4 Limitations
All athletes performed the test in their own sports wheelchairs. Each wheelchair is individually adjusted in order to achieve an optimal wheelchair-athlete interaction. Although wheelchair configuration affects mobility performance, we do not expect this have biased our conclusions regarding validity and reliability of the WMP test because of the relatively large within groups variability in wheelchair configurations. In addition, the choice to measure wheelchair basketball players in their own environment and wheelchair enhanced the external validity of the study. Another limitation of this study is the missing data of activity 1 (tik-tak box) for which, in future research, the video set-up must be examined.

4.4.5 Conclusion and practical implications
It can be concluded that the construct validity and reliability of the WMP test were good for the overall performance time score. The test can be used as a standardized mobility performance test to assess the capacity of mobility performance of elite wheelchair athletes in wheelchair basketball. In addition, novice players might use the test to achieve a higher level of mobility performance and monitor their progression in mobility performance aspects related to elite wheelchair basketball. The overall outcome of the WMP test is reliable. However, the activities related with turn on the spot (no. 2,6,10 & 14) show low reliability and construct validity.

The WMP test can be easily used to periodically monitor the capacity of wheelchair basketball players in mobility performance. The test results can be used to detect strengths and weaknesses of players in different aspects of mobility performance. For example, when a player performs driving forward actions significantly better than rotation actions -compared with team mates- the trainer can use these outcomes to develop specific training schemes. In addition, the test can be used to monitor the progress in mobility performance, to detect talented athletes and to examine whether an athlete is sufficiently recovered from an injury. For research purposes, we aim to use this WMP test to examine the impact of different wheelchair configurations on mobility performance, as recommended by Mason et al. (53).



Chapter 5 VALIDATING THE MOBILITY PERFORMANCE SIMULATION

Sensitivity to change of the field-based Wheelchair Mobility Performance Test in wheelchair basketball players

Annemarie M.H. de Witte, Fleur S.F. Sjaarda, Jochem Helleman, Monique A.M. Berger, Lucas H.V. van der Woude, & Marco J.M. Hoozemans (2018). Sensitivity to change of the field-based Wheelchair Mobility Performance Test in wheelchair basketball players. *Under review.*

The Wheelchair Mobility Performance (WMP) test assesses mobility performance in wheelchair basketball in a reliable and valid way. The aim of this study was to examine the sensitivity to change of the WMP test by manipulating wheelchair configurations. Sixteen wheelchair basketball players performed the WMP test three times in their own wheelchair: 1) without adjustments (control), 2) with 10 kg additional mass (weight) and 3) with 50% reduced tire pressure (tire). The outcome measure was time (s). If paired t-tests were significant (p<.05) and differences between conditions were larger than the Standard Error of Measurement, the effect sizes (ES) were used to evaluate the sensitivity to change. ES values ≥0.2 were judged as sensitivity to change. The overall performance times for the manipulations were significantly higher than the control condition, with mean differences of 4.40s (weight – control, ES=0.44) and 2.81s (tire – control, ES=0.27). The overall performance time on the WMP test was judged as sensitive to change. For 8 of the 15 separate tasks on the WMP test, the tasks were judged as sensitive to change for at least one of the manipulations. The WMP test has the ability to detect change in mobility performance when wheelchair configurations were manipulated.

5.1 Introduction

In wheelchair basketball, the interaction between the player, the wheelchair and the environment determine the overall performance. More specifically, and in line with several other studies (31,54), all actions a wheelchair basketball player can perform using the wheelchair, such as turning, blocking, stopping and accelerating, are considered to be part of mobility performance. In order to repeatedly monitor athletes' mobility performance, standardized field-based tests are informative and helpful (38,98). Recently, de Witte et al. (30) developed a standardized field-based Wheelchair Mobility Performance test (WMP test) to assess mobility performance in wheelchair basketball. Extensive analyses of matches with elite wheelchair basketball athletes were performed in order to determine the most common wheelchair handling activities and their characteristics (30,31,87). These characteristics were combined in a test-circuit consisting of 15 specific wheelchair basketball mobility performance tasks (Appendix I). The WMP test covers the full range of relevant mobility performance tasks in wheelchair basketball, meaning that all aspects of an athlete's mobility performance can be assessed in one single standardized test.

The reliability and construct validity of the WMP test has already been determined (30). The reliability of the WMP test for the overall performance outcome appeared to be excellent (ICC=0.95) (30). Furthermore, the construct validity of the WMP test was confirmed by showing that the WMP test was able to detect differences in mobility performance between athletes for who it was expected that they differed in their level of physical capacity (17,44). In line with expectations, men performed better than women and international male athletes performed better than national male athletes on the WMP test. A borderline significant difference in mobility performance was found between low classification (1.0 to 2.5) and high classification (3.0 to 4.5) athletes. It was concluded that the WMP test was reliable and valid and could be used to assess the capacity of mobility performance of elite wheelchair athletes in wheelchair basketball players.

Besides reliable and valid, the WMP test should also be sensitive to change to apply the test in sports practice but also in scientific research (28). A test that is sensitive to change is one that is able to detect changes. Sensitivity to change can be defined as the ability of a test to detect change in its outcome when it has occurred (16,47,48). In elite sports, differences in performance are very small and, therefore, it is important to be able to detect changes in the determinants of performance (21). If the WMP test is sensitive to change, the change or difference in performance time assessed using the WMP test can be truly attributed to a systematic change in mobility performance in-person and not to noise or random error. The psychometric characteristic sensitivity to change of the WMP test can be studied by such manipulation of the mobility performance for which it can be expected that the WMP test is able to detect its change in mobility performance. Potential manipulations that can be studied to explore the sensitivity to change of the WMP test are the configuration of the wheelchair (e.g. wheel diameter, mass), characteristics of the athlete (e.g. body weight) or manipulations in the interface between wheelchair and athlete (e.g. seat height). If the WMP test is able to detect a change in performance time when wheelchair, athlete or interface configurations were manipulated, it is justified to use the test in practice and scientific research. The test can be used, for instance, to optimize the design of the wheelchair in wheelchair basketball. Therefore, the objective of the present study was to examine the sensitivity to change of the standardized field-based WMP test in wheelchair basketball by systematically manipulating wheelchair configurations.

5.2 Methods

5.2.1 Participants

Sixteen wheelchair basketball players (15 men, 1 woman) with a mean age of 23.5 ± 8.4 years, a mean body weight of 71.1 ± 21.4 kg and 7.8 ± 6.6 years of experience in wheelchair basketball voluntarily participated in this study. All participants trained at least two times a week and played in the B- or C-division of the Dutch wheelchair basketball competition. An overview of their classification is shown in Figure 1. Prior to participation, all participants were informed about the study objectives and procedures, and signed an informed consent form. The study was approved by the Ethical Committee of the Faculty of Behavioural and Movement Sciences, Vrije Universiteit Amsterdam (VCWE 2016-091).

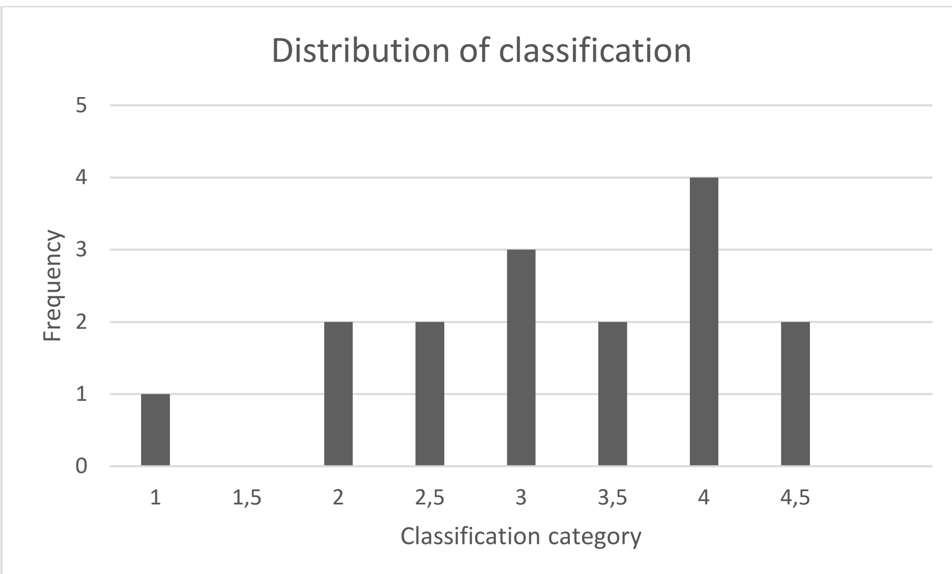


Figure 1. Overview of the classification categories for 16 wheelchair basketball players.

5.2.2 Procedure

The Wheelchair Mobility Performance (WMP) test consists of 15 sport specific tasks based on extensive observation of wheelchair basketball matches(30) (see Appendix 1 for the description of the test). The test-retest reliability of the WMP test was excellent (ICC=0.95) for the overall performance time and the WMP test is a valid tool to assess mobility performance in wheelchair basketball players (30).

The participants performed the WMP test three times in their own wheelchair: 1) in the Control Condition (CC) the participants had to perform the test with normal tire pressure (standardized at 7 bar) and with no extra mass attached to the wheelchair; 2) in the Weighted Condition (WC) the participants had to perform the test with normal tire pressure but with an additional mass of 10 kg attached to the wheelchair. The extra mass was distributed over the wheelchair frame by using five masses of 2 kg (Figure 2); 3) in the Tire Condition (TC) the participants performed the test in their own wheelchair with a tire pressure which was reduced by 50% (3.5 bar) and with no additional mass attached to the wheelchair. Tire pressure was determined using a high-pressure pump (Lezyne Alloy Drive SE Floor Pump).

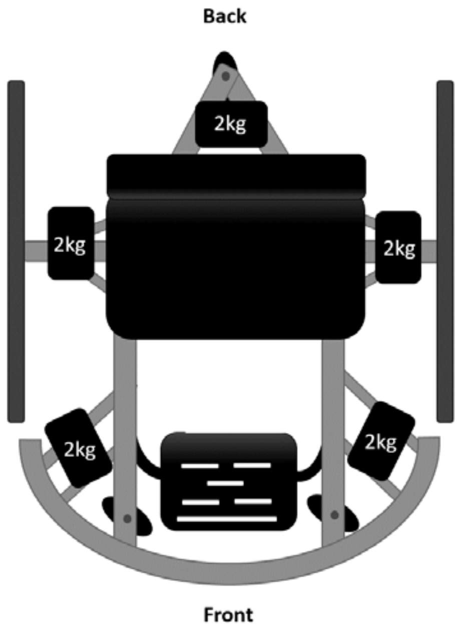


Figure 2. Top view of the distribution of 10 kg mass (5 x 2kg) on a wheelchair frame.

Prior to the WMP tests, verbal instructions were given to the participants about the procedure of performing the test and the participants had to practice the tasks of the WMP test in the presence of a researcher who gave verbal instructions on each task. After the instructions, the participants filled out a form concerning general information: age, body weight, type of impairment, years of experience in wheelchair basketball and classification. After a self-selected warm up, the participants performed the three experimental conditions of the WMP tests in a randomized and counterbalanced order to avoid learning effects. All standardized tasks of the WMP test were carried out in succession in a fixed order, separated by standardized rest periods as described in the test protocol (30). The WMP tests were performed indoors on a synthetic soft-top basketball court on one day. Each WMP test took about 6.5 minutes and was followed by a rest period of 10 to 15 minutes. .

5.2.3 Performance times

All WMP tests were video recorded from the side of the field with a Casio Exilium EX-ZR1000 (Casio, Tokyo, Japan) or a Samsung Galaxy S5 (Samsung, Seoul, South Korea), both at 30 frames per second. The outcome of the WMP test was time (s), which was manually assessed from video analyses using Kinovea (Kinovea 0.8.15, France). These analyses resulted in 16 performance time values, one for each of the 15 tasks of the WMP test (*time tasks no. 1 - 15*) and the *overall performance time,* which was the sum of the performance times of the 15 separate tasks. Measurement time was accurate to 0.03s (30Hz).

5.2.4 Statistical analysis

Normality of the data was checked with the Shapiro-Wilk test, the Z-values for kurtosis and skewness, Q-Q plots and Boxplots. For all performance time data, the assumption of normality was not violated. Descriptive statistics for performance measurements (*time WMP test tasks no. 1 - 15* and the *overall performance time)* were presented as mean ± standard deviation (SD). In line with previous research

(42,47,48,67), sensitivity to change of the measurements was examined using paired t-tests, the Standard Error of Measurement for agreement ($SEM_{agreement}$) and Cohen's d effect sizes (ES).

Paired t-tests were used to examine the differences in performance time between WC and CC and between TC and CC. All data were analysed with IBM SPSS Statistics 23 (IBM Corporation, Armonk, NY, USA) using a significance level of $p<0.05$.

The SEM for agreement was calculated with Equation (1). This analysis has previously been performed and published in the reliability and validity study of the WMP test (30). From variance component analyses, two components were estimated, variance attributable to observers ($Var_{observer}$) and residual error ($Var_{residual}$), with the square root of their summation resulting in the $SEM_{agreement}$.

Equation 1: $SEM_{agreement} = \sqrt{Var_{observer} + Var_{residual}}$

The Cohen's *d* Effect Size (ES) was calculated to assess the meaningfulness of the different test conditions (see equations 2 and 3). For the calculation of ES, the SD of the two testing conditions to be compared were converted into one pooled SD (SD_{pooled}).

Equation 2: $SD_{pooled} = \sqrt{({SD_1}^2 + {SD_2}^2)/2}$

In which SD_1= SD of the control condition, SD_2= SD of the weight or tire pressure condition.

Equation 3: $Effect\ size\ (ES) = \frac{Mean_1 - Mean_2}{SD_{pooled}}$

In which $Mean_1$= Mean of the control condition, $Mean_2$ = Mean of the weight or tire pressure condition.

5.2.5 Sensitivity to change

For the assessment of the sensitivity to change of the WMP test, a significant difference in performance time must be detected between the manipulation conditions (WC and TC) and CC. Furthermore, the observed differences between both conditions must be larger than the $SEM_{agreement}$. If the results meet both requirements, the ES was used to evaluate the magnitude of the differences between the manipulated and control conditions. Cohen's d cut-off points for ES values were: trivial ($d<0.2$), small ($0.2\leq d<0.5$), moderate ($0.5\leq d<0.8$) and large ($d\geq0.8$)(15). In our case, the WMP test was judged as not sensitive to change for ES values lower than 0.2, values equal or higher than 0.2 were judged as sensitive to change..

5.3 Results

The mean *overall performance time* on the WMP test for the Control Condition (CC) was 101.59 (±9.63) seconds, for the Weighted Condition (WC) 105.99 (±10.52) seconds and for the Tire Condition (TC) 104.39 (±11.03) seconds as can be seen in Table 1. Overall performance time for the WC and TC was significantly higher than the CC ($p<0.05$). The observed overall differences between the manipulated and control conditions (ΔWC-CC=4.40±2.05s, ΔTC-CC=2.81±2.25s) were larger than the reported Standard Error of Measurement (SEM) (>.98). The ES for the WC-CC was 0.44 and for the TC-CC 0.38. Therefore, the overall performance time was judged as sensitivity to change (ES≥.20). The individual differences in the overall performance times between the different conditions per wheelchair basketball player were shown in Figure 3.

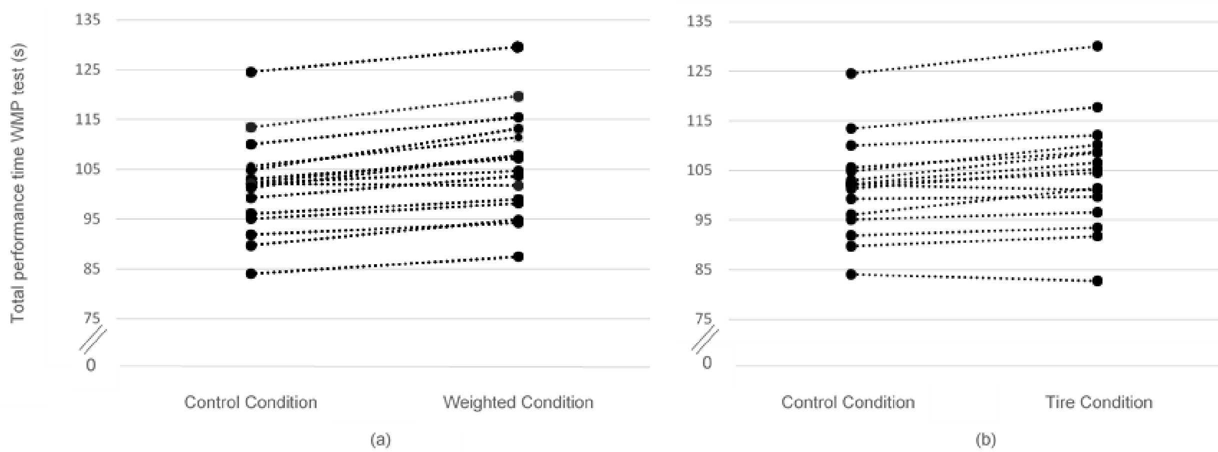


Figure 3 Differences in total performance time in seconds on the Wheelchair Mobility Performance test per wheelchair basketball player between the (a) Control Condition and Weighted Condition (10kg extra mass) and between the (b) Control Condition and 50% reduced tire pressure condition.

For the performance times of the separate tasks, only the 3-3-6m sprint showed, for both WC and TC condition, was sensitive to change (ES: WC-CC= 0.31, TC-CC=0.37). In the WC, performance times for 7 out of the 15 WMP tests tasks were significantly different from those in the CC, while at the same time the differences were larger than the SEM. The tasks 180^{o} turn on the spot left (ES=0.43), 12m sprint (ES=0.51), 3-3-6m sprint (ES=0.31), 3-3-6m rotation to the right (ES=0.50), 12m-dribble (ES=0.35), 12m-rotation dribble to the left (ES=0.34), and the combination task (ES=0.61) were judged as sensitive to change. For the TC, as indicated above, only the performance time on the 3-3-6m sprint (ES=0.37) and the overall performance time (ES=0.27) were significantly different from the CC.

5.4 Discussion

In this study, the sensitivity to change of the standardized field-based WMP test was determined in order to assess whether the WMP test is able to detect changes in mobility performance in wheelchair basketball players. The mean total performance times for the 10kg extra mass condition and the reduced tire pressure condition, were significantly more than for the control condition. The overall performance time of the WMP test was judged as sensitive to change. It can, therefore, be concluded that the WMP test has the ability to detect changes in mobility performance when wheelchair configurations were manipulated. The separate tasks of the WMP test showed different levels of sensitivity to change dependent on the manipulation condition. For 8 of the 15 separate tasks on the WMP test, the tasks were judged as sensitive to change for at least one of the manipulations.

Table 1. Mean (±SD) performance times (s) for each task and overall performance time (s) for the wheelchair mobility performance test for the control condition and the manipulation conditions, weighted and tire condition. The table is complemented with the mean differences between the manipulation conditions and control condition, *p*-values , Cohen's *d* effect sizes, 95% Confidence Intervals of the effect size and the Standard Error of Measurement retrieved from the study of de Witte et al. (2017) (30).

	Control condition	***Weighted condition***	***Tire condition***	*Standard error of measurement (sec)*	***Differences Weighted condition – Control condition***						***Differences Tire condition – Control condition***					
	Mean in sec (±SD)	*Mean in sec (±SD)*	*Mean in sec (±SD)*		*Differences in sec (±SD)*	*P-values*	*Effect Size*	*95% CI of the effect size*		*Sensitive to change?*	*Differences in sec (±SD)*	*P -values*	*Effect Size*	*95% CI of the effect size*		*Sensitive to change?*
1. Tik-Tak box	8.26 (2.06)	8.79 (2.46)	8.66 (2.54)	--	0.53 (0.80)	0.017*	0.24	-0.47	0.92	X[#]	0.40 (1.16)	0.185	0.17	-0.52	0.86	-
2. 180° Turn on the spot (left)	1.22 (0.29)	1.35 (0.31)	1.24 (0.23)	0.10	0.13 (0.24)^	0.050*	0.43	-0.28	1.12	X	0.03 (0.29)	0.732	0.10	-0.60	0.79	-
3. 12 m sprint	5.37 (0.48)	5.63 (0.51)	5.57 (0.48)	0.24	0.26 (0.17)^	<0.001*	0.51	-0.21	1.20	X	0.20 (0.15)	0.000*	0.41	-0.30	1.10	-
4. 12 m rotation (right)	6.92 (0.61)	7.08 (0.50)	7.01 (0.57)	0.16	0.17 (0.41)^	0.130	0.30	-0.41	0.99	-	0.09 (0.50)	0.486	0.15	-0.55	0.84	-
5. 12 m rotation (left)	6.85 (0.65)	7.01 (0.59)	7.08 (0.92)	0.22	0.16 (0.43)	0.147	0.26	-0.44	0.95	-	0.24 (0.46)^	0.057	0.30	-0.41	0.99	-
6. 180° Turn on the spot (right)	1.29 (0.40)	1.30 (0.23)	1.32 (0.40)	0.10	0.01 (0.29)	0.878	0.03	-0.66	0.73	-	0.03 (0.39)	0.785	0.07	-0.63	0.76	-
7. 3-3-6m sprint	8.19 (0.90)	8.50 (1.08)	8.54 (1.00)	0.28	0.31 (0.57)^	0.048*	0.31	-0.39	1.00	X	0.35 (0.47)^	0.010*	0.37	-0.34	1.06	X
8. 3-3-6m rotation (left)	9.08 (1.00)	9.39 (1.03)	9.29 (1.04)	0.26	0.32 (0.68)^	0.085	0.31	-0.39	1.00	-	0.21 (0.55)	0.150	0.20	-0.50	0.89	-
9. 3-3-6m rotation (right)	8.93 (0.80)	9.36 (0.91)	9.28 (0.93)	0.37	0.43 (0.47)^	0.002*	0.50	-0.21	1.19	X	0.34 (0.32)	0.001*	0.40	-0.31	1.08	-
10. 90°- 90° turn on the spot with stop (left)	1.99 (0.35)	2.07 (0.30)	2.04 (0.38)	0.14	0.08 (0.18)	0.093	0.25	-0.46	0.94	-	0.05 (0.22)	0.420	0.12	-0.57	0.82	-
11. 12 m dribble	6.84 (0.83)	7.18 (1.09)	7.01 (1.06)	0.31	0.34 (0.57)^	0.031*	0.35	-0.35	1.04	X	0.17 (0.53)	0.226	0.17	-0.52	0.86	-
12. 12 m rotation dribble (right)	9.32 (1.34)	9.35 (1.38)	9.43 (1.60)	0.56	0.03 (1.00)	0.919	0.02	-0.67	0.71	-	0.11 (0.83)	0.618	0.07	-0.62	0.76	-
13. 12 m rotation dribble (left)	9.40 (1.98)	10.01 (1.58)	9.67 (1.38)	0.51	0.60 (0.87)^	0.014*	0.34	-0.37	1.03	X	0.26 (1.06)	0.332	0.16	-0.54	0.85	-
14. 90°- 90° turn on the spot with stop (right)	2.03 (0.30)	2.03 (0.28)	2.09 (0.49)	0.11	0.00 (0.24)	0.992	0.00	-0.69	0.70	-	0.07 (0.30)	0.379	0.16	-0.54	0.85	-
15. Combination	15.90 (1.42)	16.94 (1.95)	16.18 (1.58)	0.34	1.04 (0.78)^	<0.001*	0.61	-0.12	1.30	X	0.28 (0.57)	0.070	0.19	-0.51	0.88	-
Overall performance time (sum tasks 1-15)	101.59 (9.63)	105.99 (10.52)	104.39 (11.03)	0.98	4.40 (2.05)^	<0.001*	0.44	-0.28	1.13	X	2.81 (2.25)^	<0.001*	0.27	-0.43	0.96	X

* Significant effect of manipulation condition (*P*<0.05) in performance time compared to control condition
^ Difference between manipulation condition and control condition larger than Standard Error of Measurement
[#] Standard Error of Measurement not available

5.4.1 Sensitivity to change

In the present study sensitivity to change was investigated in order to determine whether the WMP test is able to detect changes in mobility performance. The term "sensitivity to change" is generally used as a common measure to detect change when it has occurred (47,48,64). The cause of the change may vary, for instance, as to the topic of the present study, because of changes in wheelchair configuration but also because of changes in time. However, in the literature also the term *responsiveness* is used. Literature indicates that the term *responsiveness* is specifically used when it concerns changes over time in the construct to be measured (28,59). As we aimed to investigate whether the WMP test is able to detect changes in mobility performance because of changes in wheelchair configuration we decided to use the term sensitivity to change. This does not mean that the WMP test is not sensitive to changes in mobility performance in time. The test showed to be able to detect manipulated changes in mobility performance and we can expect the test to be able to detect change in mobility performance because of training or injury in time. Change should however be beyond the limits of agreement as described in the validity and reliability study of the WMP test (30). Furthermore, De Vet et al. (28) state that responsiveness is relevant for measurement instruments used in evaluative applications and that if an instrument is only used for discrimination between patients at one point in time, then responsiveness is not an issue. According to Deyo & Centor (32), responsiveness relates to a true change in clinical (health) status over time. This means that the outcome measure must remain stable when no (clinical) change has occurred (specificity) and it must detect meaningful (clinical) change when it has occurred (sensitivity). However, in the present study, differences in performance times on the WMP test between conditions are assumed to be caused by the manipulations in wheelchair configuration. The aim of this study was to measure whether change occurred and what the magnitude of that change was, therefore, we decided to use sensitivity to change.

5.4.2 Conditions

Sensitivity to change was examined by manipulating wheelchair configuration, which can have a significant impact on mobility performance (53). Other manipulations could have been chosen to study sensitivity to change. For instance, manipulation of the athlete or the wheelchair-athlete interaction could change the mobility performance, for instance by limiting trunk function, the movement of the trunk will be limited and performance may decrease. In this study, a 10kg extra mass and a 50% reduced tire pressure were used to examine sensitivity to change. These manipulations were chosen because they were relatively easy to apply to the athlete's own wheelchair (control condition) and they clearly increase the required external work and thus reduce mobility performance. The magnitude of the manipulations was chosen in agreement with previous studies (5,9,19,24). Beekman et al. (5) found that in a 7.8kg lighter wheelchair speed and distance travelled were greater compared to a heavier wheelchair and Cowan et al. (19) found that velocity decreased as the weight of the wheelchair increased with 9.05 kg. Therefore, we used 10kg additional mass in the weight condition. Booka et al. (9) & de Groot et al. (24) stated that less tire pressure needs more work even on a hard level surface. To increase the work, the tire pressure was reduced with 50% in this study. In both manipulated conditions, the power output was increased while this may not impact the skill of mobility performance because the wheelchair-athlete settings have remained unchanged.

5.4.3 Performance times

In the weighted condition, all tasks that were not judged as sensitive were related to rotational tasks. In this study, the masses (5 x 2 kg) were attached on the outside of the frame (Figure 2). It could be that the weight distribution had less effect on the performance time for the rotational tasks compared to translation tasks or that the amount of weight had less effect on rotational tasks. Moreover, the extra mass was for all the participants 10kg, which may mean that the relative weight gain was different between the participants. This may have led to an overestimation of the results. If the amount additional mass is determined relative to the total mass of the athlete and wheelchair, the disadvantage of extra mass is the same for all the athletes. Based on this study, it can be concluded that mass influences performance times but it does not provide insight into what extent mass influences the performance times. To research that relation, in further research the effect of additional mass should be studied relative and not absolute.

In the tire condition, only the performance on the 3-3-6m sprint and the performance time on the entire WMP test were judged as sensitive to change. A recent study of Leboeuf et al. (46) showed that a lower tire pressure (5 compared to 9 bar) only decreases sprint performance in a straight line and not when other movements were included such as stops and half-turns. This is in line with the results of the present study. It could be that the differences between the conditions on the separate tasks were too small to appear as sensitive to change but the sum of the separate tasks was large enough to appear as sensitive to change. Another explanation could be that the tires deformed during changes in directions and stops. By inflating the tires as much as possible, the friction between the ground and the tires reduces which, possibly, results in skidding. Skidding leads to loss of grip and thus waste of time. This can be an explanatory hypothesis of the comparable time between the tire pressure conditions.

In the present study, the outcome measure time (in seconds) was used which can be assessed using a timer or, as was done in the present study, using video. Therefore, the test is easy to use in practice to determine changes in performance. However, information about kinematic outcomes such as (rotational) acceleration could provide additional information and can be measured with inertial sensors on the wheelchair (6,87). The use of additional kinematic outcome measures could provide more in-depth information about the sensitivity of change. However, specific knowledge and material like the inertial sensors is required and, therefore, more difficult to use in practice. For research purposes, it is recommended to use additional kinematic outcomes to analyze the sensitivity of change.

5.4.4 The WMP test

The WMP test was developed to assess the capacity of mobility performance of wheelchair athletes in wheelchair basketball. For research purposes, Mason et al. (53) recommended that a standardized field-based test can be used to examine the impact of different wheelchair configurations on mobility performance. However, the test should be reliable, valid and sensitive to change. In a previous study the reliability and construct validity of the WMP test were determined (30) and in the present study the sensitivity to change. The combination of the results of both studies include two analyses concerning sensitivity to change (tire pressure and weight), a reliability analysis and three analyses for construct validity (gender, playing standard and classification). We decided that the reliability must meet an ICC≥0.70 (indicated as satisfactory) and that minimal 4 of the 5 remaining analyses must meet the requirements to be judged as valid and sensitive to change. Based on this requirement, it can be concluded that the WMP test is reliable, valid and sensitive to change for the 3-3-6m sprint task, the combination task (sprint, turn, slalom, turn) and the overall performance time. If the cut-off was set at all analysis must meet the requirements, than only the 3-3-6m sprint task and the overall performance time appear as an useful outcome measure. The sensitivity to change of the combination task in the tire pressure manipulation was borderline significant (*P*=.07). The selected measurement outcomes gives an overview of the mobility performance capacity of a wheelchair basketball athlete. The WMP test is not able to detect change in separate tasks in a reliable, valid and sensitive way. For further research, researchers must focus on the three described performance outcomes (3-3-6m sprint, combination task and overall performance outcome) to draw a conclusion on mobility performance capacity.

5.4.5 Implications of the WMP test

The WMP test can be used in a reliable and valid way to assess the capacity of mobility performance of elite wheelchair athletes in wheelchair basketball (30). The test can be used to periodically monitor the capacity of the mobility performance of the athlete, to detect strengths and limitations of an athlete, to detect talented athletes and to examine whether an athlete is sufficiently recovered from an injury in a reliable and valid way. Furthermore, the selected outcomes are sensitive to change and can be used to assess differences in performance time when wheelchair-athlete configurations were changed. The difference should, however, be larger than the limits of agreement as reported in the reliability and validity study (5). The test is easy to perform for athletes, little material is required and measuring time in seconds doesn't need specific knowledge. At this point, besides the applications mentioned above, the test can be used in practice to optimize the wheelchair-athlete configuration or the design of the wheelchair. The selected test parts showed that performance time was sensitive to change when configuration settings were changed and can be used in further research. However, as mentioned earlier, performance time is one outcome measure. Kinematic outcomes such as (rotational) acceleration could provide more in-depth information about the effects of configurations on mobility performance.

5.4.6 Limitations

A limitation of this study was that the test was not blinded. The sequence of test conditions was randomized, but the participants could see or hear the manipulations being applied to their wheelchair. This may have biased the results, but it is unknown to which extent this has affected the test results. In future research, the researchers must be aware of this potential effect. Furthermore, in the weighted condition, for all participants, 10kg extra mass was attached to the wheelchair. The magnitude of the effect was different for all participants which may have affected the measurements. It is possible that the results were overestimated because the relative weight gain was not the same for all the participants. In further research a relative value should be determined so the effect is for all the participants the same. Another limitation of the WMP test is that not all separate tasks can be used to analyze mobility performance. For example, the single rotational tasks could not be used in assessing the mobility performance.

It can be concluded that the WMP test has the ability to detect changes in mobility performance, for instance, the wheelchair configuration was manipulated. When the results of this study are combined with the results of the reliability and construct validity study, it is recommended to monitor the performance on the 3-3-6m sprint (task 7), the combination (task 15) and the entire WMP test when used in further research and practice.

Chapter 6 PREDICTING MOBILITY PERFORMANCE

Improving mobility performance in wheelchair basketball

Veeger, T.J.J., **de Witte, A. M. H.**, Berger, M. A. M., van der Slikke, R. M. A., Veeger, H. E. J., & Hoozemans, M. A. M. (2017). Improving mobility performance in wheelchair basketball. Journal of Sport Rehabilitation. https://doi.org/10.1123/jsr.2017-0142 [Epub ahead of print]

This study aimed to investigate which characteristics of athlete, wheelchair and athlete-wheelchair interface are the best predictors of wheelchair basketball mobility performance. Sixty experienced wheelchair basketball players performed a wheelchair mobility performance test to assess their mobility performance. To determine which variables were the best predictors of mobility performance, forward stepwise linear regression analyses were performed on a set of 33 characteristics, including ten athlete, nineteen wheelchair and four athlete-wheelchair interface characteristics. Eight of the characteristics turned out to be significant predictors of wheelchair basketball mobility performance. Classification, experience, maximal isometric force, wheel axis height and hand rim diameter - which both interchangeable with each other and wheel diameter - camber angle, and the vertical distance between shoulder and rear wheel axis – which was interchangeable with seat height - were positively associated with mobility performance. The vertical distance between the front seat and the footrest was negatively associated with mobility performance. With this insight, coaches and biomechanical specialists are provided with statistical findings to determine which characteristics they could focus on best to improve mobility performance. Six out of eight predictors are modifiable and can be optimized to improve mobility performance. These adjustments could be carried out both in training (maximal isometric force) and in wheelchair configurations (e.g. camber angle).

6.1 Introduction

Wheelchair basketball is one of the most popular Paralympic sports with professional competitions at a high level. At these high levels, coaches are always trying to improve the overall game performance of their team, for instance by adjusting tactics and improving performance of individual players. For the latter, both ball skills and wheelchair handling skills - or “mobility performance” - are essential. Mobility performance in itself is dependent on both physical performance and capacity, and quality of wheelchair handling. Thus, mobility performance is not only dependent on physical athlete characteristics like strength, power and aerobic capacity, but also on the interface between athlete and wheelchair. In mobility performance, key determinants are the ability to accelerate, sprint, brake or rotate (31,52,87).

De Witte et al. (30) recently developed and validated a wheelchair mobility performance test (WMP test) for the assessment of mobility performance in wheelchair basketball players. With this test it is possible to validly and reliably measure mobility performance in a controlled setting. The WMP test consists of a set of 15 mobility exercises such as a 12-meter sprint and a rotation, with and without handling a ball. It provides the opportunity for coaches to actually quantify the mobility performance of the players and to monitor changes due to, for instance, their training schemes. Mobility and game performance of an athlete can be improved in different ways, for example, by improvement of physical performance, which will influence wheelchair handling, but also by optimization of the wheelchair configuration (12,39,51,53). The characteristics that potentially can be modified to enhance mobility performance can be divided in three categories: athlete characteristics, wheelchair characteristics and characteristics describing the interface between athlete and wheelchair (31). Athlete characteristics are, for example, body dimensions, strength, impairment, gender or age. Wheelchair characteristics consist mainly of the wheelchair configurations, for example the seat height or the length of the wheelbase. Characteristics of the interface between the athlete and the wheelchair include, for example, the athlete’s sitting position or the position of the shoulder relative to the hand rims. Within all three categories characteristics are known that influence mobility performance and, if modifiable, can be adjusted to improve mobility performance (51,53-55,91).

However, most studies related to mobility performance have focused on the effect of just one or a couple of athlete, wheelchair or athlete-wheelchair characteristics (51,53-55,91). As a consequence, it is not really known which of those characteristics have the most impact on performance. Besides, these studies mainly investigated these relationships in healthy participants or in daily life wheelchairs, this makes the translation to wheelchair basketball mobility performance difficult. For coaches and biomechanical specialists, to be able to improve mobility performance, it would be helpful to know which characteristics are the most beneficial or limiting regarding athlete, wheelchair or athlete-wheelchair interface. With the developed WMP test and additional measurements of wheelchair, athlete and athlete-wheelchair interface characteristics, it is now feasible to collect data that allow such in-depth analyses.

Therefore, the goal of the present study is to investigate which athlete, wheelchair and athlete-wheelchair interface characteristics are the best predictors of mobility performance in wheelchair basketball.

6.2 Methods

6.2.1 Subjects

Sixty wheelchair basketball players participated in this study with 44 men and 16 women. The age of the participants ranged from 12 to 50 years with an average of 25.0 (SD 9.4) years. All participants were active in the Dutch first division or at international level. Participation was not restricted to certain classification levels. Twenty athletes had a classification equal to or below 2.5 (low classification group) and forty athletes had a classification equal to or higher than 3.0 (high classification group), see also table 1. Before testing, the participants and/or their parents signed an informed consent form. The study was approved by the Ethical Committee of the Faculty of Behavioral & Movements Sciences, Vrije Universiteit Amsterdam, the Netherlands (2015-26).

Table 1. Descriptive statistics of all variables with mean and standard deviation (SD) for normally distributed variables and median and interquartile range (IQR) for not normally distributed (*) variables. N=Newton ;kg=kilogram, cm=centimetres; °=degrees; sec=seconds.

Code in figure 1	Variable (unit)	n	Minimum	Maximum	Mean/Median*	SD/IQR*
	Athlete characteristics					
-	Age (years)	56	12	50	23*	13.8*
-	Experience (years)	60	0	27	7*	7.8*
-	Classification (low/high)	Low (≤2.5):	20			
-		High (≥3.0):	40			
-	Weight athlete + wheelchair (kg)	49	45	123	81.2	15.7
-	Maximal isometric force (N)	51	152	817	496.3	128.8
-	Fore arm length (cm)	57	19	31	25.8	3.0
-	Upper arm length (cm)	58	24	34	30.1	2.4
A1	Lower leg length (cm)	54	30	45	38.0	3.7
A2	Upper leg length (cm)	56	28	47	38.3	4.8
A3	Trunk length (cm)	57	33	56	46.1	5.4
	Wheelchair characteristics					
-	Wheel diameter (cm)	49	56	70	63.6	2.8
-	Hand rim diameter (cm)	59	52	62	56.8	2.5
-	Ratio hand rim/wheel	48	0.85	0.93	0.894	0.019
W1	Width wheelbase (cm)	58	70	92	80.9	4.8
W2	Distance TDC (cm)	57	34	50	42.5	3.3
W3	Distance hand rim and tire (cm)	57	2	4	3.1	0.6
W4	Distance between front wheels (cm)	57	26	44	30.9*	5.1*

W5	Vertical distance front seat height and footrest (cm)	55	31	53	43.0	4.2
W6	Camber angle (°)	57	15	21	17.8	1.3
W7	Wheel axis height (cm)	58	28	36	31.3	1.7
W8	Height back support (cm)	57	11	28	18.0	4.1
W9	Rear seat height (cm)	59	45	70	58.2	6.1
W10	Front seat height (cm)	58	48	72	58.2	4.5
W11	Seat depth (cm)	58	32	54	41.9	4.1
W12	Length wheelbase (cm)	58	31	48	39.8	3.8
W13	Horizontal distance rear axis and back support (cm)	58	12	25	19.0	3.2
W14	Horizontal distance footrest and rear axis (cm)	56	17	48	35.9	7.0
W15	Front wheel diameter (cm)	58	5	9	6.5*	1.4*
W16	Horizontal distance anti-tip wheel and rear axis (cm)	57	17	27	23.9*	3.1*
	Athlete/Wheelchair interface					
I1	Knee angle (°)	54	50	114	80.3	14.2
I2	Vertical distance shoulder and rear wheel axis (cm)	57	52	91	73.1	8.8
I3	Horizontal distance shoulder and rear wheel axis (cm)	57	1	22	10.5	4.6
I4	Elbow angle (°)	57	77	168	122.4	21.6
	Outcome variables					
-	12-meter sprint (sec)	56	4.3	6.0	4.97	0.38
-	12-meter sprint + stops (sec)	57	5.3	8.6	6.94	0.72
-	Rotation (sec)	57	10.3	15.1	11.98*	1.11*
-	Rotation + stops (sec)	57	11.6	19.5	15.24	1.67
-	Total (sec)	56	65.6	96.3	79.12	7.30

6.2.2. Design

Before the measurements started, participants were verbally introduced to the procedures and the wheelchair mobility performance test (WMP test) was demonstrated with a video. The participants were asked to refrain from smoking, drinking caffeine or alcohol for at least 2 hours prior to testing. The handedness, the cause of the disability, the competition in which they played and the years of experience in playing wheelchair basketball were noted. After that, six reflective markers were placed on the following anatomical landmarks: on the dorsal side of the distal radioulnar joint, on the lateral epicondyle of the humerus, on the radial head of the elbow, on the acromial angle of the right shoulder and just lateral to the coracoid process on both shoulders (Figure 1). In order to measure wheelchair settings and anthropometrics, pictures were taken of both frontal and sagittal views of the athlete in their own wheelchair.

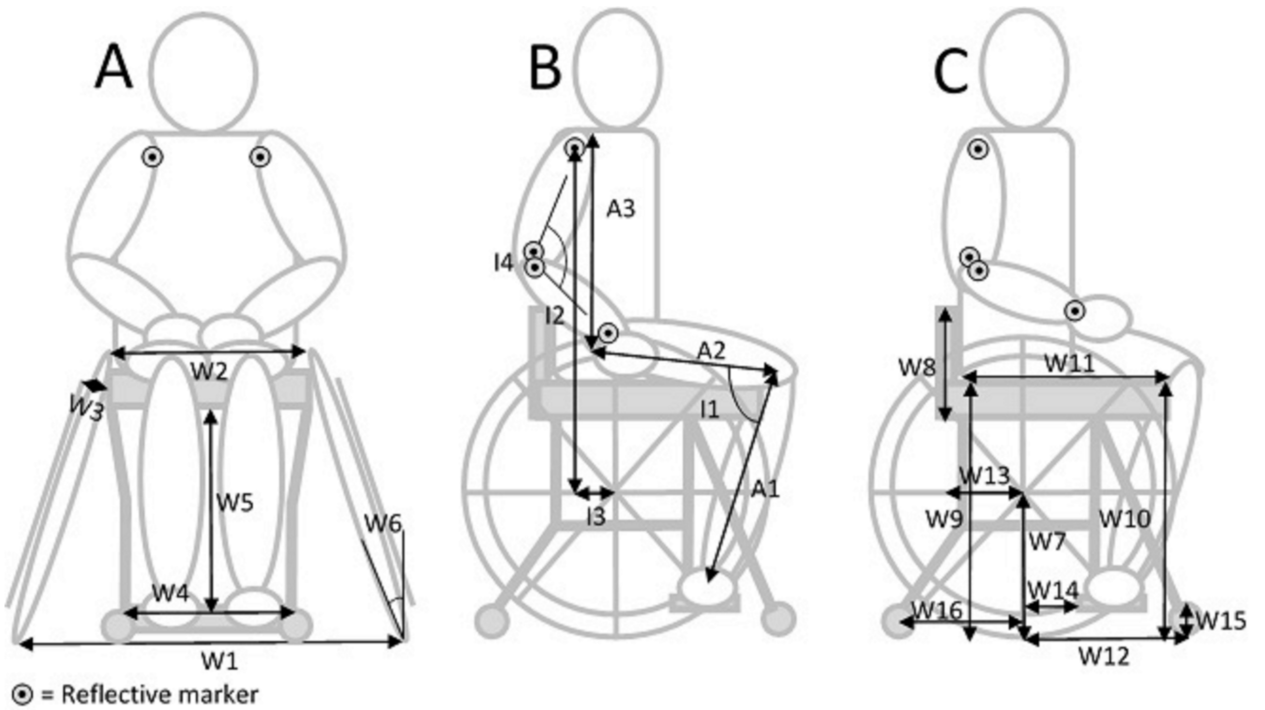


Figure 1. Example of the characteristics measured in Kinovea. The exact axplanation of the codes is listed in table 2.

The athletes performed a self-selected warm-up before starting the test using their regular game warm-up. The tests were performed in their own sports wheelchair and with their usual wheelchair configurations. The tires of the wheelchair were inflated to minimal 7 bar dependent on tire type. The participants had to perform the WMP test, which consists of 15 tasks (30). To be able to study the predictors for each important key determinant of mobility performance individually (i.e. sprint, brake and rotation), not only the total time needed for the WMP test, but also the performance of four tasks separately were included in the analyses of this study. These four tasks were the 12-meter sprint, the 12-meter sprint with stops, the rotation (clockwise / counter clockwise) and the rotation with stops (clockwise / counter clockwise) (Figure 2). The WMP test includes standardised rests between tests to avoid fatigue. With the 12-meter sprint, the athlete started from a standstill and had to sprint as fast as possible for 12 meters at the end of which the athlete had to arrive at a standstill again (Figure 2A). For the 12-meter sprint with stops, the athlete had to sprint for 12 meter again, but he or she had to come at a full stop at 3, 6 and 12 meter (Figure 2B). The rotation task consisted of riding a curve of 12 meter with a radius of 1.9 meter, beginning from a standstill and ending at the starting position in a standstill, performed in both clockwise and counter clockwise directions (Figure 2C). For the rotation task with stops, the athlete had to ride the curve but had to stop at a quarter of the curve (3 meters) and halfway (6 meters), before coming to a standstill at the starting position (Figure 2D). For a detailed description of the complete WMP test, the study from De Witte et al. (30) can be consulted. Also, in Appendix I of this thesis a schematic representation of the WMP test can be found.

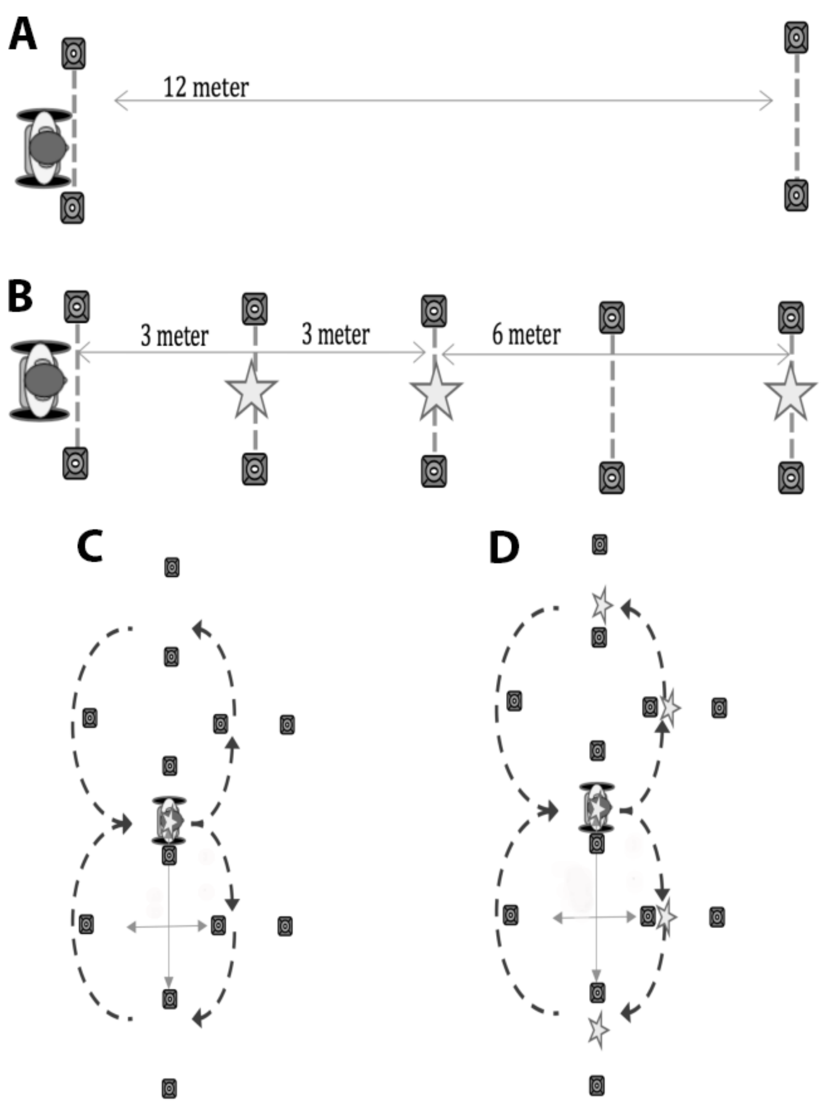


Figure 2. Wheelchair Mobility Performance test tasks: A) 12-meter sprint; B) 12-meter sprint with stops (stars); C) rotation clockwise/counterclockwise; D) rotation clockwise/counterclockwise with stops (stars).

6.2.3 Data acquisition

To measure wheelchair configurations and anthropometrics, two cameras (CASIO EX-FH100) were used to produce a photo in the frontal plane of the athlete in the wheelchair (Figure 1A) and in the sagittal plane, one with the athlete keeping his or her hands on the top of the hand rim (top dead center: TDC) (Figure 1B) and one with keeping his or her hands on their lap (Figure 1C). All lengths and angles of the athlete, wheelchair and the interface between athlete and wheelchair were determined using Kinovea (Kinovea, 0.8.15, France), as described in Table 2 and shown in Figure 1. The validity and reliability of Kinovea has been tested in vertical jumps and turned out to be a very reliable and valid way to measure jump height (3). The markers were used as reference points. Two reference frames, both with a height of 0.25m and a width of 0.25m, were visible in the pictures and were used to calibrate the pictures. In the frontal plane, one frame was placed in line with the axis of the rear wheels of the wheelchair and one frame was placed in line with the axis of the front wheels. In the sagittal plane, one reference frame was placed in line with the axis of the closest rear wheel and one frame was placed in line with the front wheel nearest to the camera. For the maximal isometric force the Mecmesin Advanced Force Gauge (Mecmesin Ltd, Broadbridge Heath, West Sussex, UK), with an accuracy of $\pm$0.1% of full-scale values, was used. The participants applied maximal force for five seconds with both arms, the mean over five trials was calculated.

All measurements added up to a total of 33 variables and were divided in three categories: ten variables describing athlete characteristics, nineteen variables concerning wheelchair characteristics and four variables describing the interface between athlete and wheelchair characteristics (Table 2). As outcome variables, the time the participants needed for each task was determined based on frame counts using video analyses in Kinovea and was recorded in seconds. The time needed for the two directions in the rotation tasks were summed. Overall performance was determined as the sum of the time needed for each of the 15 tasks of the WMP test. Thus, in total five outcome variables were taken into account: 12m sprint time, 12m sprint with stops time, rotation time, rotation with stops time and total time on the WMP test.

6.2.4 Statistical analysis

Descriptive statistics were used to characterize the study population. Mean and standard deviation (SD) were used for normally distributed variables, otherwise median and interquartile range (IQR) were calculated. The normality of distributions of the variables was explored visually using histograms, q-q plots and box-plots and using the Kolmogorov-Smirnov test.

To determine which variables among the athlete, wheelchair and athlete-wheelchair interface characteristics are the best predictors of mobility performance in the WMP test, forward stepwise linear regression analyses were performed. All variables had sufficient collinearity tolerance (>0.10) and therefore were included in the regression analysis. A significance level of $p<0.05$ was used to include the characteristics as predictor variables in the regression models. Regression analyses were performed for each of the five outcome variables (12m sprint time, 12m sprint with stops time, rotation time, rotation with stops time, total time on the WMP test) separately. For each outcome variable a regression analyses was performed with all athlete, wheelchair and interface characteristics included. Retrospectively, the statistical power (1-β error probability) was analysed using effect size f^2, predictor number of the actual models, α error probability of 0.05 and sample size with G*Power 3.1 software (41). The rest of the statistical analyses were performed using SPSS 23.0 (IBM Corporation, Armonk, New York, USA).

Table 2. Overview of variables with the description of the measurement and the corresponding code for Figure 1.

Code in figure 1	Variable	Description
	Frontal view	
W1	Width wheelbase	Distance between the ground contact points of the rear wheels
W2	Distance TDC	Distance between the tops of the rear wheels
W3	Distance hand rim and tire	Distance between the midpoints of hand rim and the tire
W4	Distance between front wheels	Distance between the front wheels where they are attached to the frame
W5	Vertical distance front seat height and footrest	Distance between the seat and the top of the footrest
W6	Camber angle	The angle between the vertical and the rear wheel (=90°-W6)
	Sagittal view – hands on the lap	
-	Wheel diameter	Diameter of the rear wheel, measured manually
-	Hand rim diameter	Diameter of the hand rim attached to the rear wheel, measured manually
-	Ratio hand rim/wheel	Ratio between hand rim diameter and rear wheel diameter
W7	Wheel axis height	Height of the rear axis measured from axis to ground contact point
W8	Height back support	Height of the back support measured from the seat
W9	Rear seat height	Vertical distance between ground contact point and the rear end of the seat
W10	Front seat height	Vertical distance between ground contact point and the front end of the seat
W11	Seat depth	Horizontal distance between the front and rear end of the seat
W12	Length wheelbase	Distance between the ground contact point of the rear wheel and the ground contact point of the front wheel
W13	Horizontal distance rear axis and back support	Horizontal distance between the rear axis and the midpoint of the back support
W14	Horizontal distance footrest and rear axis	Horizontal distance between the rear axis and the frontal end of the footrest
W15	Front wheel diameter	Diameter of the front wheel
W16	Horizontal distance anti-tip wheel and rear axis	Horizontal distance between the rear axis and the anti-tip wheel
	Sagittal view – hands on TDC	
-	Fore arm length (-)	Length of the fore arm, measured manually
-	Upper arm length (-)	Length of the upper arm, measured manually
A1	Lower leg length	Length of the lower leg from knee to ankle
A2	Upper leg length	Length of the upper leg from hip to knee
I1	Knee angle	Angle of the knee joint
I2	Vertical distance shoulder and rear wheel axis	Vertical distance between the shoulder acromial angle marker and the rear axis
I3	Horizontal distance shoulder and rear wheel axis	Horizontal distance between the shoulder acromial angle marker and the rear axis
A3	Trunk length	Distance between acromial angle marker and the hip joint
I4	Elbow angle	Angle of the elbow joint with hand on TDC

6.3 Results

6.3.1 Descriptives

In Table 1 all characteristics and outcome variables are listed and split according to the earlier described categories. The number of included participants for each variable is shown – which was different among variables due to missing values related to disability of participants or visibility on the pictures – together with the minimum and maximum value, the mean and the standard deviation for normally distributed variables and median and IQR for not normally distributed variables. The time (s) the participants needed for the different tasks is shown in the last part of the Table.

6.3.2 Best predictors of performance

Table 3 shows the regression models resulting from the forward stepwise procedure for each of the five outcome variables with all the predictor variables as input. In total, eight out of the 33 characteristics appeared in the regression models. Only four of those eight characteristics were included as predictors for multiple outcome variables, the others for just one task. The vertical distance between shoulder and rear wheel axis (I2) and the vertical distance between front seat height and footrest (W5) were included in three and four models, respectively, where a smaller vertical distance between front seat height and footrest and a larger vertical distance between shoulder and rear wheel axis was associated with a better performance. However, the vertical distance between shoulder and rear wheel axis was not a significant predictor for the 12-meter sprint with and without stops. Classification and average maximal isometric force were included in two and three models, respectively, both variables were associated with a better performance on the 12-meter sprint, 12-meter sprint with stops and rotation. Wheel axis height (W7), hand rim diameter, experience and camber angle (W6) appeared in only one of the models. The amount of variance explained by the models was between 38% and 60%. The statistical power (1-β error probability) of all models was >0.95, which is considered to be acceptable (41).

Table 3. Regression models variables together and the five different tasks as outcome variables. B= unstandardized regression coefficient; β= standardized regression coefficient; R^2= the coefficient of determination.

All together

Outcome variable	**Predictor (code in figure 1)**	**B**	**β**	***p*-value**	**R^2**
12-meter sprint	(Constant)	8.619		<0.001	
	Wheel axis height (W7)	-0.094	-0.322	0.027	
	Classification low/high (-)	-0.282	-0.376	0.004	
	Maximal isometric force (-)	-0.001	-0.411	0.007	0.51
12-meter sprint + stops	(Constant)	15.032		<0.001	
	Hand rim diameter (-)	-0.173	-0.568	<0.001	
	Vertical distance front seat height and footrest (W5)	0.059	0.363	0.004	
	Classification low/high (-)	-0.617	-0.438	0.001	
	Experience (-)	-0.046	-0.319	0.010	0.60
Rotation	(Constant)	12.784		<0.001	
	Max. isometric force (-)	-0.003	-0.372	0.005	
	Vertical distance front seat height and footrest (W5)	0.125	0.507	<0.001	
	Vertical distance shoulder and rear wheel axis (I2)	-0.062	-0.513	0.001	0.54
Rotation + stops	(Constant)	18.701		<0.001	
	Vertical distance shoulder and rear wheel axis (I2)	-0.129	-0.677	<0.001	
	Vertical distance front seat height and footrest (W5)	0.144	0.368	0.014	0.38
Total	(Constant)	116.215		<0.001	
	Vertical distance shoulder and rear wheel axis (I2)	-0.551	-0.660	<0.001	
	Vertical distance front seat height and footrest (W5)	1.001	0.583	<0.001	
	Max. isometric force (-)	-0.019	-0.347	0.006	
	Camber angle (W6)	-1.671	-0.284	0.026	0.60

6.4 Discussion

The aim of this study was to investigate which athlete, wheelchair, and athlete-wheelchair interface characteristics are the best predictors of mobility performance in wheelchair basketball. With this insight, coaches and biomechanical specialists are provided with statistical findings to determine characteristics to improve mobility performance. When all characteristics are evaluated together, eight different variables - three athlete, four wheelchair and one athlete-wheelchair interface characteristic - were included as significant predictors for the different performance tasks of the WMP test. Classification, experience, maximal isometric force, wheel axis height (W7), hand rim diameter, camber angle (W6), and the vertical distance between shoulder and rear wheel axis (I2) are positively associated with mobility performance, while the vertical distance between the front seat height and the footrest (W5) is negatively associated with mobility performance. However, not all of these variables are modifiable and can thus be used to improve mobility performance. Without those non-modifiable variables (i.e. classification and experience), six modifiable variables remain.

The inclusion of classification in both sprint models is in line with the findings of Cavedon et al. (12) and Gil et al. (35), who found significant correlations between sprinting and classification. Furthermore, Cavedon et al. (12) found, also in line with this study, significant correlations between experience and sprinting, while Gil et al. (35) did not. These results indicate that, as expected, classification and experience should be taken into account by coaches and trainers. However, these variables are non-modifiable and may, therefore, not be the best variables to focus on.

The modifiable athlete variable maximal isometric force was included as a predictor in the 12-meter sprint, the rotation and the total test model. A higher force was associated with a better performance in the models. This is in line with the findings of Granados et al. (39), who reported that forces assessed using multiple strength tests were significantly higher in athletes of a First-Division team compared to athletes of a Third-Division team. Wheelchair athletes that are able to produce higher forces on the hand rim are likely to reach higher accelerations and thus better performances on both tasks. However, it is not suggested that coaches and trainers should focus purely on the maximal isometric force itself. The actual (maximal) forces that are exerted during handling the wheelchair while attempting the best performance on the WMP test tasks would be preferable information. Unfortunately, isometric force was measured instead. At the moment it is possible to measure the exerted hand force during riding itself with, for example, a SmartWheel (Three Rivers Holding, Mesa, AZ, USA). However, the relatively large mass of the SmartWheel itself will influence the performance and, therefore, the data gathered would not be useful in this situation. Still, increasing the force that an athlete can produce might improve their performance. Furthermore, this isometric force is measured while sitting in the chair and the configuration of the chair can influence the amount of force that can be produced.

Two of the modifiable wheelchair variables that were predictors of mobility performance were hand rim diameter and wheel axis height (W7): an increase in diameter or height was associated with a better performance on the 12-meter sprint with and without stops, respectively. This is in line with Guo et al. (40) who reported that the work that was done during a full propulsion cycle was significantly higher when a larger hand rim was used, although this result was found in able bodied participants. It has also been found that smaller wheels resulted in a greater rolling resistance and, therefore, an increased physiological demand and that the performance on a 20-meter sprint was better with a 65 cm wheel compared to a 59 cm wheel (54,57). Although wheel diameter itself was not included as predictor in the models, wheel axis height and hand rim diameter were highly correlated with wheel diameter (r=.76 and r=.89, respectively; see also the correlations between predictor variables in the supplemental material (online available). So it might be the case that for the WMP test not only a larger hand rim but also larger wheel diameters and a higher wheel axis heights are beneficial. However, it should be noted that larger hand rim sizes result in a higher cardiorespiratory stress and lower mechanical efficiency during a 15-minute exercise test (90). So when the cardiorespiratory system becomes the limiting factor, which might be the case in a match situation, a larger hand rim might not result in a better performance.

Another interesting modifiable wheelchair variable that appeared in one of the models was camber angle (W6). An increase of one single degree camber angle was associated with an as much as 1.67 s faster time on the total WMP test. However, Mason et al. (55) reported that a camber angle of 24° has clear negative effects on both linear and rotational movements. They indicate that 18° looks like the optimal angle, but 20° would still be fine. Since the mean camber angle in this study was nearly 18° (range 15-21°), the possibility to increase the camber angle with beneficial results might be limited.

In several studies it is found that seat height – defined as the distance between the floor and the top of the head or defined in terms of elbow angle - affects wheelchair performance in healthy non-wheelchair users, spinal cord patients and wheelchair basketball players (12,91,92). The seat height affects physiological parameters, propulsion technique, mechanical efficiency and basketball specific tasks, with optimal seat heights when the elbow angle was 100°-130° and with lower seat height having a clear negative effect on the performance. It should be noted that two of these studies tested the participants in daily use wheelchairs or wheelchair ergometers. Although, in the current study, rear seat height and elbow angle were not included in the regression models themselves (Table 3), other variables which are highly correlated were included (see also the correlations between predictor variables in the online supplemental material). Vertical distance between shoulder and rear wheel axis (I2) and vertical distance between front seat height and footrest (W5) were included in four and three models, respectively, and are highly correlated with elbow angle (I4:I2: r=.68) and/or rear seat height (W9:I2: r=.84; W9:W5: r=.54). But also the wheel axis height (W7) was highly correlated with elbow angle (r=.66) and hand rim diameter with both rear seat height and elbow angle (r=.55 and r=.69, respectively), and were both included in the models. A larger vertical distance between the shoulder and the rear axis (I2) was associated with a better performance. However, according to van der Woude et al. (91,92) this association might not be linear, but more curvilinear. Surprisingly, a larger vertical distance between front seat height and footrest (W5) was associated with a decreased mobility performance. This would mean that performance would be better if vertical distance between the shoulder and rear wheel axis would be larger and the vertical distance between the front seat height and footrest would be smaller. This can be accomplished by increasing the rear seat height and decreasing the front seat height and thereby increase the hip angle. Often players with a low classification use a so-called “bucket” seat, where the front of the seat is higher up than the back of the seat and thus the hip angle smaller. Mason et al. (52) reported that highly impaired players found that the “bucket” seat was useful for creating more stability in the wheelchair. Although less impaired players also felt more stable, they also found that it hindered their performance due to the impaired ability to use their trunk. So minimizing the "bucket" seat as much as possible for the athlete might have a positive effect on their mobility performance. Moreover, when you decrease this distance, the hip-angle increases and the feet go backwards, this has also been found to be beneficial for the manoeuvrability and thus for the performance of the athlete (52). It should be noted that classification is positively correlated with both rear seat height (r=.50) and elbow angle (r=.58) and that athletes with a lower classification often have a lower rear seat height. Increasing the seat height in athletes with a lower classification is only possible if athletes are well strapped to the wheelchair, however, the stability will be impaired due to the increase in seat height. So the benefit of increasing rear seat height might be limited for some athletes.

This study is the first to evaluate such an amount of variables together in wheelchair athletes and provides a comprehensive overview of wheelchair-athlete characteristics and their associations with performance. It provides a good insight in which variables might be most important for mobility performance. Coaches, trainers and mechanics can use this information to effectively optimize mobility performance in wheelchair basketball players. The inter-researcher reliability for the data analysis was not an issue, since the analysis has been executed by only one researcher. The validity and reliability of Kinovea has been tested in vertical jumps and turned out to be a very reliable and valid way to measure both flight time and jump height (3). This suggests that it is a sufficient way for the measurements of the lengths in this study. The WMP test has found to be a valid test to measure the mobility performance of wheelchair basketball athletes (30). Using a forward stepwise approach the best predictors of performance were identified based on statistical associations. Considering that only a sample of wheelchair basketball players is studied, some of the findings may be caused by chance, resulting in statistical associations and not because of actual relationships in the population, causing these findings to be difficult to explain. However, the sample is representable for the population of professional wheelchair basketball players, and it should be investigated if the same associations will be found in other populations, such as amateur wheelchair basketball players. The forward stepwise procedure was chosen to arrive at a set of variables that best predict performance. Due to collinearity of predictors some of the variables in the final regression models might be interchangeable with other (comparable) variables as indicated above and this should be taken into account when interpreting and explaining the final regression models (see also the correlations between predictor variables in the online supplemental material II). Current literature is insufficient to deal with these interactions between different characteristic, so this study only addressed the statistical associations between characteristics and mobility performance. It was decided not to include certain variables beforehand. For instance, classification or the athlete's power could have been forced into the regression model before running the stepwise procedure. This would have resulted in the best predictors of performance independent of classification as confounding variable. This is, however, a different research question but a logical next step after the explorative approach of the present study although these kinds of questions are better studied in experimental settings. The results of the present study can guide the development of questions for follow-up (experimental) studies to arrive optimal (mobility) performance in wheelchair basketball and other wheelchair sports.

6.5 Conclusion

The findings of the present study provide coaches and biomechanical specialists with statistical findings to determine on which characteristics they can focus best to improve mobility performance such as wheel axis height and maximal isometric forces. It gives an indication of how certain variables can be modified to improve mobility performance. Not only can these findings help to improve mobility performance, but also to prevent injuries. When the wheelchair can be modified to enhance mobility performance, the load on the musculoskeletal system needed to achieve the same performance may be less, reducing the risk of injury. However, for all variables mentioned in this discussion, it should be determined what their optimal values are to improve mobility performance without increasing the risk of injuries.

Chapter 7 OPTIMIZING MOBILITY PERFORMANCE

Effects of seat-height, weight distribution and glove use on mobility performance in wheelchair basketball players

de Witte, A. M. H., van der Slikke, R.M.A., Berger, M. A. M., Hoozemans, M. J. M., Veeger, H. E. J., & van der Woude, L.H.V. (2018). Effects of seat height, mass and glove use on a field-based wheelchair basketball mobility performance test. *Under review.*

The purpose of this study was to determine the effects of seat height, wheelchair mass and glove use on mobility performance among wheelchair basketball players and to investigate whether these effects differ between classification levels. Elite wheelchair basketball players with a low (n=11, class 1 or 1.5) or high (n=10, class 4 or 4.5) classification performed a standardized field-based wheelchair basketball mobility performance (WMP) test. Athletes performed the test six times in their own wheelchair, of which five times with different (wheelchair) configurations, with a higher or lower seat height, with additional distally or centrally located mass, and with use of gloves. The effects of these configurations on performance times on the WMP test and the interaction with classification were determined. Total performance time on the WMP test was significantly reduced when using a 7.5% lower seat height. Additional mass (7.5%) and glove use did not lead to changes in performance time. Effects were the same for the two classification levels. The methodology can be used in a wheelchair fitting process to search for the optimal individual seat height to enhance mobility performance. Out of all adjustments possible, this study focused on seat height, mass and grip only. Further research can focus on these adjustments to optimize mobility performance in wheelchair basketball.

7.1 Introduction

Wheelchair mobility performance, defined as the ability of a wheelchair athlete to perform athlete-wheelchair activities such as driving forward, driving backward or turning with a wheelchair (54), is an important performance aspect in wheelchair basketball. Overall (team) performance may be improved by focussing on mobility performance which is dependent on a combination of ergonomic factors associated with the athlete, the wheelchair and the interface between them (103). Athlete characteristics, such as physical capacity and muscle strength, can influence mobility performance as well as wheelchair settings such as wheelchair mass and camber. Furthermore, adjustments in the athlete-wheelchair interface, such as seat height and handrim grip, have been shown to have an effect on mobility performance (24,53). Insight in the relationship between mobility performance and the athlete, wheelchair and interface characteristics could help athletes, coaches and wheelchair technicians to improve the overall performance of the individual athlete and thus also the team performance.

Mobility performance can be influenced by changes in the wheelchair and interface configuration. Seat height can have an effect on mobility performance in wheelchair basketball through its influence on the stability of the wheelchair-athlete combination and the propulsion technique or efficiency (22,50,58,97). Most studies on the effects of seat height in wheelchair handling focused on physiological and mechanical responses in laboratory settings, and mainly in the context of daily life activities or sports such as wheelchair racing (53). The conclusions of these laboratory studies may, therefore, not be directly transferrable to wheelchair basketball. In wheelchair basketball, for instance, it is often desirable for centre players to sit as high as possible for optimal ball handling at the expense of stability. Whether seat height (when manipulated within reasonable and allowable ranges) actually has an effect on mobility performance in wheelchair basketball is therefore unknown, although a recent study indicated that seat height is a predictor of mobility performance (103).

The same is true for wheelchair mass, which has been studied and discussed before in relation to performance, but mainly in forward velocity conditions (19,24,73). In a study with able-bodied participants on a wheelchair treadmill, additional mass (5 and 10kg) did not result in a significant higher physical strain (24). Sagawa et al. (73) also found no effects of additional mass (5kg) on sprint performance, but a decrease in performance in the Stop-and-Go test for the able-bodies subgroup. However, Cowan, et al. (19) found that average self-selected velocity decreased when the mass of the wheelchair was increased with 9.05kg. The effect of wheelchair mass is ambiguous in the current literature and the effect on mobility performance in wheelchair basketball is also unknown.

In wheelchair racing and wheelchair rugby, it is common to use gloves to increase the friction between hand and rim. Gloves had a beneficial effect on wheelchair handling skills in rugby players and racers were able to achieve higher top end velocities by applying larger peak forces on the handrim (49,56,69). Additional grip can, therefore, also be advantageous to mobility performance in wheelchair basketball.

Considering the limited transfer of knowledge from results of laboratory studies with able-bodied participants with respect to activities of daily life, the effects of seat height, wheelchair mass and glove use on mobility performance in wheelchair basketball might be studied using a recently developed standardized field-based test. The wheelchair mobility performance assessed using this test was considered to be representative for the mobility performance in wheelchair basketball matches (30).

In exploring the effect of different wheelchair and interface configurations on mobility performance, the classification of athletes in wheelchair basketball should be taken into account (53). Active trunk stability and rotation have been identified as central components determining performance (35) and are key factors in the current wheelchair basketball classification system (43). Due to less trunk function it is expected that low class players are not able to compensate for the larger distance between shoulder and handrim in the higher seat height position and, therefore, performed less. Furthermore, players with a low classification have less power output than players with a higher classification (99)and based on this relationship, it is expected that the extra mass condition should have more effect on the low classification group. Therefore, the aim of this study was to determine the potential effects of seat height, wheelchair mass and additional grip on wheelchair mobility performance while performing a standardized field-based wheelchair mobility performance test, and to determine whether these effects are different for wheelchair basketball athletes of either low or high classification.

7.2 Methods

7.2.1. Participants

Twenty-one elite wheelchair basketball players participated in this study with fourteen men and seven women. Eleven players had a classification of 1 or 1.5 (low classification group) and ten players had a classification of 4 or 4.5 (high classification group). For detailed information about the study population see Table 1. Participants gave written informed consent prior to participating. This study was approved by the Ethics Committee of the Faculty of Behavioural and Movement Sciences, Vrije Universiteit Amsterdam, the Netherlands (2016-091R1).

Table 1. Player characteristics (n=21)

	Mean (SD)	Classification group	
		Low (1-1.5) (n=11)	High (4-4.5) (n=10)
Age (y)	30.1 (11.4)	34.6 (9.5)	25.1 (11.7)
Mass (athlete + wheelchair) (kg)	84.1 (14.0)	82.1 (13.1)	86.6 (15.5)
Experience (y)	9.0 (9.3)	8.0 (6.8)	10.1 (11.7)

7.2.2. Procedure

Participants had to perform the Wheelchair Mobility Performance (WMP) test, which consists of 15 sport specific tasks and has been shown to be a valid and reliable test to assess mobility performance capacity in wheelchair basketball (30). All 15 tasks were carried out in succession, separated by standardised rest periods to avoid fatigue (see Appendix I). Participants were familiar with the WMP test because of their participation in previous experiments.

The participants performed the WMP test six times in their own wheelchair of which five times with different configurations. Tire pressure was standardized at seven bar. The first time the WMP test was performed, no wheelchair configurations were changed (control condition). After the first test, the wheelchair was changed to one of five conditions in a randomised order to eliminate learning or fatigue effects. All adjustments were made by a highly-experienced wheelchair technician. The five configurations were: 1) 7.5% lower seat height; 2) 7.5% higher seat height; 3) 7.5% additional mass centrally placed at the wheel axis (mass central); 4) 7.5% additional mass distributed evenly at 0.3m in front of and behind the wheel axis (mass distal); 5) use of rubber coated gloves to increase grip on the handrim without changes to seat height or mass. Although a percentage of the seat height was used for adjustment, the change was measured with a reference point on the top of the participant's head. When the wheelchair was adjusted, all other wheelchair configurations were kept as in the original configuration.

Each WMP test took about 6.5 minutes and was followed by a rest period of 15-30 minutes to allow recovery and to make adjustments to the wheelchair before the next test. For each participant, the WMP tests were performed on the same wooden indoor basketball court on one day.

7.2.3. Data acquisition and analysis

All WMP tests were video recorded from the side of the field with two high-definition video cameras (CASIO EX-FH100, 1280*720, 20-240mm) with a frame rate of 30Hz. The outcome of the WMP test was total performance time (sec) and was manually determined from video analyses using Kinovea (Kinovea 0.8.24, France). Next to total performance time, the performance times on the 3-3-6m sprint (task 7) and the combination task (task 15) were analysed separately. Previous research indicated that these performance time, as well as the total performance time on the entire WMP test were found to be valid, reliable and sensitive to change.(29,30).

7.2.4. Statistical analysis

The assumption of normality was checked by visual inspection of the distribution of the data and a Shapiro-Wilks test was performed of the data within the groups. Homogeneity of variance was checked using Levene's test. There were no violations of these assumptions. Descriptive statistics for performance measurements were, therefore, presented as mean ± standard deviation.

Two-way mixed design analyses of variance were used for seat height (low-control-high), added mass (control-central-distal) and glove use (control-gloves) separately to determine whether these wheelchair and interface configuration have an effect on performance times of the 3-3-6m sprint (task 7), combination task (task 15) and the total WMP test time and to determine whether the effects of these adjustments were influenced by classification (interaction effect).

For the independent variable seat height and mass, Tukey post hoc tests were performed when their main effect was found to be significant. When a significant interaction was observed, t-tests with Bonferroni correction were used to examine the interaction effect. In addition, Cohen's *d* effect sizes (ES) were calculated for the differences between pairs of conditions (Cohen, 1992). The (absolute) magnitude of the ES was classified as large (≥0.80), medium (0.50-0.79) small (0.20-0.49) or trivial (0-0.19) (14). All statistical analyses were performed using IBM SPSS statistics version 22 (IBM Corporation, Armonk, NY, USA) and *p*-values below 0.05 were considered significant.

7.3 Results

All 21 athletes performed the control condition. One low class athlete didn't perform the lower seat height position and glove use trials, and one high class athlete didn't perform the WMP test with additional mass centrally placed. Due to differences in group size, the results of the control condition for the different configurations showed small differences as can be seen in Tables 2,3 and 4.

For the performance time on the 3-3-6m sprint (Table 2), no significant differences were found between the seat heights. On the combination task, performance times in the lower seat position (*M*=14.60s, *SD*=1.40) were 0.26s (ES=0.19) faster compared to the higher seat position (*M*=14.86s, *SD*=1.32). Furthermore, there was a significant main effect of seat height for the total performance time (*p*=.002) (Table 2/Figure 1). Post-hoc tests showed significant differences between the lower seat height condition and the control condition, and between the lower and higher seat height conditions. The performance with a lower seat condition resulted in a 1.69s faster performance than the control condition (*p*=.014) and a 1.75s faster performance than with a higher seat height (*p*=.002). However, the effect sizes were classified as trivial, i.e. ES=0.18 and ES=0.19 respectively. The difference in total performance time between the control conditions and the higher seat height conditions was not significant. Overall, there were no statistically significant interaction effects observed between the seat height conditions and classification (for 3-3-6m sprint, *P*=.394; for combination task, *p*=.546; for total WMP test, *p*=.158).

There were no significant main effects observed for wheelchair mass (Table 3). Furthermore, no significant interaction effects were found between classification and wheelchair mass (3-3-6m sprint, *p*=.475; Combination, *p*=.415; Total WMP test, *p*=.215).

The differences in performance times on the WMP test between the trials with and without the use of gloves were not found to be significant (Table 4). Moreover, there were no significant interaction effects between classification and glove use for all three outcome variables (3-3-6m sprint, *p*=.372; Combination, *p*=.354; Total WMP test, *p*=.721).

Table 2. Mean and standard deviation (SD) of performance times (s) for the 3-3-6 m sprint, combination task and the total performance time on the wheelchair mobility performance (WMP) test for the control condition (CC) and the manipulation conditions seat height higher (SHH) and seat height lower (SHL). The table is complemented with the mean differences (s) between the manipulation conditions and control condition and Cohen's *d* effect sizes.

	Classification	Control Condition (CC)		Seat Height Higher (SHH)		Differences in time (s) between CC-SHH	Effect Size	Seat Height Lower (SHL)		Differences in time (s) between CC-SHL	Effect Size	Differences in time (s) between SHH-SHL	Effect Size
		Mean (s)	SD	Mean (s)	SD			Mean (s)	SD				
3-3-6msprint	Total	7.35	0.75	7.32	0.84	0.03	0.03	7.16	0.99	0.19	0.21	0.16	0.17
	Low (n=10)	7.94	0.50	7.92	0.74	0.02	0.02	7.89	0.90	0.05	0.07	0.04	0.04
	High (n=10)	6.76	0.42	6.72	0.37	0.04	0.10	6.43	0.28	0.32	0.91	0.28	0.88
Combination	Total	14.70	1.38	14.86	1.32	-0.16	-0.12	14.60	1.40	0.10	0.07	0.26*	0.19
	Low	15.51	1.24	15.64	1.29	-0.13	-0.10	15.51	1.18	-0.01	0.00	0.12	0.11
	High	13.90	1.02	14.09	0.82	-0.19	-0.20	13.70	0.95	0.20	0.21	0.39	0.44
Total WMP	Total	88.90	9.25	88.96	8.88	-0.06	-0.01	87.22	9.45	1.69*	0.18	1.75*	0.19
test	Low	95.34	7.74	95.00	7.53	0.34	0.04	94.25	6.85	1.08	0.15	0.74	0.10
	High	82.47	5.38	82.93	5.39	-0.46	-0.09	80.18	5.60	2.29	0.42	2.75	0.50

*Significant difference (*p*<0.05)

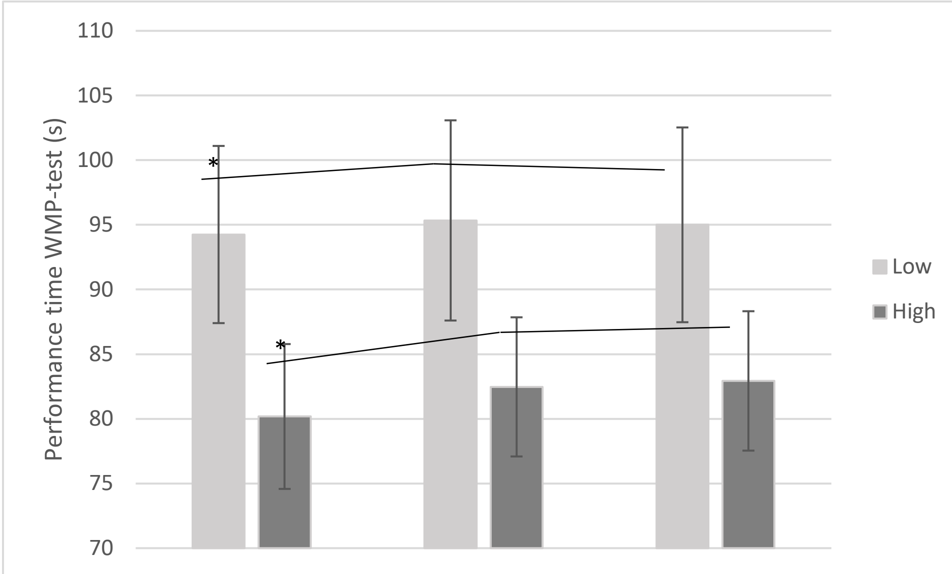


Figure 1. Performance times (s) of low and high class players on the Wheelchair Mobility Performance Test. *Significant difference (p<0.05) between lower seat height and control condition and between lower seat height and higher seat height position.

Table 3. Mean and standard deviation (SD) of performance times (s) for the 3-3-6 m sprint, combination task and the total performance time on the wheelchair mobility performance test for the control condition (CC) and the manipulation conditions mass central (MC) and mass distal (MD). The table is complemented with the mean differences (s) between the manipulation conditions and control condition and Cohen's *d* effect sizes.

	Classification	Control Condition (CC)		Mass Central (MC)		Differences in time (s) between CC-MC	Effect Size	Mass Distal (MD)		Differences in time (s) between CC-MD	Effect Size	Differences in time (s) between MC-MD	Effect Size
		Mean (s)	SD	Mean (s)	SD			Mean (s)	SD				
3-3-6msprint	Total	7.51	0.91	7.33	0.82	0.18	0.21	7.38	0.96	0.13	0.13	-0.05	-0,06
	Low(n=11)	8.11	0.75	7.89	0.64	0.22	0.31	8.06	0.75	0.05	0.07	-0.16	-0,24
	High (n=9)	6.78	0.43	6.64	0.33	0.14	0.37	6.56	0.36	0.22	0.62	0.08	0,23
Combination	Total	14.91	1.42	14.96	1.43	-0.05	-0.03	14.99	1.46	-0.08	-0.05	-0.03	-0,02
	Low	15.66	1.28	15.63	1.23	0.03	0.02	15.85	1.30	-0.19	-0.15	-0.22	-0,17
	High	14.01	1.03	14.15	1.27	-0.14	-0.13	13.94	0.84	0.07	0.08	0.21	0,20
Total WMP	Total	90.52	10.11	89.37	9.10	1.15	0.12	90.21	9.65	0.31	0.03	-0.84	-0,09
test	Low	96.73	8.69	94.71	8.31	2.03	0.24	96.40	8.03	0.33	0.04	-1.69	-0,21
	High	82.92	5.50	82.84	4.82	0.08	0.02	82.64	4.85	0.28	0.06	0.20	0,04

Table 4. Mean (±SD) performance times (s) for the 3-3-6 m sprint, combination task and the total performance time on the wheelchair mobility performance test for the control condition (CC) and the manipulation condition Gloves. The table is complemented with the mean differences (s) between the manipulation condition and control condition and Cohen's *d* effect sizes.

	Classification	Control Condition (CC)		Gloves (G)		Differences in time (s) between CC-G	Effect Size
		Mean (s)	SD	Mean (s)	SD		
3-3-6msprint	Total	7.45	0.93	7.38	0.86	0.07	0.08
	Low (n=10)	8.14	0.78	7.93	0.73	0.21	0.28
	High (n=10)	6.76	0.42	6.83	0.59	-0.07	-0.14
Combination	Total	14.80	1.48	14.80	1.58	-0.01	-0.01
	Low	15.69	1.34	15.83	1.55	-0.14	-0.09
	High	13.90	1.02	13.78	0.76	0.12	0.13
Total WMP	Total	89.65	10.37	88.74	10.09	0.91	0.09
test	Low	96.83	9.15	96.14	8.01	0.70	0.08
	High	82.47	5.38	81.34	5.38	1.13	0.21

7.4 Discussion

In this study, we determined the effect of seat height, mass and glove use on mobility performance in a standardized field-based wheelchair basketball test in elite wheelchair basketball players and we determined whether these effects are different for players with a low or high classification. The key findings of this study are that (1) a 7.5% lower seat height resulted in a faster performance on the total wheelchair mobility performance (WMP) test and on the combination task, and (2) 7.5% extra mass or the use of gloves did not lead to a significant change in performance time. Furthermore, high and low classification players showed similar responses to the interventions.

Performance times on the combination task and on the total WMP test were significantly influenced by seat height. Moreover, as can be seen in Table 2, the differences in all performance outcomes between high and low seat height have a positive value. This means that athletes performed the three different test parts faster with a 7.5% lower seat height than that they were used to, compared to the condition in which they had to perform the test with a 7.5% higher seat height. Based on the results of this study, one can assume that lowering the seat height then they were used to has a positive effect on mobility performance time in wheelchair basketball. In practice, the range of possible seat heights may be larger than the tested ±7.5% range. The optimal individual seat height is dependent on the athlete and the requirements of the game. The association between seat height and performance is by definition not linear because there is a limit to the seat height at which the handrims can be used. A trend in seat height can be seen, but the optimal seat height cannot be determined based on the present data, as only three heights have been tested. Previous studies focused on the effect of seat height on physiological parameters, propulsion technique and mechanical efficiency in wheelchair propulsion, and their results are in line with the results of the present study. Van der Woude et al. (94) observed that raising the seat height above the standardized position resulted in a higher oxygen uptake and reduced mechanical efficiency, which underlines the results in this study where more complex wheelchair handling tasks were tested. Lower seat height positions have been associated with increases in handrim contact and push-time and a reduction in push frequency (58,75,97). The increased handrim contact time and longer push time could explain the increase in mobility performance in the present study because it allows a longer power transfer.

Extra mass (7.5%), distally or centrally attached to the wheelchair, did not significantly change the outcome variables and no interaction effect with classification was observed. Extra mass was expected to decrease mobility performance time, as it is assumed that extra mass would have a negative effect on forward acceleration and braking. However, no noteworthy differences between the conditions were observed in performance times, despite the relatively large extra mass of 5 to 9kg. This was somewhat surprising. Future research using accelerometer data can shed light on the actual differences in acceleration and braking between conditions during the different test parts. The results were quite similar to previous research with daily life focus, which found no effect of extra mass on wheeling velocity (24,73). However, when the sensitivity to change of the WMP test was studied, the performance times on the total WMP test decreased significantly 4.40s when 10 kg extra mass was attached to the wheelchair (29). In the present study the extra mass varied, but was in all cases less than 10kg, which could explain these differences. The outcomes measure time in the present study shows no significant difference.

We also evaluated the effect of distributed mass addition, which not only influenced linear acceleration and braking, but also rotational acceleration as it changes the system's moment of inertia. For the combination task and overall performance, which contains rotations, again to our surprise, no differences were observed. Van der Slikke et al. (84) observed with inertial sensors during the WMP-test reduced maximal rotational speed and rotational acceleration when the extra mass was distributed. However, this was not determined for the separate tasks of the WMP-test. With the current knowledge and results of both studies, there is still no clear answer to what extent added mass influences mobility performance while no differences were observed in performance time despite the fact that there were differences in kinematic outcomes. Synchronization of both systems, to get an overview of time and kinematic outcomes for all separate tasks, is recommended. It appears that changes up to 7.5% extra mass, even when distally added, does not lead to large decreases in performance time.

In several wheelchair sports, such as wheelchair rugby and wheelchair racing, the use of gloves is common and the benefits on performance are scientifically proven (49,56,69). However, this study does not show a positive or a negative significant effect on mobility performance in wheelchair basketball. Moreover, no significant differences were observed in kinematic outcomes (84). The time to get used to the use of gloves was, however, very short and the reported experience of the athletes was very diverse, from very comfortable to very disadvantageous. Players indicated that ball handling was more difficult due to reduced ball feeling. As such, the test results indicated that the benefits of glove use are highly linked to both wheelchair and ball handling. It is an option to place the extra grip only on a specific part of the hand so ball feeling isn't influenced. Further research with longer adaptation periods and other grip material and placing is therefore recommended.

No interaction effects of classification were observed in this study for the different wheelchair configurations. It was expected that classification could cause different performance effects as a result of changes in the seat height and the mass. Low-class players have less trunk function and in a higher seat height position it was expected that they would not be able to compensate for the larger shoulder-handrim distance. Furthermore, due to the relationship between power output and classification (99), it was expected that the extra mass condition would have a more substantial effect on the low classification group. However, athletes with a low classification did not respond differently, in terms of performance time needed, to a wheelchair adjustment compared to athletes with a high classification. The results have to be interpreted with care, given the limited datasets (n=21). However, in practice, a dataset of eleven elite low-class players is in itself very exceptional.

7.4.1. Limitations and recommendations

This study examined the potential effects of ergonomic wheelchair settings in a standardized field-based test with experienced elite wheelchair basketball players of different classifications. The methodology used is in line with the recommendations of Mason et al. (53) to achieve the highest level of internal and external validity when studying the effect of wheelchair and athlete-wheelchair characteristics on mobility performance in wheelchair basketball. However, the choice for this method also imposes some limitations:

All experimental conditions were performed in a randomised order to eliminate learning or fatigue effects. The resting periods between the tests allowed full recovery of the players. However, the experimental setting was not optimal to acquire total adaptation to the new seat heights and the use of gloves. We do not expect that the short adaptation period has biased our conclusions. It is plausible that a longer adaptation period would have led to more obvious differences and it is recommended to use longer adaptation time in further research. In the current study, all tests took place at the same day, so the adaptation time was limited.

Another limitation (and strength) of this study is the choice to apply adjustments to the subjects' own wheelchairs, assuming that their own wheelchair was optimally tuned. Based on this assumption, the wheelchair seat height was individually raised and lowered with 7.5% and the mass was increased with 7.5%. These percentages were chosen to simulate realistically possible seat heights and were experienced as very small by the players. With this approach the number of possibilities for wheelchair adjustments was however limited. A multi-adjustable wheelchair could be beneficial for research purposes. The multi-adjustable wheelchair must first be tuned to the settings of their own wheelchair, and from that point, manipulations should be made with the same methodology as used in this study.

Within the limitations, the results of this study can be used by athletes, coaches and wheelchair technicians to improve individual and team mobility performance. This study provides insight in the performance effects of key wheelchair configurations. The methodology can be used in a wheelchair fitting process to search for the optimal individual seat height to enhance mobility performance. The WMP test is easy to use and little material is required. This study focused only on seat height, mass and grip while several other adjustments can be made to the wheelchair, such as changes in camber and wheel size. Further research can focus on these adjustments to optimize mobility performance in wheelchair basketball.

Chapter 8 GENERAL DISCUSSION

In this thesis, information about the wheelchair-athlete-interaction in wheelchair basketball is studied by means of *defining, quantifying, simulating, predicting* and *optimizing* mobility performance. Mobility performance takes into account the individual capacities of the athlete, the possibilities of the material, and the requirements of the environment, and the continuous interaction between them (Figure 1). For wheelchair basketball athletes, the individual adjustment of the wheelchair to the athlete, with their specific impairment and abilities, supplemented with the requirements of the environment (where environment is defined as both the physical and social or game-related environment), are of great importance. To improve mobility performance in wheelchair basketball, understanding of how athletes handle their wheelchair, for instance during actions in matches and the effect of wheelchair adjustments on that, will lead to a better wheelchair - athlete - environment interaction which improves mobility performance and, therefore, game play and team performance. This thesis provides a methodology to understand mobility performance in wheelchair basketball which can be used to further optimize wheelchair-athlete interaction and game performance.

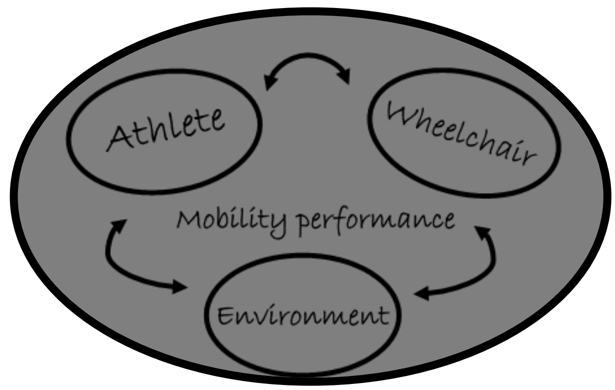


Figure 1. Mobility performance in wheelchair basketball consists of three aspects; the athlete, the wheelchair, the environment and the continuously interaction between them.

The main findings of this thesis are:

- *Defining* and *quantification* of mobility performance shows that during an entire wheelchair basketball game there are significant differences in mobility performance between national and international playing standards. National players drove more forward and performed fewer rotational movements than international players. Furthermore, it is concluded that the environmental characteristics offense, defense, and ball possession influenced mobility performance for the different field positions guard, forward and centre differently.
- To *simulate* mobility performance in a controllable setting, the field-based Wheelchair Mobility Performance (WMP) test is developed based on the quantification of the observed game behavior data. This led to a set of 15 test parts and a total overall test performance time score. The construct validity, reliability and sensitivity to change indicated that the overall performance time on the WMP-test can be used to monitor and assess mobility performance of individual athletes.
- A *prediction* study indicated eight wheelchair-athlete characteristics as a predictor for mobility performance. Six of these performance determinants are modifiable and can be employed both in individual training (maximal isometric force) and wheelchair adjustments (wheel axis height, handrim/wheel diameter, camber angle, vertical distance between shoulder and rear wheel axis (seat height) and the vertical distance between the front seat and the footrest).
- A first exploration on *optimizing* mobility performance showed in improvement in overall mobility performance on the WMP test when the seat height was 7.5% lower than the athletes' common

seat height. No differences in performance time were observed with 7.5% extra mass or additional grip.

8.1 Defining and quantifying mobility performance

In order to define and quantify mobility performance it was necessary to get an overview of the game activities of the wheelchair-athlete combination and the influence of the environment on that during match play. The studies in **Chapters 2** and **3** give an extensive overview of wheelchair-athlete activities during wheelchair basketball matches. Besides observation of all the wheelchair-athlete actions, comparisons between field positions, classifications and playing standards were performed. The influence of the environment, in terms of individual ball possession and offense/defense, gives additional relevant information. Time-motion video-analysis was used to observe the different aspects of mobility performance. The developed observation scheme to observe mobility performance, contained all possible characteristics of mobility performance that were observable with video-analysis. However, the used video-analysis system does not provide insight into all aspects of mobility performance. More specific information about the wheelchair (e.g. kinematic/kinetic outcomes), the environment (e.g. actual field position) and the athlete (e.g. trunk movement) cannot be retrieved with the used method. Kinematic and kinetic outcomes can be derived from a new method using inertial sensors: "the wheelchair mobility performance monitor" (87). This method provides detailed quantification of selected kinematic and kinetic outcomes of the wheelchair which discriminate well between wheelchair basketball athletes of different playing standards. However, these results give only an overview of the wheelchair kinematic outcomes averaged over the entire match. Specific information about how athletes handles their wheelchair and the influence of the environment, for example ball possession, is not incorporated. The observation scheme of mobility performance described in **Chapter 2** should be combined with the kinematics outcomes like linear and rotational speeds and accelerations. Another potential improvement would be the use of an indoor tracking system for wheelchair court sports that provides position data of the athlete in the playing field (68). Position data is also a part of mobility performance which enables tactical team analyses. The indoor tracking system enables the wheelchair mobility performance analysis to be split by environment specific characters such as offense and defense. One of the studies from the project parallel to this project by van der Slikke et al. (88) combined the inertial sensor method, which is described above, and the indoor tracking method. Van der Slikke et al. (88) recommended this hybrid solution as the new standard for mobility performance measurements in wheelchair court sports. However, specific information about wheelchair-athlete actions and ball possession is missing in both systems. It is recommended to combine these methods with the video-based studies in **Chapter 2** and **3**.

In the used observation scheme, not only the wheelchair movements were observed, also the way the wheelchair is handled by the athlete. For example, driving forward with 1 or 2 hands or otherwise. This athlete information is not complete. Athletes who can, used their trunk as well in manoeuvring the wheelchair. Information about trunk movements in the frontal and sagittal plane could provide insight in propulsion during wheelchair movements. Trunk motion in the frontal and sagittal plane can, in principle, be measured with an inertial sensor on the back of the trunk. The validity and reliability of this system should be determined during games, so that trunk motion can be included in mobility performance observation to get a full overview about how athletes handle their wheelchair. Furthermore, trunk motion is a key-factor in the current classification system. Further information about trunk motion during match play could provide insight in the validity of the current classification system.

In sum, to get a total overview of mobility performance, additional information needs to be added to the current video-based system used to define and quantify mobility performance during wheelchair basketball. In order to accomplish this, the video-analysis method, inertial sensors method and indoor tracking methods should be combined. Integration and synchronization of the three methods is of great importance so that they can fortify each other. For the inertial sensor and indoor tracking method, expensive material and specific knowledge is necessary to perform and analyze the measurements. In contrast, the used video-analysis system in this thesis requires little and cheap material compared to the other systems and requires less specific knowledge. Therefore, despite being time-consuming, the observation method and scheme can be used well by trainers and coaches to gain insight in mobility performance in their individual players and team in a relatively easy way.

8.2 Simulating mobility performance

Assessing mobility performance is a fundamental requirement for trainers, coaches and wheelchair technicians to, for example, develop training schemes, discuss and improve the athlete's level of performance, detect strength and weaknesses, and to adjust wheelchair settings. In order to repeatedly monitor and assess athletes' mobility performance in a controllable setting, the continuously changing environmental aspects must be excluded. Therefore, the Wheelchair Mobility Performance (WMP) test for wheelchair basketball players was developed (**Chapter 4**) which simulated the most common wheelchair-athlete activities during matches in a standardized test.

To simulate mobility performance as described in **Chapter 4**, a field test was developed in which wheelchair-athlete activities were selected and combined that were most common during match play video analyses, supplemented with kinematics results from the study of van der Slikke et al. (87). The developed WMP test meets the requirements which have been reported in previous studies of wheelchair court sports (38,53,96). The test is easy to perform for athletes and only common materials such as a ball, cones and a stopwatch are required. This test can be used in several ways: as a standardized mobility performance test to assess the capacity of mobility performance of athletes, their performance transitions over time or to investigate the effects of adjustments of the wheelchair setting. To date, the wheelchair fitting process for performance optimization is highly dependent on the experience level of athlete and/or the wheelchair technician and the WMP test can be used to objectively measure (potential) effects of wheelchair-athlete adjustments on mobility performance.

The used outcome measure of the WMP test in this thesis is performance time in seconds. Performance time is easy to measure and, therefore, the test can easily be used in practice. Unfortunately, for small and short (rotational) movements, performance time showed low reliability and construct validity. However, these actions are frequent elements of mobility performance during wheelchair basketball matches and, therefore, important to include in the WMP test. As a general outcome of the WMP-test only the performance time on the 3-3-6m sprint, the combination task and the overall performance time are recommended to be used in both practice and research. The test results could be combined with the "wheelchair mobility performance monitor" which provide six valuable kinematic outcomes (87).

The current WMP test is based on extensive overviews of wheelchair-handling activities during wheelchair basketball. Because of this, the test is not expected to be representative for other wheelchair court sports like tennis or rugby, because it is plausible that the wheelchair-athlete-environment activities are different for these different court sports. It is advised to use the described methods to develop, understand and simulate the sport-specific requirements of mobility performance in the different wheelchair (court) sports. This method has previously also been used for daily life wheelchair users (34) or in other domains. For example, the physical test for Dutch police officers is based on the method of defining and quantifying (60). In general, to assess performance, it is necessary to understand the (sport)-specific requirements through intensive observation independent of the domain.

8.3 Predicting and optimizing mobility performance

Several wheelchair-athlete characteristics will influence mobility performance (Figure 2). Most studies related to mobility performance have focused on the effect of just one or a couple of athlete, wheelchair or athlete-wheelchair characteristics (51,53-55,91). A complicating factor in this research topic is the continuous interaction between the three aspects of mobility performance. For example, when the hand rim diameter is increased, the elbow angle becomes sharper. This change can have an effect on the propulsion technique and forces and, therefore, on mobility performance. When the mobility performance changes it is possible that the risk of an injury also changes. As a consequence of the complicated interaction, it is not really known, and difficult to investigate, which of those characteristics have the most impact on performance. The outcomes on the WMP test were used to make a prediction which wheelchair-athlete characteristics may have an effect on mobility performance and can be used in optimization research (**Chapter 6**).

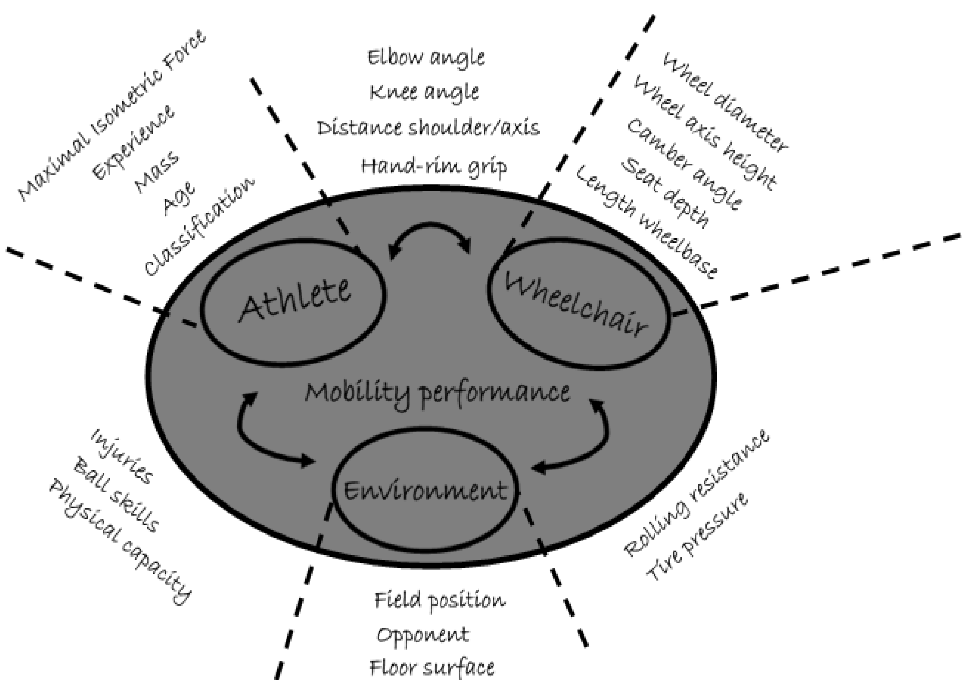


Figure 2. Mobility performance in wheelchair basketball consists of three aspects; the athlete, the wheelchair and the environment. These three aspects continuously interact with each other. To enhance mobility performance, focusing is possible on the different aspects related to mobility performance. Examples of possibilities are described.

To determine which characteristics were the best predictors of mobility performance, a prediction study was performed (**Chapter 6**). Six modifiable characteristics with a potentially predictive value for optimizing mobility performance were derived: the wheelchair characteristics 1) wheel axis height 2) handrim/wheel diameter and 3) camber angle, the wheelchair-athlete characteristics 4) vertical distance between shoulder and rear wheel axis (seat height) and 5) the vertical distance between the front seat and the footrest, and the athlete characteristic 6) maximal isometric force. The findings of the present study provide coaches and biomechanical specialists with statistical findings to determine on which characteristics they can focus best to improve mobility performance. However, for all characteristics mentioned, it should be determined what their optimal individual values are to improve mobility performance.

The selected characteristics were based on statistical associations between mobility performance and the collected characteristics in a cross-sectional study design. Because of this, the name "predictive" is perhaps somewhat optimistic. One can only know whether a characteristic is actually predictive when it is examined in another design, such as an experimental or longitudinal observation research. Despite this limitation, doing such analyses as a starting-point is very valuable. With this insight, coaches and biomechanical specialists are provided with findings to determine which characteristics they could focus on best to optimize mobility performance.

As a first step towards optimizing mobility performance in wheelchair basketball, the WMP test was used to measure the effects of the characteristics seat height, mass and grip on mobility performance. Despite the fact that mass did not emerge as a predictor, mass was taken into account because the lack of clarity in the current literature during wheelchair propulsion on one hand (5,24,73) and by the ongoing discussion among wheelchair technicians on the other hand. Additional grip was not a characteristic in the prediction study but it was plausible that extra grip on the hand rim has an effect on mobility performance. Besides the presented study in **Chapter 7,** testing different wheelchair configurations during field-based testing in a sport-specific setting is very scarce. Mason et al. (54,55) have investigated the effects of a sports-specific range of camber angle and wheel size on maximal effort mobility performance in wheelchair athletes. When focusing on the aim "optimizing mobility performance in wheelchair basketball", further research must focus first on the effect of the characteristics wheel axis height, vertical distance between the front seat and the footrest (bucket seat) and maximal isomeric force.

To investigate these characteristics in practice, a multi-adjustable wheelchair can be an alternative for the method used in **Chapter 7**. The multi-adjustable wheelchair must first be tuned to the settings of their own wheelchair, and from that point, manipulations should be made with the same methodology as used in this study. Note that exact copying of one's own wheelchair settings (weight distribution/dimensions) is difficult. The current available multi-adjustable wheelchairs have limited possibilities and are not adjustable to all athletes. Although during this research period, the possibilities of a multi-adjustable wheelchair have been considered several times, a design for a solid multi-adjustable wheelchair was not found. Further research is necessary to achieve a multi-adjustable wheelchair for research purposes.

The individual perfect sports wheelchair

The results of this thesis can contribute to the knowledge to improve the individual sports wheelchair in wheelchair basketball. The results of the defining and quantifying studies in **Chapter 2** and **3** provides quantification data to determine field-specific requirements of the wheelchair. For example, during offense, the guards and forwards performed longer driving forward activities than during defense. Based on the data in **Chapter 2** and **3** one can state that guards and forwards could benefit more from improved acceleration characteristics of the wheelchair (driving forward) in offensive situations, whereas centers could benefit more from improved stability (standing still). When the responsibilities of a field position are implemented on court, wheelchair changes can influence mobility performance. For example, lower seat heights have been associated with reductions in push frequency, and increasing seat height was reflected in decreased push duration. Therefore, seat height could be a key interface characteristic that may improve the acceleration characteristics of the wheelchair for guards and forwards (58,75,91,94). Furthermore, fore-aft position of the wheelchair-athlete combination influences, as with seat height, the center of gravity and therefore will affect stability (58). Fore-aft position may improve stability characteristics of the wheelchair which could be beneficial for centers.

To increase mobility performance, players have to find the best compromise between the wheelchair adjustments, field position specific requirements and their physical capacity. When it is considered how many compromises are possible to potentially optimize mobility performance, it is clear that further research is required. In the search for the optimal individual sports wheelchair, the described methods and resulting data to define, quantify, simulate and predict mobility performance can be used in the search for optimizing mobility performance in wheelchair basketball. This thesis gives handles to understand the requirements of a match with respect to mobility performance and how to simulate them. With the presented knowledge, extensive and additional research to the effect of wheelchair adjustments can be performed in order to optimize wheelchair basketball performance.

The presented research in **Chapter 7** is only a first exploration of limited adjustments on the wheelchair or athlete (seat height, mass and grip) and further investigation should be performed. It is important to know how (all possible) different wheelchair adjustments influence mobility performance. When the effect of multiple adjustments is known, evidence-based choices can be made to enhance the individual sports wheelchair adjustment. To reach the individual perfect sports wheelchair, the individual environmental requirements such as field position have to be included again. This can be done by individual observation of the mobility performance requirements during match play as described in **Chapter 2** and **3**. It therefore remains a continuous interaction between wheelchair-athlete and environment. For example, a guard performs a lot of driving forward movements and may choose a lower seat height because this gives him an, for example, 8% advantage in speed. It is possible that this leads to a 5% disadvantage in terms of manoeuverability. If the roles on court are known, a conscious decision can be made where to aim for. Unfortunately, based on the results in the current studies it is not yet possible to make such considerations in practice yet. However, the described methods can be used as a starting point for further research about the effect of other adjustments on mobility performance. And on another note, systematic and longitudinal monitoring following the methods developed in the current thesis is instrumental to understand wheelchair basketball athlete and team-specific game play and provides stepping stones to improve mobility, athlete and team performances.

Classification system

In all studies in this thesis, classification is a debated topic. Classification depends on the impairment of an athlete. Wheelchair basketball classification is the system that allows for even levels of competition at team level on the court. Classification plays an important role in the sport as the classification system uses total points of athletes to determine who can be on the court and who not during the game. The individual level of classification is dependent on the limitation-based functional capacity of the athlete (43). Eight classes are defined – ranging from 1.0 to 4.5 – with 1.0 being the class for players with most limiting impairment. This system implies that players with a lower classification perform less compared to players with a higher classification as a consequence of their impairment (and independent of training, skill and talent). The classification system should be reflected in the three performance aspects of athlete performance; game, physical and mobility performance. For all three performance aspects, research was done into the relationship with classification.

The classification system in wheelchair basketball proportionally represents the game performance of the players and it is concluded that that the game performance of elite female wheelchair basketball players depends on functional ability (100,101). For physical performance, Molik et al. (63) suggests that for the aspect anaerobic performance, no significant differences were found across levels 1-2.5 and 3-4.5 and that the functional classification system should be reexamined. On the other hand, Vanlandewijck et al. (102) studied the relationship between game performance and aerobic power and results indicated significant differences in field performance and aerobic power between Class I and the rest of the classes. Furthermore, De Lira et al. (27) found a correlation between classification and aerobic and anaerobic performance parameters of elite wheelchair basketball players. The relationship between classification and physical performance isn't clear in the current literature.

During the Wheelchair Mobility Performance test, the performance time on the WMP test was borderline not significant between low (≤2.5) and high class (≥3.0) players (**Chapter 4**). In a further analysis, when the classification levels were not grouped, no significant differences in performance time were observed between all the classification levels (Figure 3), which is in contrast with previous research (33,35). In a study of Doyle et al. (33), results of a 20m sprint task shows that class 1 players were significantly slower than players of class 2 and 3 and Gil et al. (35) found also significant correlations between sprinting time and classification. Furthermore, besides the outcome time, kinematic outcomes differed as well between low classified players compared to the adjacent higher-class athletes (83,85). During a match, differences between adjacent classes are even less prominent and the results provided arguments for a reduced number of classes in wheelchair basketball. Based on the kinematic outcomes of mobility performance, a single separation between the current class 1-1.5 athletes and the rest would be adequate (83,85). This recommendation is in line with findings of physical and game performance. However, the results of the relationship between mobility performance time and classification in this thesis didn't support to split the classification system in two classes.

The relationship between athlete performance aspects and classification is debatable. Further research into the classification system related to athlete performance, should take the three performance aspects together (physical, game and mobility performance). Furthermore, one of the key-settings in the classification system, is trunk function. Use of the trunk is dependent on the impairment of the athlete (1). The trunk can be used in propulsion and players with more trunk function have a higher classification.

Information about trunk function and movement during games in relation to classification is not available and recommended (1). Measuring trunk motion during matches with inertial sensors, also recommend during quantifying mobility performance, could be used to explore the relationship between athlete performance and the current classification system.

In conclusion, the available literature about the relationship between performance in wheelchair basketball and classification is not clear. The recommendation to split or reduce the existing classes to two classes (83,85,102) is not supported by the results presented in this thesis. The results in this thesis shows no differences between mobility performance in time and classification level.

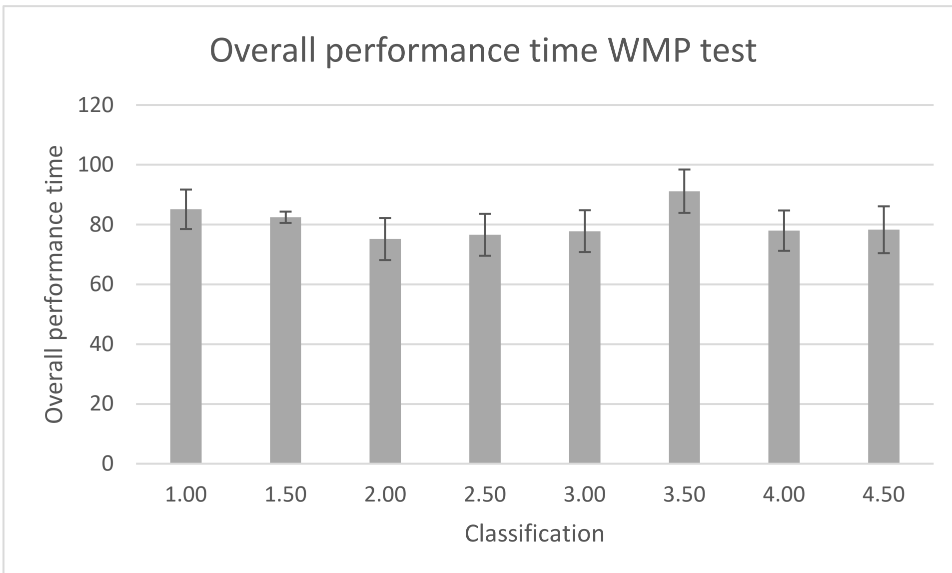


Figure 3. Overall performance time of the Wheelchair Mobility Performance test (n=56) related to classification level. No significant differences were observed between classes.

Practical implications

Nowadays, wheelchair basketball is one of the most popular Paralympic sports. Due to the increased professionalism, there is a need for scientific input. This thesis provides a practical pathway to enhance mobility performance, an important performance determining factor in wheelchair basketball. The results of the observation studies in **Chapters 2** and **3** can be used to design training protocols. The practical implications of the presented results are that wheelchair-handling training can be the same for all field positions in a team irrespective of playing standard. However, the focus on training differs between playing standards. The difference in standard could be used by national basketball coaches to highlight the wheelchair activities of internationals. This could assist teams to aspire a higher playing standard. Specifically, national teams have to focus more on rotational movements and more on the control option “two hands on the rim” within all wheelchair-movement activities. Coaches should advise players to keep moving to respond quickly to changing situations such as rebounds or opponent actions. Nowadays, the design of training practices should focus on rotational movements and one-to-one duels, especially for national standard teams. When all teams train on these aspects, the mobility performance during matches will change. In that case it is important to constantly monitor the mobility performance and react on the changes on court with training protocols and wheelchair adjustments.

The developed WMP test can be used in several ways described in paragraph 8.2. In addition to the added value for the wheelchair basketball practice, the WMP test is also valuable for wheelchair technicians. To date, the wheelchair fitting process for performance optimization is highly dependent on the experience level of athlete and the wheelchair technician. More detailed insight in the relationship between key wheelchair adjustments, such as seat height/position and performance could support athlete and wheelchair expert in their decision making. At the moment, evidence-based knowledge of the relationship between wheelchair adjustments is not available. The WMP test can be used as an objective tool to test the individual influence of adjusting settings on mobility performance in order to search for the optimal (individual) adjustment. It is recommended to develop a platform for wheelchair technicians and coaches where they could share their individual results of the different wheelchair adjustments related to mobility performance. In this way, a valuable database will arise which can be used in the search for optimal wheelchair-athlete adjustments.

The used methods in this thesis are not only useful for wheelchair basketball, the described methods in this thesis for defining, quantifying, simulation and prediction can be used as a pathway in several other domains to enhance or test performance. For each sport or domain there are different requirements. To enhance performance, it is necessary to understand these (sport-)specific requirements. After understanding, it should be explored how to measure these requirements in a valid and reliable way. The same applies for rehabilitation and daily life wheelchair users (25,34). To enhance the optimal adjustment of the wheelchair to the athlete, it is recommended to start with exploring the underlying requirements by means of defining, quantifying, simulating and predicting before starting optimizing.

Conclusions and recommendations

Conclusions

The aims of this thesis were to *define, quantify, simulate, predict* and *optimize* mobility performance in wheelchair basketball. The following can be concluded from the studies described in this thesis:

- *Defining* and *quantification* of mobility performance shows that during wheelchair basketball game there are differences in mobility performance between national and international playing standards. Moreover, offense, defense, and ball possession influenced mobility performance during wheelchair basketball games for the different field positions guard, forward and centre.
- To *simulate* mobility performance in a controllable setting, the field-based Wheelchair Mobility Performance (WMP) test was developed based on the observed data from video-analysis. The test can be used as a valid and reliable test to assess the capacity of mobility performance of elite players in wheelchair basketball and to detect changes in wheelchair adjustments. The performance times on the 3-3-6m sprint, the combination task and the overall performance time are recommended to use in both practice and research.
- Six modifiable wheelchair-athlete characteristics were indicated as a *predictor* for mobility performance which could be carried out both in training (maximal isometric force) and in wheelchair adjustment (wheel axis height, handrim/wheel diameter, camber angle, vertical distance between shoulder and rear wheel axis (seat height) and the vertical distance between the front seat and the footrest.

- In a first exploration about *optimizing* mobility performance it was observed that a 7.5% lower seat height increased mobility performance time and no differences in performance were observed with 7.5% extra mass or additional grip.

Recommendations for further research

- Synchronization between the used time-motion video analysis, inertial sensor method (kinematic outcomes and trunk movement) and an indoor tracking system to determine field position should be explored to gain a full overview of mobility performance during wheelchair basketball game play.
- The validity and reliability of measuring trunk motion with inertial sensors must be examined in order to gain more information about wheelchair-handling during matches. This method can also provide information which could be used to explore the relationship between athlete performance and the current classification system.
- The possibilities to perform computer-controlled video-analyses with algorithms for action/activity recognition must be studied in order to save time and enable direct feedback to players, coaches and trainer.
- The effect of the wheelchair and fitting characteristics wheel axis height, vertical distance between the front seat and the footrest (bucket seat) and the athlete's maximal isometric force on mobility performance in wheelchair basketball should be explored first because they are potentially related with mobility performance.
- The possibilities to develop a platform for wheelchair technicians and coaches where they could share their individual results of the different wheelchair adjustments related to mobility performance should be explored.
- To monitor performance in other (wheelchair court) sports or domains, the described analysis method must be applied.

References

(1) Altmann VC, Hart AL, Vanlandewijck YC, van Limbeek J, van Hooff ML. The impact of trunk impairment on performance of wheelchair activities with a focus on wheelchair court sports: a systematic review. Sports medicine-open 2015;1(1):22.

(2) Atkinson G, Nevill AM. Statistical Methods For Assessing Measurement Error (Reliability) in Variables Relevant to Sports Medicine. Sports Medicine 1998 10;26(4):217-238.

(3) Balsalobre-Fernandez C, Tejero-Gonzalez CM, del Campo-Vecino J, Bavaresco N. The concurrent validity and reliability of a low-cost, high-speed camera-based method for measuring the flight time of vertical jumps. J Strength Cond Res 2014 Feb;28(2):528-533.

(4) Barfield J, Malone LA. Performance Test Differences and Paralympic Team Selection: Pilot Study of the United States National Wheelchair Rugby Team. International Journal of Sports Science & Coaching 2012 12;7(4):715-720.

(5) Beekman CE, Miller-Porter L, Schoneberger M. Energy cost of propulsion in standard and ultralight wheelchairs in people with spinal cord injuries. Phys Ther 1999 Feb;79(2):146-158.

(6) Bergamini E, Morelli F, Marchetti F, Vannozzi G, Polidori L, Paradisi F, et al. Wheelchair propulsion biomechanics in junior basketball players: A method for the evaluation of the efficacy of a specific training program. BioMed research international 2015, http://dx.doi.org/10.1155/2015/275965

(7) Bland JM, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. The lancet 1986;327(8476):307-310.

(8) Bloxham LA, Bell GJ, Bhambhani Y, Steadward RD. Time motion analysis and physiological profile of Canadian World Cup wheelchair basketball players. Sports Medicine, Training and Rehabilitation 2001;10:183-198.

(9) Booka M, Yoneda I, Hashizume T, Lee H, Oku H, Fujisawa S. Effect of Tire Pressure to Physical Workload at Operating a Manual Wheelchair. Stud Health Technol Inform 2015;217:929-934.

(10) Bradley PS, Di Mascio M, Peart D, Olsen P, Sheldon B. High-Intensity Activity Profiles of Elite Soccer Players at Different Performance Levels. Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins) 2010 09;24(9):2343-2351.

(11) Byrnes D, Hedrick B. Comprehensive basketball grading system. In: Hedrick B, Byrnes D, Shaver L, editors. Wheelchair Basketball Washington: Paralyzed Veterans of America; 1994. p. 79.

(12) Cavedon V, Zancanaro C, Milanese C. Physique and performance of young wheelchair basketball players in relation with classification. PloS one 2015;10(11):e0143621.

(13) Chow JW, Millikan TA, Carlton LG, Chae W, Lim Y, Morse MI. Kinematic and Electromyographic Analysis of Wheelchair Propulsion on Ramps of Different Slopes for Young Men With Paraplegia. Archives of Physical Medicine & Rehabilitation 2009 02;90(2):271-278.

(14) Cohen J. Statistical Power Analysis. Current Directions in Psychological Science 1992;1(3):98-101.

(15) Cohen J. Statistical Power Analysis for the Behavioral Sciences. 2nd ed. ed. Hillsdale, NJ: Lawrence Erlbaum; 1988.

(16) Corzillius M, Fortin P, Stucki G. Responsiveness and sensitivity to change of SLE disease activity measures. Lupus 1999;8(8):655-659.

(17) Coutts KD. Drag and sprint performance of wheelchair basketball players. Journal of rehabilitation research and development 1994;31:138-138.

(18) Coutts KD. Dynamics of wheelchair basketball. Med Sci Sports Exerc 1992 Feb;24(2):231-234.

(19) Cowan RE, Nash MS, Collinger JL, Koontz AM, Boninger ML. Impact of surface type, wheelchair weight, and axle position on wheelchair propulsion by novice older adults. Arch Phys Med Rehabil 2009;90(7):1076-1083.

(20) Croft L, Dybrus S, Lenton J, Goosey-Tolfrey V. A Comparison of the Physiological Demands of Wheelchair Basketball and Wheelchair Tennis. International Journal of Sports Physiology & Performance 2010 09;5(3):301-315.

(21) Currell K, Jeukendrup AE. Validity, Reliability and Sensitivity of Measures of Sporting Performance. Sports Medicine 2008 04;38(4):297-316.

(22) de Groot S, Gervais P, Coppoolse J, Natho K, Bhambhani Y, Steadward R, et al. Evaluation of a new basketball wheelchair design. Technology and Disability 2003;15(1):7-18.

(23) de Groot S, Balvers IJM, Kouwenhoven SM, Janssen TWJ. Validity and reliability of tests determining performance-related components of wheelchair basketball. J Sports Sci 2012 05;30(9):879-887.

(24) de Groot S, Vegter RJ, van der Woude, Lucas HV. Effect of wheelchair mass, tire type and tire pressure on physical strain and wheelchair propulsion technique. Med Eng Phys 2013;35(10):1476-1482.

(25) de Groot S, Vegter RJ, Vuijk C, van Dijk F, Plaggenmarsch C, Sloots M, et al. WHEEL-I: development of a wheelchair propulsion laboratory for rehabilitation. J Rehabil Med 2014;46(6):493-503.

(26) de Groot S, Valent LJ, Fickert R, Pluim B, Houdijk H. An Incremental Shuttle Wheel Test for Wheelchair Tennis Players. Int J Sports Physiol Perform 2016;11(8):1111-1114.

(27) De Lira C, Vancini R, Minozzo F, Sousa B, Dubas J, Andrade M, et al. Relationship between aerobic and anaerobic parameters and functional classification in wheelchair basketball players. Scand J Med Sci Sports 2010;20(4):638-643.

(28) de Vet HC, Terwee CB, Mokkink LB, Knol DL. Measurement in medicine: a practical guide. : Cambridge University Press; 2011.

(29) de Witte AMH, Sjaarda SF, Helleman J, Berger MAM, van der Woude LHV, Hoozemans MJM. Sensitivity to change of the field-based Wheelchair Mobility Performance Test in wheelchair basketball. *Under review.*

(30) de Witte AMH, Hoozemans MJM, Berger MAM, van der Slikke, RMA, van der Woude, LHV, Veeger D. Development, construct validity and test–retest reliability of a field-based wheelchair mobility performance test for wheelchair basketball. J Sports Sci 2017;36(1):23-32.

(31) de Witte AMH, Hoozemans MJM, Berger MAM, van der Woude, LHV, Veeger DH. Do field position and playing standard influence athlete performance in wheelchair basketball? J Sports Sci 2016 05;34(9):811-820.

(32) Deyo RA, Centor RM. Assessing the responsiveness of functional scales to clinical change: an analogy to diagnostic test performance. J Chronic Dis 1986;39(11):897-906.

(33) Doyle TL, Davis RW, Humphries B, Dugan EL, Horn BG, Shim JK, et al. Further evidence to change the medical classification system of the National Wheelchair Basketball Association. Adapted Physical Activity Quarterly 2004;21(1):63-70.

(34) Fliess-Douer O, van der Woude, Luc HV, Vanlandewijck YC. Test of Wheeled Mobility (TOWM) and a short wheelie test: a feasibility and validity study. Clin Rehabil 2013 06;27(6):527-537.

(35) Gil SM, Yanci J, Otero M, Olasagasti J, Badiola A, Bidaurrazaga-Letona I, et al. The functional classification and field test performance in wheelchair basketball players. Journal of human kinetics 2015;46(1):219-230.

(36) Gomez MA, Perez J, Molik B, Szyman RJ, Sampaio J. Performance analysis of elite men's and women's wheelchair basketball teams. J Sports Sci 2014 07/03; 2015/03;32(11):1066-1075.

(37) Goosey-Tolfrey V. Physiological Profiles of Elite Wheelchair Basketball Players in Preparation for the 2000 Paralympic Games. Adapted Physical Activity Quarterly 2005 01;22(1):57.

(38) Goosey-Tolfrey V, Leicht C. Field-Based Physiological Testing of Wheelchair Athletes. Sports Medicine 2013 02;43(2):77-91.

(39) Granados C, Yanci J, Badiola A, Iturricastillo A, Otero M, Olasagasti J, et al. Anthropometry and Performance in Wheelchair Basketball. Journal of Strength & Conditioning Research (Lippincott Williams & Wilkins) 2015 07;29(7):1812-1820.

(40) Guo L, Su F, An K. Effect of handrim diameter on manual wheelchair propulsion: mechanical energy and power flow analysis. Clin Biomech 2006;21(2):107-115.

(41) Hopkins W. A new view of statistics: A scale of magnitudes for effect sizes. Retrieved January 2006;9:2014.

(42) Hsiang-Hui W, Hua-Fang L, Ching-Lin H. Reliability, sensitivity to change, and responsiveness of the peabody developmental motor scales-for children with cerebral palsy. Phys Ther 2006;86(10):1351-1359.

(43) International Wheelchair Basketball Federation. Official wheelchair basketball rules 2014. Incheon, Korea: International Wheelchair Basketball Federation; 2014.

(44) Janssen TWJ, Dallmeijer AJ, Veeger D, van der Woude, Luc H.V. Normative values and determinants of physical capacity in individuals with spinal cord injury. Journal of rehabilitation research and development 2002;39(1):29-39.

(45) Krause J, Meyer D, Meyer J. Basketball skills and drills. Champaign, United States of America: Human Kinetics; 2008.

(46) Leboeuf A, Binot S, Weissland T. Influence d'une basse pression des pneumatiques sur les performances chronométrées chez des handibasketteurs. Science & Sports 2017;32(6):327-333.

(47) Liang MH. Longitudinal construct validity: establishment of clinical meaning in patient evaluative instruments. Med Care 2000;38(9):II-84-II-90.

(48) Liang MH, Lew RA, Stucki G, Fortin PR, Daltroy L. Measuring clinically important changes with patient-oriented questionnaires. Med Care 2002 Apr;40(4 Suppl):II45-51.

(49) Lutgendorf M, Mason B, van der Woude L, Goosey-Tolfrey VL. Effect of glove type on wheelchair rugby sports performance. Sports Technology 2009;2(3-4):121-128.

(50) Majaess GG, Kirby RL, Ackroyd-Stolarz SA, Charlebois PB. Influence of seat position on the static and dynamic forward and rear stability of occupied wheelchairs. Arch Phys Med Rehabil 1993;74(9):977-982.

(51) Mason BS, Lemstra M, van der Woude, Lucas HV, Vegter R, Goosey-Tolfrey VL. Influence of wheel configuration on wheelchair basketball performance: Wheel stiffness, tyre type and tyre orientation. Med Eng Phys 2015;37(4):392-399.

(52) Mason B, Porcellato L, van der Woude, Luc HV, Goosey-Tolfrey VL. A qualitative examination of wheelchair configuration for optimal mobility performance in wheelchair sports: a pilot study. J Rehabil Med 2010;42(2):141-149.

(53) Mason B, Van der Woude L, Goosey-Tolfrey V. The Ergonomics of Wheelchair Configuration for Optimal Performance in the Wheelchair Court Sports. Sports Medicine 2013 01;43(1):23-38.

(54) Mason B, van der Woude LHV, Lenton JP, Goosey-Tolfrey V. The Effect of Wheel Size on Mobility Performance in Wheelchair Athletes. Int J Sports Med 2012 10;33(10):807-812.

(55) Mason B, van der Woude LHV, Tolfrey K, Goosey-Tolfrey V. The Effects of Rear-Wheel Camber on Maximal Effort Mobility Performance in Wheelchair Athletes. Int J Sports Med 2012 03;33(3):199-204.

(56) Mason BS, van der Woude LH, Goosey-Tolfrey VL. Influence of glove type on mobility performance for wheelchair rugby players. Am J Phys Med Rehabil 2009 Jul;88(7):559-570.

(57) Mason BS, Van Der Woude LH, Tolfrey K, Lenton JP, Goosey-Tolfrey VL. Effects of wheel and hand-rim size on submaximal propulsion in wheelchair athletes. Med Sci Sports Exerc 2012 Jan;44(1):126-134.

(58) Masse LC, Lamontagne M, O'Riain MD. Biomechanical analysis of wheelchair propulsion for various seating positions. J Rehabil Res Dev 1992 Summer;29(3):12-28.

(59) Mokkink LB, Terwee CB, Patrick DL, Alonso J, Stratford PW, Knol DL, et al. The COSMIN study reached international consensus on taxonomy, terminology, and definitions of measurement properties for health-related patient-reported outcomes. J Clin Epidemiol 2010;63(7):737-745.

(60) Mol E, Vusser B. The development of a Competence-Based Physical Test for Dutch police recruits. Annual Meeting Abstracts of the 51th Meeting of the American College of Sports Medicine, Indianapolis, USA. Med Sci Sports Exercise; 2004.

(61) Molik B, Kosmol A. In search of objective criteria in wheelchair basketball player classification. Vista 2001;99:355-368.

(62) Molik B, Kosmol A, Morgulec-Adamowicz N, Laskin JJ, Jezior T, Patrzalek M. Game efficiency of elite female wheelchair basketball players during world championships (gold cup) 2006. European Journal of Adapted Physical Activity 2009;2(2):26-38.

(63) Molik B, Laskin JJ, Kosmol A, Skucas K, Bida U. Relationship Between Functional Classification Levels and Anaerobic Performance of Wheelchair Basketball Athletes. Research Quarterly for Exercise & Sport 2010 03;81(1):69-73.

(64) O'Dell MW, Kim G, Finnen LR, Polistena C. Clinical implications of using the arm motor ability test in stroke rehabilitation. Arch Phys Med Rehabil 2011;92(5):830-836.

(65) Ortega E, Cardenas D, Sainz de Baranda MP, Palao JM. Differences in competitive participation according to player's position in formative basketball. Journal of Human Movement Sciences 2006;50(2):103-122.

(66) Pallant J. SPSS Survival manual. second edition ed.: New York; 2005.

(67) Pardasaney PK, Latham NK, Jette AM, Wagenaar RC, Ni P, Slavin MD, et al. Sensitivity to change and responsiveness of four balance measures for community-dwelling older adults. Phys Ther 2012;92(3):388-397.

(68) Rhodes J, Mason B, Perrat B, Smith M, Goosey-Tolfrey V. The validity and reliability of a novel indoor player tracking system for use within wheelchair court sports. J Sports Sci 2014;32(17):1639-1647.

(69) Rice I, Dysterheft J, Bleakney A, Cooper R. The influence of glove type on simulated wheelchair racing propulsion: a pilot study. Int J Sports Med 2016;37(01):30-35.

(70) Rodriguez-Alonso M, Fernandez-Garcia B, Perez-Landaluce J, Terrados N. Blood lactate and heart rate during national and international women's basketball. J Sports Med Phys Fitness 2003 Dec;43(4):432-436.

(71) Rose LH. The basketball handbook. Champaign, IL: Human Kinetics; 2004.

(72) Rowe P, Boutmans J. Basketbal-Theorie en Praktijk. status: published 1997.

(73) Sagawa Y, Watelain E, Lepoutre F, Thevenon A. Effects of wheelchair mass on the physiologic responses, perception of exertion, and performance during various simulated daily tasks. Arch Phys Med Rehabil 2010;91(8):1248-1254.

(74) Salas E, Dickinson TL, Converse SA, Tannenbaum SI. Toward an understanding of team performance and training. : Ablex Publishing; 1992.

(75) Samuelsson KA, Tropp H, Nylander E, Gerdle B. The effect of rear-wheel position on seating ergonomics and mobility efficiency in wheelchair users with spinal cord injuries: a pilot study. J Rehabil Res Dev 2004 Jan-Feb;41(1):65-74.

(76) Schmid A, Huonker M, Stober P, Barturen JM, Schmidt-Trucksaess A, Duerr H, et al. Physical performance and cardiovascular and metabolic adaptation of elite female wheelchair basketball players in wheelchair ergometry and in competition. American Journal of Physical Medicine & Rehabilitation 1998 Nov;77(6):527-533.

(77) Shrout PE, Fleiss JL. Intraclass correlations: uses in assessing rater reliability. Psychol Bull 1979;86(2):420-428.

(78) Skucas K, Stonkus S, Molik B, Skucas V. Evaluation of wheelchair basketball s kill performance of wheelchair basketball players in different game positions. Education Physical Training Sport 2009 11;75(4):65-69.

(79) Sporner ML, Grindle GG, Kelleher A, Teodorski EE, Cooper R, Cooper RA. Quantification of Activity During Wheelchair Basketball and Rugby at the National Veterans Wheelchair Games: A Pilot Study. Prosthetics and Orthotics International 2009 September 01;33(3):210-217.

(80) Titmuss D. Wheelchair basketball: transition from defense to offense. Coaches - fundamentals and youth basketball 2005;13:15-17.

(81) van der Scheer, Jan W, de Groot S, Vegter RJ, Veeger DH, Van der Woude, Lucas HV. Can a 15m-overground wheelchair sprint be used to assess wheelchair-specific anaerobic work capacity? Med Eng Phys 2014;36(4):432-438.

(82) van der Slikke, Rienk MA. Out of the lab, on to the court; wheelchair mobility performance quantified. 2018.

(83) van der Slikke, Rienk MA, Bregman DJ, Berger MA, de Witte AMH, Veeger D(H.EJ.). The future of classification in wheelchair sports; can data science and technological advancement offer an alternative

point of view? International journal of sports physiology and performance 2017:1-25. https://doi.org/10.1123/ijspp.2017-0326

(84) van der Slikke, Rienk MA, de Witte AMH, Berger MAM, Bregman D, Veeger DH. Wheelchair Mobility Performance enhancement by changing wheelchair properties; what is the effect of grip, seat height and mass? International journal of sports physiology and performance 2018. *Accepted.*

(85) van der Slikke R, Berger M, Bregman D. Wheelchair mobility performance only supports the use of two classes in wheelchair basketball. ISBS Proceedings Archive 2017;35(1):254.

(86) van Der Slikke R, Berger M, Bregman D, Lagerberg A, Veeger H. Opportunities for measuring wheelchair kinematics in match settings; reliability of a three inertial sensor configuration. J Biomech 2015;48(12):3398-3405.

(87) van der Slikke R, Berger M, Bregman D, Veeger H. From big data to rich data: The key features of athlete wheelchair mobility performance. J Biomech 2016;49(14):3340-3346.

(88) van der Slikke R, Mason BS, Berger M, Goosey-Tolfrey VL. Speed profiles in wheelchair court sports; comparison of two methods for measuring wheelchair mobility performance. J Biomech 2017;65:221-225.

(89) van der Slikke R, Berger M, Bregman D, Veeger H., Estimated athlete's basketball match performance based on measurement of wheelchair kinematics using inertial sensors. Glasgow, UK: International Society of Biomechanics.

(90) van der Woude L, Veeger D, Rozendal R, van Ingen Schenau G, Rooth F, Van Nierop P. Wheelchair racing: effects of rim diameter and speed on physiology and technique. Med Sci Sports Exerc 1988;20(8):492-500.

(91) van der Woude LHV, Bouw A, van Wegen J, van As H, Veeger D, de Groot S. Seat height: effects on submaximal hand rim wheelchair performance during spinal cord injury rehabilitation. J Rehabil Med 2009 Feb;41(3):143-149.

(92) van der Woude LHV, Veeger DJ, Rozendal RH, Sargeant TJ. Seat height in handrim wheelchair propulsion. J Rehabil Res Dev 1989 Fall;26(4):31-50.

(93) van der Woude LHV, Veeger HEJ, Dallmeijer AJ, Janssen TWJ, Rozendaal LA. Biomechanics and physiology in active manual wheelchair propulsion1. Med Eng Phys 2001 12;23(10):713-733.

(94) van der Woude LHV, Veeger DEJ, Rozendal RH. Ergonomics of Wheelchair Design: A Prerequisite for Optimum Wheeling Conditions. Adapted Physical Activity Quarterly 1989 04;6(2):109-132.

(95) van Strien J. Handvoorkeur en taaldominantie. Neuropraxis 2001;5(2):30-35.

(96) Vanlandewijck Y, Theisen D, Daly D. Wheelchair Propulsion Biomechanics: Implications for Wheelchair Sports. Sports Medicine 2001 03;31(5):339-367.

(97) Vanlandewijck Y, Daly D, Spaepen A, Theisen D, Pétré L. Biomechanics in handrim wheelchair propulsion:-wheelchair-user interface adjustment for basketball. Education, physical training, sport 1999;33(4):50-53.

(98) Vanlandewijck YC, Daly DJ, Theisen DM. Field test evaluation of aerobic, anaerobic, and wheelchair basketball skill performances. Int J Sports Med 1999 11;20(8):548-554.

(99) Vanlandewijck YC, Spaepen AJ, Lysens RJ. Wheelchair propulsion: functional ability dependent factors in wheelchair basketball players. Scand J Rehabil Med 1994 Mar;26(1):37-48.

(100) Vanlandewijck YC, Evaggelinou C, Daly DD, van Houtte S, Verellen J, Aspeslagh V, et al. Proportionality in Wheelchair Basketball Classification. Adapted Physical Activity Quarterly 2003 10;20(4):369-380.

(101) Vanlandewijck YC, Evaggelinou C, Daly DJ, Verellen J, Van Houtte S, Aspeslagh V, et al. The relationship between functional potential and field performance in elite female wheelchair basketball players. J Sports Sci 2004 07;22(7):668-675.

(102) Vanlandewijck YC, Spaepen AJ, Lysens RJ. Relationship between the level of physical impairment and sports performance in elite wheelchair.. Adapted Physical Activity Quarterly 1995 04;12(2):139-150.

(103) Veeger TT, De Witte AMH, Berger MA, Van Der Slikke, RMA, Veeger DH, Hoozemans MJ. Improving Mobility Performance in Wheelchair Basketball. J Sport Rehab 2017:1-26.

(104) Walsh CM, Marchiori GE, Steadward RD. Effect of seat position on maximal linear velocity in wheelchair sprinting. Can J Appl Sport Sci 1986 Dec;11(4):186-190.

(105) Wang YT, Chen S, Limroongreungrat W, Change L. Contributions of selected fundamental factors to wheelchair basketball performance. Med Sci Sports Exerc 2005 01;37(1):130-137.

(106) Wootten M, Wootten J. Coaching basketball succesfully. 3rd revised edition ed. Champaign, IL: Human Kinetics; 2012.

(107) Yanci J, Granados C, Otero M, Badiola A, Olasagasti J, Bidaurrazaga-Letona I, et al. Sprint, agility, strength and endurance capacity in wheelchair basketball players. Biology of Sport 2015 01;32(1):71-78.

(108) Yilla AB, Sherrill C. Validating the Beck battery of quad rugby skill tests. Adapted Physical Activity Quarterly 1998;15:155-167.

Summary

During a wheelchair basketball game, the interaction between wheelchair and athlete has an impact on the performance of the athlete. Optimal interaction is therefore extremely important because it may be decisive for winning or losing the game. But what is optimal interaction and how to achieve it? A basketball sports wheelchair can be adjusted in many ways and all adjustments have a potential effect on the interaction and therefore on the performance. In the search for the optimal adjustment of the wheelchair to the athlete, detailed information about all wheelchair movements and athlete actions during a wheelchair basketball game is required. These wheelchair movements and athlete actions are called *mobility performance*. The research in this thesis describes the way to model mobility performance by means of *defining, quantifying, simulating, predicting* and *optimizing* mobility performance (**Chapter 1**).

The first aim was to *define* mobility performance in wheelchair basketball (**Chapter 2**). Based on interviews with Dutch wheelchair basketball coaches from the first division and the national team, clearly described activities of the wheelchair and the way it is handled by an athlete during wheelchair basketball were obtained.

The second aim was to *quantify* wheelchair basketball mobility performance during a game (**Chapters 2** & **3**). The defined wheelchair-athlete activities were the basis for the assessment of athlete and wheelchair activities by systematic observation from video footage. Fifty-six elite wheelchair basketball players were observed during matches. Interesting differences were found between playing standards, field position and ball possession. For instance, players at a national standard drove more forward and started more often driving forward during a match while the mean activity duration for these driving forward activities was longer than for players playing at an international standard. Moreover, national standard players performed fewer rotational movements and started less often with the rotational movements while the mean activity duration for a single rotation was shorter than for international standard players. Offense, defense and ball possession influenced mobility performance for the different field positions. During offense, the guards and forwards performed longer driving forward than during defense. Without ball, centers performed driving forward longer than with ball possession.

The third aim was to *simulate* mobility performance in wheelchair basketball. Based on the quantification data, the Wheelchair Mobility Performance (WMP) test was developed (**Chapter 4**). The test can be used as a standardized mobility performance test to validly and reliably assess the mobility performance capacity of elite wheelchair basketball players. Furthermore, the WMP test has the ability to measure changes in mobility performance when substantial manipulations were applied to the wheelchair (**Chapter 5**).

The fourth aim was to *predict* mobility performance (**Chapter 6**). The wheelchair characteristics wheel axis height, hand rim diameter, camber angle, and the vertical distance between shoulder and rear wheel axis (seat height) were positively associated (increased performance) with mobility performance, while the vertical distance between the front seat height and the footrest were negatively associated

(decreased performance). Furthermore, the athlete characteristics classification, experience and maximal isometric force were also positively associated with mobility performance.

The fifth aim of the research was to *optimize* mobility performance (**Chapter 7**). As a first step towards optimizing mobility performance in wheelchair basketball, the WMP test was used to measure the effects of the characteristics seat height, mass and grip on mobility performance. For both high and low classification players, a lower seat height resulted in an increased performance while extra mass and glove use did not led to a significant change in mobility performance. Further research must focus first on the effect of the modifiable characteristics wheel axis height, the vertical distance between the front seat and the footrest (bucket seat) and the maximal isomeric force because these may also have a potential effect on mobility performance (**Chapter 6**).

The described method, i.e. defining, quantifying, simulating and predicting can be used in several other domains to gain an extensive understanding of (sport)-specific requirements which then can be used for optimizing the performance in the domain under study.

About the author

Annemarie de Witte was born on the 7th of December 1985 in Eindhoven, the Netherlands. In 2004 she graduated from secondary school. Annemarie started her Bachelor of Physical Education at the Hague University of Applied sciences. She obtained her degree in 2009 and continued her interest in sports and exercise at the Faculty of Human Movement Sciences at the Vrije Universiteit Amsterdam. She received her Master degree in 2011 with the specialization Sport. During her master, she got the chance to become a lecturer at The Hague University for the courses Human Movement Analysis and Research.

In September 2013, Annemarie got the opportunity to start with the PhD-research of the current thesis at the Hague University of Applied sciences in collaboration with i.a. the Vrije Universiteit Amsterdam. This resulted in a combined position of lecturer and PhD-student.

Contact details

Email: annemariedewitte@hotmail.com

Phone: +31 6 21691636

Publications

Publication as part of this thesis

Chapter 2:

de Witte, A. M. H., Hoozemans, M. J. M., Berger, M. A. M., van der Woude, L. H. V. & Veeger, H. E. J. (2016). Do field position and playing standard influence athlete performance in wheelchair basketball? *Journal of Sports Sciences, 34*(9), 811-820.

Chapter 3:

de Witte, A. M. H., Berger, M. A. M., Hoozemans, M. J. M., Veeger, H. E. J., & van der Woude, L. H. V. (2017). Effects of offense, defense and ball possession on mobility performance in wheelchair basketball. *Adapted Physical Activity Quarterly*, 34(4), 382-400.

Chapter 4:

de Witte, A. M. H., Hoozemans, M. J. M., Berger, M. A. M., van der Slikke, R. M. A., van der Woude, L. H. V., & Veeger, H. E. J. (2017). Development, construct validity, and test-retest reliability of a field-based wheelchair mobility performance test. *Journal of Sports Sciences, 36*(1), 23-32.

Chapter 5:

de Witte, A. M. H., Sjaarda, S. F. , Helleman, J., Berger, M. A. M., van der Woude, L. H. V., & Hoozemans, M. J. M. (2018). Sensitivity to change of the field-based Wheelchair Mobility Performance Test in wheelchair basketball players. *Under review.*

Chapter 6:

Veeger, T.J., **de Witte, A. M. H.**, Berger, M. A. M., van der Slikke, R. M. A., Veeger, H. E .J., & Hoozemans, M. J .M. (2017). Improving mobility performance in wheelchair basketball. *Journal of Sport Rehabilitation.* https://doi.org/10.1123/jsr.2017-0142 [Epub ahead of print]

Chapter 7:

de Witte, A. M. H., van der Slikke, R.M.A., Berger, M. A. M., Hoozemans, M. J. M., Veeger, H. E. J., & van der Woude, L.H.V. (2018). Effects of seat height, mass and additional grip on a field-based wheelchair basketball mobility performance test. *Under review.*

Other related publications

Articles in International Journals

R.M.A van der Slikke, M.A.M. Berger, D.J.J. Bregman, **A.M.H. de Witte**, H.E.J. Veeger (2017). The future of classification in wheelchair sports; can data science and technological advancement offer an alternative point of view. *International Journal of Sports Physiology and Performance.* https://doi.org/10.1123/ijspp.2017-0326 [Epub ahead of print]

Slikke, van der, R. M. A., de Witte, A.M.H., Berger, M. A. M., Bregman, D. J. J. & Veeger, H. E. J. (2018?). Wheelchair Mobility Performance enhancement by changing wheelchair properties; what is the effect of grip, seat height and mass? *International Journal of Sports Physiology and Performance.* Conditionally accepted.

Articles in Dutch Journals

Annemarie de Witte, Rienk van der Slikke & Monique Berger (2015). 'Op weg naar de perfecte sportrolstoel en naar goud in Rio?' *Sportgericht*, 2015, 69 (6), 6-10

Annemarie de Witte, Rienk van der Slikke, Marco Hoozemans, Monique Berger, Daan Bregman, DirkJan Veeger & Luc van der Woude (2016). De perfecte sportrolstoel in rolstoelbasketbal; op zoek naar de optimale afstemming van rolstoel en atleet. *Human Factors, 41*(3), 27-31

Conference proceedings

de Witte AMH, van der Slikke RMA, Hoozemans MJM, Berger MAM, van der Woude LHV & Veeger HEJ (2014). *Rehabilitation; mobility, exercise & sports.* Assessment of wheelchair-athlete interaction in wheelchair basketball. Poster presented at 5th international State-of-the-Art Congress, Groningen, 23-25 April 2014 (pp. 305-307). Groningen: Wenckebach Instituut

de Witte, A., Hoozemans, M., Berger, M., van der Woude, L. & Veeger, H. (2015). *Book of abstracts.* Differences between ball possession on wheelchair-athlete activities in relation to field position in wheelchair basketball. Paper presented at 20TH Annual congress of the European college of sport science, Malmo, 24-27 June 2015 (p. 194). Cologne: SporTools GmbH

Witte, A.M.H. **de**, Hoozemans, M.J.M., Berger M.A.M., Woude, L.H.V. van der & Veeger, H.E.J.(2015). Differences between offence and defence during wheelchair-athlete activities in relation to field position in elite wheelchair basketball. Paper presented at VISTA, Girona, 7-10 October 2015.

Witte, A.M.H. **de,** Berger, M.A.M., Hoozemans, M.J.M., Woude, L.H.V. van der & Veeger, H.E.J. (2015). Development of a field-based mobility test in wheelchair basketball. Poster presented at VISTA, Girona, 7-10 October 2015.

Witte, A.M.H. de, Hoozemans, M.J.M., Berger M.A.M., Woude, L.H.V. van der & Veeger, H.E.J. (2016). Difference between ball possession and game states in relation to field position in wheelchair basketball. Paper presented at Science and Engineering Conference on Sports Innovation, Amsterdam, 8 April 2016.

de Witte, Annemarie M.H., Berger, Monique A.M., Hoozemans, Marco J.M., van der Slikke, Rienk M.A., van der Woude, Lucas H.V., & Veeger, Dirkjan (H.E.J.), (2016). Trunk flexion during the first pushes of a 12 meter sprint in wheelchair basketball. Paper presented at ICSEMIS, Santos, 1-4 September 2016.

Roovers, B., Zanders, R.J.M., **Witte, A.M.H. de**, Berger M.A.M., (2016). Development of a system for measuring weight distribution during measurement of isometric forces and range of motion of wheelchair athletes. Poster presented at ICSEMIS, Santos, 1-4 September 2016.

Witte, A.M.H. de, Berger M.A.M., & van der Slikke, R.M.A. De perfecte sportrolstoel. Paper presented at Bessenap, Amsterdam, 10 juni 2016.

Witte, A.M.H. de, Berger M.A.M., Slikke, R.M.A. van der, Hoozemans, M.J.M., Woude, L.H.V. van der & Veeger, H.E.J., De perfecte sportrolstoel, Paper presented at Dag van het Sportonderzoek, Groningen, 9 november 2016.

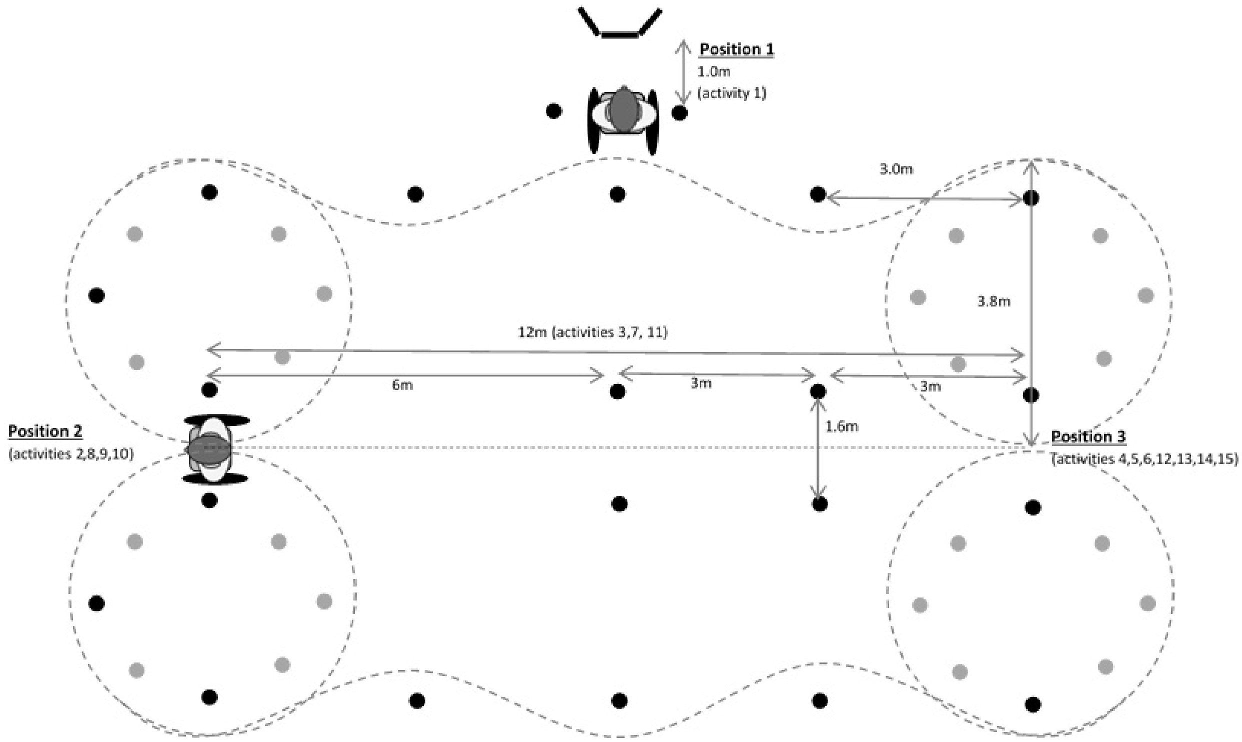
Berger, M.A.M., **Witte, A.M.H**. **de,** Hoozemans, M.J.M., Slikke, R.M.A. van der, Veeger, H.E.J, & Woude, L.H.V. van der (2017). Validity, reliability and sensitivity to change of the basketball wheelchair mobility performance test. Poster presented at VISTA, Toronto, 20-23 September 2017.

Other media

NPO Radio 1, website: http://www.nporadio1.nl/nieuws-en-co/onderwerpen/372880-de-ideale-rolstoel-voor-een-paralympische-basketballer
1 september 2016 17.50 uur

Vernieuwing op wieltjes, EOS maandblad voor wetenschap, nr. 9, september 2016 http://eoswetenschap.eu/artikel/vernieuwing-op-wieltjes

Appendix I: Wheelchair Mobility Performance test



Set up of the gym for the wheelchair mobility performance test.

The measurement outcome of the test is time (s). The time is recorded for each activity and the sum of the 15 separate activities is overall performance time. Time is recorded based on video-analysis and time started when the wheelchair started to move and stopped when the wheelchair was stationary. For each starting and stopping position the wheel axis should coincided with the pawns. All ball-handling moves performed during the test had to be in accordance with the IWBF rules for dribbling.

Activity 1: Tik-Tak box

Athlete starts on position 1, between two pawns 1 meter from the tik-tak box. The athlete has to perform 3 short movements. On the start signal, the athlete drives forward and makes a collision with the tik-tak box at the left side and drives backward back to the pawns. The athlete repeats the movement but makes a collision with the tik-tak box in the middle and the third time the athlete makes a collision with the right side of the tik-tak box. The performance time of test 1 is the time necessary to complete the three movements.

Activity 2: 180° Turn on the spot (left)

Athlete moves to the start position (position 2) while facing outwards (figure 2). Athlete starts from a stationary position with their wheel axis between the pawns). After the start signal the athlete makes a half turn on the spot (180 degrees) to the left.

Activity 3: 12 meter sprint

The athlete stays on the same place and is now facing inwards due to activity 2. The athlete starts from standstill and sprint as quick as possible 12 meter. The athlete has to stop the wheelchair on the 12 meter between the pawns.

Activity 4: 12 meter rotation (right)
The athlete is facing outwards now at position 3. The athlete starts from standstill and performs a curve of 12 meter to the left (radius 1.9m) as quickly as possible. The athlete has to stop the wheelchair on position 3.

Activity 5: 12 meter rotation (left)
The athlete performs the same activity as activity 4, however, this time to the left direction.

Activity 6: 180° Turn on the spot (right)
The athlete performs the same activity as activity 2, however, this time to the right direction. In other words, on position 3 the athlete changes from facing outwards to inwards.

Activity 7: 3-3-6m sprint
The athlete performs a 12 meter sprint forward with full stops at 3, 6 and 12 meters from position 3 back to position 2. Starting and stopping should be performed as quickly as possible. The stops are assessed visually by the trainer/coach. The rotation of the wheels must come to a complete standstill.

Activity 8: 3-3-6m rotation (left)
The athlete is back on position 2 and facing outwards. The athlete starts from standstill and performs a curve of 12 meter to the left as quickly as possible with stops at a quarter circle (3 meter), a half circle (6 meter) and then back to the starting position.

Activity 9: 3-3-6m rotation (right)
The athlete performs the same activity as activity 6, however, but this time to the right.

Activity 10: 90°- 90° turn on the spot with stop (left)
The athlete performs a half turn on the spot (180 degrees) to the left with a stop at 90°. On position 2 the athlete changes facing outwards to inwards.

Activity 11: 12 meter dribble
The athlete performs a 12 meter sprint while dribbling the ball and stops at 12 meter. The athlete moves from position 2 to 3.

Activity 12: 12 meter rotation dribble (right)

The athlete performs a curve of 12 meter to the right while dribbling the ball. The athlete has to stop at position 3.

Activity 13: 12 meter rotation dribble (left)

The athlete performs a curve of 12 meter to the left while dribbling the ball. The athlete has to stop at position 3 and is facing outwards.

Activity 14: 90°- 90° turn on the spot with stop (right)

The athlete performs the same activity as activity 10 on position 3 (facing outwards to inwards), however, this time to the right direction.

Activity 15: Combination

The athlete performs a 12 meter sprint (to position 2), a turn right or left, a 12 meter slalom and a turn back to position 3. All activities are performed in succession.