J Rehabil Med 2010; 42: 141–149

ORIGINAL REPORT

A QUALITATIVE EXAMINATION OF WHEELCHAIR CONFIGURATION FOR OPTIMAL MOBILITY PERFORMANCE IN WHEELCHAIR SPORTS: A PILOT STUDY

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Objective: **To examine wheelchair athletes' perceptions of wheelchair configuration in relation to aspects of mobility performance.**
Methods: **Nine elite wheelchair athletes from wheelchair basketball, wheelchair rugby and wheelchair tennis were interviewed using a semi-structured format. Interview transcripts were analysed using an Interpretative Phenomenological Analysis, whereby emergent themes with common connections were identified and clustered into 3 superordinate themes: (*i*) performance indicators; (*ii*) principal areas of wheelchair configuration; and (*iii*) supplementary areas of wheelchair configuration.**
Results: **Participants revealed that stability was the most important contributor towards successful performance. Whilst there was some agreement amongst participants on how manipulating most areas of wheelchair configuration influenced performance, opinions were divided as to whether camber had a positive or negative effect on straight line performance.**
Conclusion: **Experienced athletes seemed to display a good understanding of how modifying wheelchair configurations can affect sports performance, yet the methods offered for identifying optimal settings were extremely subjective. Therefore, future quantitative research into specific areas of configuration is imperative to identify these optimums and to inform athletes about the decisions they make when configuring a new sports wheelchair.**

Key words: interviews; wheelchairs; sports equipment; sports performance.

J Rehabil Med 2010; 42: 141–149

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Submitted March 16, 2009; accepted September 29, 2009

INTRODUCTION

Wheelchairs used for the court sports of wheelchair basketball (WCB), wheelchair rugby (WCR) and wheelchair tennis (WCT) have undergone major developments over recent years in terms of their design (1, 2). In conjunction with the improved physical conditioning of wheelchair athletes, these developments in design are thought to have contributed to improved performance levels (1–3).

Extensive research has been conducted into the ergonomics of wheelchair configurations for daily life wheelchair users (4–18, 21–25). These studies have focused predominantly on the more prominent areas of wheelchair configuration, including the seat (4–18), main wheels (17–20) and hand rims (21–25).

The effects of manipulating areas of wheelchair configuration on aspects of mobility performance specific to the wheelchair court sports has received limited research attention (19, 20). Subsequently, very little is known about the influence that specific areas of wheelchair configuration have on performance. When it is considered how large a phenomenon wheelchair configuration is, due to the large number of different characteristics that can be manipulated and potentially contribute towards performance (Fig. 1), it is clear that further research is required.

Wheelchair users have often been the subject of the quantitative investigations into wheelchair configuration. However, to the authors' knowledge, no previous studies have explored the opinions of these users. Kratz et al. (26) emphasized the need for adaptive equipment in disability sport and demonstrated the value of gaining users' experiences in this process. By adopting a qualitative approach and gauging the opinions of experienced athletes who have been through the chair configuration process on numerous previous occasions a better understanding could be developed about this phenomenon, through the more holistic appraisal this approach can provide (27).

The purpose of the current study was to investigate how elite wheelchair athletes perceive certain areas of wheelchair configuration to impact on aspects of mobility performance. It is anticipated that this would help to identify areas of wheelchair configuration that would benefit from future research in order to inform athletes about the choices they make when configuring a new sports wheelchair and, ultimately, to improve the ergonomics of wheelchair propulsion.

METHODS

Participants

Purposive sampling was employed to recruit 9 male wheelchair athletes (39 (standard deviation (SD) 5) years) from WCB ($n=3$), WCR ($n=3$) and WCT ($n=3$), who were interviewed for the current

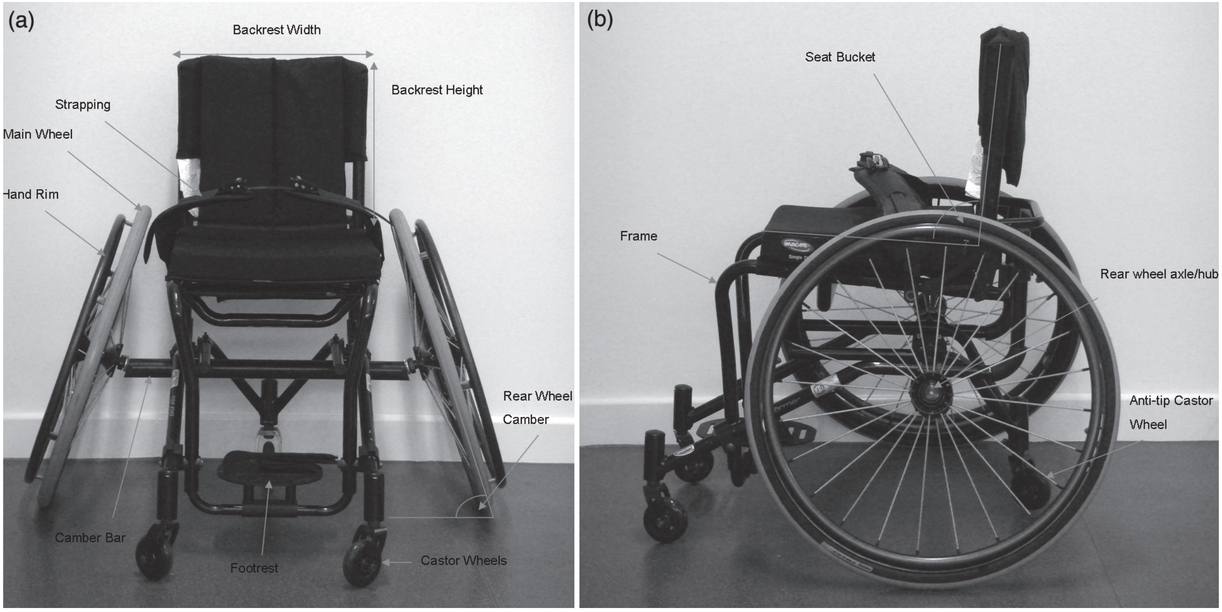

Fig. 1. (a) Front on and (b) side on view of a sports wheelchair typically used for wheelchair basketball and wheelchair tennis, illustrating some of the areas of configuration that can be manipulated.

investigation. To ensure participants had a strong understanding of wheelchair configuration, participants were required to have more than 10 years playing experience at an international level to be included in the current investigation. Given that wheelchair configurations can be dependent on the player's functional ability and role on court (28), it was imperative that a range of athletes with differing classifications and impairment levels were included in order to obtain a representative sample (Table I). In addition to this, participants were also divided into 2 "disability groups" and were categorized as either high-point (least impaired (HP)) or low-point (most impaired (LP)) players. HP participants had a classification of ≥ 3.0 in WCB and ≥ 2.0 in WCR. For WCT, participants who competed in the "open division" were classed as HP and those who competed in the "quadriplegic" were classed as LP.

Table I. *Participant's characteristics and current sports chair configurations*

Sport	Age, years	Level/world ranking	Classification/ disability group	Wheel size, inches	Camber, degrees
WCB	36	International	4.0/HP	27	15
WCB	42	International	1.5/LP	25	18
WCB	44	International	1.0/LP	25	18
WCR	31	International	3.5/HP	25	18
WCR	34	International	2.5/HP	25	18
WCR	36	International	1.5/LP	24	18
WCT	41	Top 10	Amputee/HP	26	24
WCT	46	Top 25	T6 SCI/HP	25	20
WCT	46	Top 10	T4 SCI (C7/8 Hemiplegia)/LP	26	20

WCB classified by International Wheelchair Basketball Federation (IWBF); WCR classified by International Wheelchair Rugby Federation (IWRF).
HP: high point player; LP: low-point player; SCI: spinal cord injury; WCB: wheelchair basketball; WCR: wheelchair rugby; WCT: wheelchair tennis.

Procedure

Semi-structured interviews were conducted for the current investigation, due to the greater flexibility they allow for probing areas in greater detail. Typically participants were questioned on mobility performance in their sport: "Which areas of on-court mobility do you feel is most important to your performance?" and then on how they felt that altering chair configuration could influence performance: "Have you experimented with different sized wheels and if so, how do you think these have influenced areas of your performance?" Following a successful pilot interview to test the validity of the questioning, all participants were interviewed at a time and location that was convenient for them. Anonymity and confidentiality were guaranteed to participants, who possessed the right to terminate the interview at any stage without further questioning. All interviews were recorded using a Sony ICD-SX57 Digital Voice Recorder (Sony, San Diego, CA, USA).

Analysis

Dialogue from the interviews was transcribed into word processing format and analysed using an Interpretative Phenomenological Analysis (IPA). This method of analysis was selected to accommodate the small sample size in the current investigation and because of the subsequent detail that IPA can construct about a phenomenon (27, 31, 32). The fact that this analysis was predominantly inductive was also a contributing factor to the use of IPA, as no predetermined framework had been created prior to interviewing (33).

Interpretations were made on any themes present in each interview transcript and were then coded with headings and annotations (29, 31). Member feedback was also sought from 2 randomly selected participants in order to improve validity (30, 31). This involved a copy of the coded transcripts being sent to the participants to ensure that interpretations gave an accurate reflection of what had been said, and allowed them the opportunity to alter or add any information (34). Two further investigators were also involved in the analysis process. One investigator was very experienced in qualitative research, whilst the other had a substantial knowledge of wheelchair sports. All coded transcripts and interpretations were verified by these investigators in order to further enhance validity by guarding against researcher bias (35).

The initial list of themes that emerged from the interviews were then further analysed and clustered into a smaller number of themes with common connections (32). Each cluster was then titled with a superordinate theme based on the nature and content of the subordinate themes present.

RESULTS

Data from the current investigation was grouped into 3 superordinate themes: (*i*) performance indicators; (*ii*) "principal" areas of wheelchair configuration; and (*iii*) "supplementary" areas of wheelchair configuration. A series of quotes from the transcripts were included to support any interpretations and were labelled by the sport and classification level of the participants to assist with any inferences.

Theme (i): Performance indicators

Establishing which areas were deemed to lead to successful mobility performance in wheelchair court sports was essential before specific areas of configuration were discussed. Participants from all sports repeatedly identified 4 important areas that they felt were paramount to successful sports performance: stability, initial acceleration, manoeuvrability and sprinting.

Stability. The majority of participants acknowledged the need for stability in their chairs as the principal element of performance. It was frequently mentioned that, without this, all of the other areas of mobility performance could become negatively affected.

Initial acceleration. In terms of wheelchair mobility, all participants from WCB and WCR felt that acceleration over the first couple of pushes was the most important indicator of successful performance:

> "….you are going from a starting position a lot because you are getting stopped, so you have got to be able to start again quickly…." *WCB – LP*

Within WCB and WCR, LP players seemed to place further emphasis on the need for rapid initial acceleration in order for them to gain dominant positions on the court and to compete with HP players.

Although initial acceleration was also important for WCT players, it seemed to be slightly less vital from a standstill for these individuals. Instead, initial acceleration was revealed to be more important over the first 2 pushes from a rolling start as a reaction to an opponent's shot.

Manoeuvrability. Alternatively, participants from WCT valued the ability to turn as the most important area of mobility performance for their sport, regardless of disability, due to the frequency with which this movement is performed.

There seemed to be a slight discrepancy surrounding the need for manoeuvrability amongst disability groups within WCB and WCR. HP players rated manoeuvrability far higher than LP players due to their differing roles on court:

> "….as a low pointer, twisting and turning is not that important, because it is rare that I am going to have the ball and that I am going to have break press." *WCR – LP*

Sprinting. The ability to reach high top-end speeds was a desirable aspect of performance for all sports, but was not viewed as such a high priority. It was suggested that the distances you cover in a straight line are not sufficient to reach top speeds. Linear propulsion was also thought to be limited, particularly in WCB and WCR due to the multidirectional nature of the movements involved.

Theme (ii): Principal areas of wheelchair configuration

Participants' responses to the "principal" areas of wheelchair configuration were clustered into 2 higher order themes relating to "seating" and "wheels" (Table II). These principal areas were labelled and clustered as such, based on the fact that these were areas that have received previous quantitative research attention from a biomechanical, physiological or sports performance perspective (4–24).

Seat height. Participants' initial responses to the issue of sitting height centred predominantly on factors related to match play as opposed to mobility. For example, players from all

Table II. *Subordinate themes and clusters surrounding the "principal areas" of wheelchair configuration*

Seating
Height
Game-related benefits of sitting high
Relationship with stability
Influence on manoeuvrability
Association with propulsion technique
Methods for optimizing
Fore-aft position
Association with manoeuvrability
Influence on straight line performance
Relevance to propulsion technique
Game-related drawbacks of posterior seat positions
Bucket
Improvements in stability
Consequences for mobility performance
Backrest
Influence of height on stability and mobility
Relevance of inclination angle
Tensions effect on propulsion and stability
Wheels
Size
Consequences for straight line performance
Impact on manoeuvrability
Association with pushing economy
Dependence on physical strength and disability
Relationship to sitting height
Camber
Influence on manoeuvrability performance
Influence on straight line performance
Importance of chair maintenance
Relationship with sitting position and stability
Relationship with individuals sport and role on court
Hand rims
Distance to wheels and preferred pushing technique
Proximity settings relevance to match play activities
Influence of material on match play activities
Ratio to wheel size as a gear mechanism

sports commented that sitting higher is favourable from a ball-handling perspective in WCB and WCR and for a better view of the court in WCT. Despite being viewed as the ideal position, players acknowledged its negative impact on stability and that the ability to sit high was ultimately governed by each player's level of impairment. In addition to improving stability, sitting lower was also thought to benefit aspects of mobility through allowing players to turn more effectively.

Another area relating to wheelchair mobility that participants deemed important when selecting seat height was determined by the accessibility of the wheels. A number of participants identified this as being the most important consideration of wheelchair configuration. It was proposed that by having more of the wheel available to push on, more rapid acceleration and sprinting would result due to the longer pushing stroke it permitted.

However, methods for determining how high to sit and how much "enough" of the wheel actually was, involved a number of different subjective approaches:

"….it is relative to the hub of the wheel, your arm to the hub. I feel comfortable pushing when my hand can comfortably hang down and reach the hub." *WCT – LP*

"….when I am sat in my chair and I fold my arms in a relaxed position, my elbows just touch the top of the wheel…." *WCB – HP*

Fore-aft seat position. The fore-aft positioning of the seat (frequently referred to as the horizontal positioning of the camber bar) was viewed by some participants as the most important area when configuring a new wheelchair. Participants felt strongly that the positioning of the camber bar influences the manoeuvrability of the chair:

"The further back the camber bar is, a lot of the weight of the chair is behind you, which makes it harder to turn." W*CR – LP*

Contrasting views emerged regarding the influence of the camber bars positioning on straight line performance. Some felt that having the camber bar positioned further forwards could cause a loss in speed. This was suggested to occur as a result of the forwards shift in body weight that was required in order to reach and drive the wheels. Conversely, some participants were of the opinion that they may be able to accelerate and sprint faster in a straight line if the camber bar was in a more anterior position. It was proposed that having the wheels further forward potentially allows more of the wheel to be available to push on.

Having enough of the wheel to push on was, as with seat height, an area that generated different opinions between players of different disability levels. Some HP players highlighted the desire to have a push that lasted from "12 o'clock to 3 o'clock" (0° to 90°) on the wheel in order to be able to drive the wheels down effectively (Fig. 2). Therefore, HP players wished to sit directly above the camber bar so that they were directly above the top of the wheel. However, a participant from WCR commented that this may not be a suitable approach for those with a higher level of impairment:

"….as we cannot all really extend our arms properly there is no point trying to sit on top of the wheel and trying to push down….I think some should sit behind the wheel and pull and try and use that more." *WCR – LP*

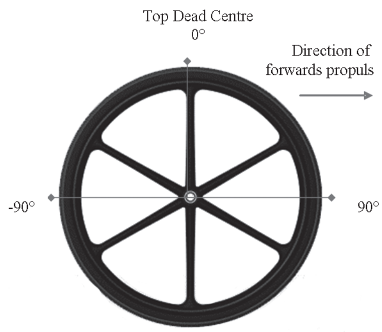

Fig. 2. Illustration of a wheel accompanied by the terminology used to explain temporal parameters of wheelchair propulsion.

Although LP players appeared to advocate a more posterior seating position by having the camber bar positioned more towards the front of the chair, some potential drawbacks during match play were associated with this, as demonstrated in WCT:

"….you want to be hitting the ball out in front of you…. whereas if you are laid back in your chair, you are almost hitting the ball back from behind you…." *WCT – LP*

Seat bucket. Having the front of the seat higher up than the back of the seat creates what is known as a "bucket". LP players indicated that a bucket was particularly useful for them as it provided them with a greater degree of stability in their chairs. Although HP players agreed that having a bucket improved stability, they felt that it hindered their performance, as it minimized the contribution that their trunk could add to propulsion.

Seat backrest. Similarly to the bucket of the seat, the configuration of the backrest was thought to play a major role in a player's stability. The height of the backrest appeared to be particularly influential in this, with a higher backrest advocated to provide a higher degree of stability. Alternatively, in accordance with what was previously mentioned with respect to the seat bucket, it was unsurprising to discover that HP players favoured as lower backrest as possible, so that it did not restrict their movement.

The inclination angle of the backrest was also commented on by participants. Having an upright backrest was suggested to be beneficial by WCT players, as it pushed them further forwards, which was said to assist ball striking. However, LP players from WCB and WCR felt that being thrown too far forward in their seat could negatively affect their stability.

Tension of the backrest was also considered; HP players from WCB and WCT seemed to favour a tighter backrest to keep them in a better position to receive or hit a ball, respectively. A looser backrest was thought to have negative consequences on their mobility, as they felt like they were losing "thrust" and "energy" during propulsion.

Wheel size. A number of participants strongly believed that smaller diameter main wheels contributed to greater initial acceleration and might enable better manoeuvrability. However, larger diameter wheels were suggested to be advantageous for other areas of performance. For instance, sprinting over longer distances was thought to be more effective using larger wheels, as was the economy of propulsion.

Disability group also seemed to have a bearing on wheel size selection. Smaller wheels may be more appropriate for players with a higher degree of impairment, due to the higher magnitude of force that is required to accelerate a chair with larger wheels. It was mentioned by LP players that they often do not have the physical power to start the chair moving from a standstill.

Wheel size selection was also considered in relation to sitting height. As mentioned previously, correct seat positioning was vital for allowing sufficient access to the wheels. One reason offered for selecting larger wheels was to allow players to sit quite high, whilst still being able to access enough of their wheels.

Rear wheel camber. Rear wheel camber was commonly thought to have a favourable influence on manoeuvrability by all participants. However, the effect of camber on areas of straight line performance seemed less conclusive, with conflicting views expressed. Some participants stated that increased degrees of camber had negative effects on straight line performance, whereas others did not believe that such a negative impact existed, especially if the wheels were well maintained, as one participant emphasized:

> "I don't actually believe there is a great deal in your acceleration (with increased camber) if your wheels are true and toed properly." (WCR – HP)

Rear wheel camber was also thought directly to influence the lateral stability of the wheelchair-user combination, due to the wider wheelbase it provides. However, LP players warned against selecting excessively cambered wheels, in order to avoid compromising the stability of the user themselves during turning.

Seat height was also thought strongly to influence camber selection. As previously mentioned a lower seat has been associated with improved stability. Consequently, some participants commented that players who sit lower may not require as much camber to aid with stability and, alternatively, players who sit higher may benefit from greater camber.

Camber selection also seemed to depend on both the sport and the role of the participant. For example, LP players from WCB and WCR tended to favour slightly higher degrees of camber to HP players due to their defensive responsibilities:

> "….lower pointers want to be as long and wide as possible so they can take up a lot of court space to make it a long way to travel round them." *WCR – HP*

Alternatively, HP players often opt for lower degrees of camber to assist them with their more offensive roles on court and avoiding other wheelchairs.

Hand rims. Various areas of hand rim configuration were thought to impact on mobility performance. Proximity of the rims in relation to the wheels was one area listed, which seemed to depend on the player's propulsion technique and role on court. Participants who pushed with a combination of both the hand rim and tyre favoured having the rims closer to the tyre. However, players who felt more comfortable pushing solely on the hand rims tended to favour a slightly wider setting. Participants from WCR also commented on how the proximity of the rim to the tyre can influence game-related activities. For example, LP players stated that having their rims out wider from the tyre suited their defensive roles, as it made it is easier to "pick" opponents.

Material was another area of hand rim configuration that was considered by participants. This area also seemed to have a relevance to match play related activities in WCR, with LP players favouring a rubber-coated rim to assist with their defensive roles on court.

The diameter of the hand rim in relation to the diameter of the wheel was also highlighted by 2 participants as a factor that could influence performance. It was commented that players were experimenting with different diameter hand rims in relation to wheel size to give different gear ratios, although no insights into how this could influence performance were offered.

Theme (iii): Supplementary areas of wheelchair configuration

Areas of wheelchair configuration that have been relatively unexplored by previous research from a biomechanical, physiological or sports performance perspective were clustered into the superordinate theme "supplementary areas of wheelchair configuration". These areas were frequently proposed, unprompted, by participants as areas which can influence performance and were grouped into a total of 6 higher order themes (Table III).

Frames. The main consideration given to wheelchair frames centred around the weight of the material used. All participants favoured the lightest chair possible, due to its positive impact on mobility and the efficiency of propulsion.

Table III. *Higher order and subordinate themes on "supplementary areas" of wheelchair configuration*

Frames
Relationship between weight of material and mobility
Importance on strength and rigidity of material
Chair length
Impact on manoeuvrability
Incidental effects on stability
Footrest
Positioning in the sagittal plane for manoeuvrability
Positioning of feet for enhanced stability
Strapping
Positive influence on stability and manoeuvrability
Potential hindrances for mobility
Castor wheels
Significance of number of front castor wheels
Anti-tip wheels role in improved manoeuvrability
Tyres
Influence on straight line speed and manoeuvrability
Relationship of tyre pressure with playing surface

Adjustability was another consideration that was given to the frames. Participants stated that "adjustable" frames were beneficial to younger, inexperienced players who were uncertain of their optimal settings. However, for the elite, experienced participants interviewed, a "fixed" frame wheelchair was preferable. The greater rigidity these chairs provided allowed them to withstand contact and, ultimately, last longer.

Chair length. Some participants felt that chair length contributed towards manoeuvrability performance, with a shorter wheelbase thought to improve turning. However, if the length of the chair was too short, a HP player from WCR suggested that stability could be compromised, particularly if combined with a high sitting position.

Foot-rest position. Positioning of the feet was thought to influence both the manoeuvrability and stability of a performer in their chair. Placing the feet back underneath the seat was associated with greater manoeuvrability. A HP player from WCT explained that this was the result of keeping more of one's body weight closer to one's centre of mass. However, as with chair length, this improved manoeuvrability could cause a decrease in stability if a rearward placement of the feet was combined with a high seating position.

Strapping. Although, not directly related to wheelchair configuration, all participants mentioned the vital contribution strapping has on stability and, as a consequence, mobility performance. Strapping appeared to have a positive impact on players from both disability groups. LP players commented on the greater feeling of core stability and degree of function that strapping enabled them. Whereas HP players often commented on the advanced manoeuvres they were capable of performing as a result of strapping. For example, WCB participants highlighted the ability to tilt as a benefit of strapping and being more manoeuvrable due to feeling more "at one" with their wheelchairs. However, there appeared to be a risk that players can strive for too much stability through strapping, which comes at the expense of their mobility, by making them so rigid in their chairs that their movements become impinged.

Castor wheels. The smaller wheels at the front and rear of sports wheelchairs, referred to as castor wheels, were proposed by many participants to have assisted mobility performance. In WCT one participant revealed that having 1 front castor wheel allowed for greater straight line speed through a reduced feeling of drag. However, the 2-wheeled design was favoured by the majority of participants due to the greater stability that was exhibited when turning at high speeds.

The rear "anti-tip" castor wheel was described as being one of the major developments in wheelchair sports, due to the positive impact it has had on rearwards stability and the fact that this has allowed the camber bar to be moved further forwards, which has already been associated with improved manoeuvrability.

Tyres. Tyre pressure was an area that some participants considered when attempting to optimize their mobility performance. It was generally commented that the higher the pressure, the less drag and resistance experienced during propulsion, yet too much pressure could lead to reduced grip during turning, as a result of the smaller surface area of the wheel in contact with the ground.

A participant from WCT mentioned how tyre pressures can be adjusted to suit the hardness of the surface they are competing on. Unlike WCB and WCR players, WCT players compete on a variety of different surfaces and it was thought to be beneficial to have a lower pressure than normal on softer playing surfaces and a higher pressure on harder surfaces.

DISCUSSION

It is evident from this investigation that participants consider game-related activities very highly when configuring a new sports wheelchair. Being in a position to handle the ball effectively in WCB and WCR and hit the ball effectively in WCT was an extremely high priority for players when selecting areas of their wheelchair configuration. Mobility performance, the main focus of previous wheelchair configuration studies (4–25) as well as the current investigation, was given a fair amount of consideration by participants too, although to a slightly lesser extent.

Theme (i): Performance indicators

The ability to accelerate, sprint, brake and turn have been identified previously as the key determinants of mobility performance in wheelchair sports (36). However, participants in the current investigation identified that stability was the most important performance indicator as it facilitated all other areas of mobility performance. In accordance with Vanlandewijck et al. (36), the ability to accelerate from a standstill was still viewed by the current participants as being a vital determinant of successful mobility performance. However, the current investigation revealed that subtle differences exist with regards to how players of different sports and disability groups prioritize these performance indicators. For example, initial acceleration from a standstill was of greater importance to participants from WCB and WCR than WCT, who placed a higher emphasis on turning ability. These differences were likely to be due to the team nature of WCB and WCR, as other opponents can directly influence their movements. This was said to cause these players to stop quite frequently and would explain why the ability to accelerate again was so important. However, as WCT players do not have obstacles to avoid and are more in control of their own movements, they rarely have to come to a complete standstill; hence manoeuvrability is vital to their mobility performance.

Theme (ii): Principal areas of wheelchair configuration

Determining how participants' perceived certain areas of performance was a valuable step when attempting to explore athlete's experiences of wheelchair configuration. This was due to the fact that it became clear that making even minor adjustments significantly influenced these performance indicators.

Seating. The main area for concern that emerged from the current investigation was based on how participants determined their optimal configurations. Participants frequently commented on how important it was to access "enough" of their wheels during propulsion. Some participants felt that having more of the wheel to push on allowed for more rapid propulsion due to the longer stroke it permitted. However, explanations concerning "how much was enough" and when "more" became "too much" seemed to be slightly ambiguous. Consequently, participants' methods for determining their optimal seat height in order to access "enough" of the wheels were extremely subjective. Some participants commented on methods whereby their hands should comfortably be able to reach the hub of the wheel when sitting in a relaxed position. However, a concern with this approach is that it does not take wheel size into consideration. For example, if seat height was maintained, but the wheel size was reduced, the part of the wheel used for propulsion would be further away, altering the temporal and kinematic parameters of propulsion as a result.

Van der Woude et al. (7) utilized a more standardized method for adjusting seat height, which was dictated by the degree of elbow extension induced when the hands were placed on the top dead centre of the wheel. It was revealed that increasing seat height significantly influenced the amount of wheel that could be accessed. Mean push angles reduced from 97.5° at a seat height inducing 100° of elbow extension to 80.3° when the seat was raised to induce 160° of elbow extension, which would suggest that optimal positions can be determined quantifiably.

A similar problem appeared to exist for establishing the optimal position of the seat in the fore-aft direction in order to access enough of the wheels. Only one participant provided a remotely quantifiable method as to how they determined their fore-aft seat position, other than subjectively "what feels right or comfortable". This participant stated that, as long as the seat was in a position that allowed him to get his shoulders forward to a point directly above the hub of the wheel, then it should provide a sufficient stroke length.

Previous quantitative methods have utilized percentiles of arm length as a means for adjusting the seat in the fore-aft direction (9, 12). Hughes et al. (9) identified greater ranges of motion for both the elbow and shoulder in the frontal and transverse planes in the anterior seat positions and greater shoulder range of motion in the sagittal plane for the posterior positions, which again suggests that optimal positions can be established. However, further research is required to assess this, as both the studies of Hughes et al. (9) and Wei et al. (12) were conducted at sub-maximal speeds and consequently their findings may have little relevance to the more dynamic mobility involved in wheelchair sports.

Fore-aft position of the seat also identified some conflicting beliefs from participants as to its impact on straight line mobility performance. Participants felt certain that the further forward the camber bar was positioned, the more manoeuvrable the chair became and some felt that this also made more of the wheel available, which would lead to greater acceleration and sprinting performance. However, van der Woude et al. (37) suggested that having the centre of mass of the wheelchair-user combination positioned over the axle of the main wheels in the fore-aft direction would reduce rolling friction. This would imply that this position would in fact have the most favourable effect on mobility performance.

Wheels. Rear wheel camber was another area of wheelchair configuration that was deemed to have a positive influence on manoeuvrability, but again caused uncertainty amongst participants with respect to its influence on straight line performance. Increasing camber was unanimously linked with improved turning performance by all participants. This reinforced the findings of Faupin et al. (19), who revealed that turning speed improved with increasing camber. However, the camber angles investigated by Faupin et al. (19) only ranged between 9° to 12°, whereas the camber angles used by athletes from wheelchair court sports are slightly more extreme (Table I).

Some participants believed that an increase in camber was associated with reduced straight line mobility performance, with an increased feeling of drag and resistance said to be experienced. Yet some participants felt that increasing camber had no or little effect on straight line performance. This disparity is also reflected within the scientific literature. Veeger et al. (17) identified small but significant decreases in rolling resistance when increasing rear wheel camber from 0° to 9°, whereas Buckley & Bhambhani (18) believed that the influence of camber on rolling resistance was negligible. Unfortunately neither of these studies has ensured that the alignment of the wheels was maintained during each camber condition. This could be quite a significant omission, as 1 participant from the current investigation felt that camber had negligible effects, as long as the wheels were perfectly aligned. This appeared to correspond with the findings of Faupin et al. (20), who controlled main wheel alignment and subsequently revealed that rolling resistance increased and mean velocities decreased significantly when camber angles were increased from 9° to 15°.

Wheel size was another area that was clearly felt to impact on mobility performance. However, a few participants mentioned that some players would use larger wheels to allow them to sit higher and still be able to access enough of the wheel. This was slightly concerning given the fact that larger wheels have been associated with reduced acceleration performance. Therefore, although it seems clear that players can make adjustments to benefit one area of performance, other areas of performance can be directly and often negatively influenced as a result. Consideration to the movements that were most important to each individual, given their specific impairment level and role on court, seemed to be needed when configuring a wheelchair, as previously mentioned by Yilla et al. (28).

The current study also helped to identify innovative areas of wheelchair design that have been integrated into some sports, which may benefit from future quantitative research. An example of this was hand rim diameter in relation to the main wheel (hand rim: wheel size ratio). Traditionally, hand rims for the court sports are one inch (25 mm) smaller in diameter than the wheel size. However, it emerged that varying the hand rim: wheel size ratio was an area of wheelchair configuration that was being manipulated by some competitors in WCT. van er Woude et al. (21) investigated the effects of manipulating hand rim: wheel size ratios within racing wheelchairs and revealed an increase in oxygen cost and heart rate with increasing hand rim diameters of 0.30–0.56 m. It remains to be seen whether a similar trend exists within wheelchairs designed for WCB, WCR and WCT, and therefore may warrant further investigation.

Theme (iii): Supplementary areas of wheelchair configuration

Some areas of wheelchair configuration, which have not previously been considered from a research perspective, were still thought to have a significant impact on performance. For instance, participants were of the opinion that selecting a longer chair with a more posterior footrest position and the use of strapping all contributed towards improved stability. This seemed particularly valuable to the LP players, as the additional stability that they attributed to these areas has allowed for more advanced configurations to be selected, which their impairment level would previously never have allowed. Yet, participants acknowledged that adjusting areas of wheelchair configuration for improved stability could compromise mobility and manoeuvrability performance if adjusted "too much". However, the point at which "too much" occurs was, again, frequently decided by trial and error and what subjectively felt right. Once again this demonstrates how fine a line exists in optimizing chair set-up, even with some of the potentially smaller areas. In order to assist athletes with the selection process when configuring a new sports wheelchair, future quantitative research is required to determine where the optimal positions for each of these settings occur in relation to the user.

Even though, future research into the effects of manipulating some of the supplementary areas on performance would also be beneficial, it is perhaps not the most pressing issue, as it has become clear that a great deal of sport-specific research is still required into some of the principal areas of wheelchair configuration. However, given the obvious contribution that the supplementary areas of configuration were said to have, it is imperative that future studies into the principal areas of wheelchair configuration acknowledge and control these supplementary areas.

Limitations

It may be considered that the small sample size in the current investigation was not sufficient enough to achieve data saturation. This may hold some truth; however, given the phenomenological nature of the study, a sample size of 9 should be sufficient (38). In addition to this, the fact that participants were recruited for the current investigation through purposive sampling means the participant group were particularly homogenous. This should ensure that the information provided by this group of participants should be detailed enough not to warrant a larger sample size.

The homogenous nature of the participants could alternatively be viewed as a slight limitation. In order to gain greater detail into how wheelchair athletes perceive areas of configuration to impact on performance and to establish which areas are in need of future research, a more heterogeneous sample may be advantageous. For example, establishing the opinions and beliefs of less experienced athletes may have provided further insights into the phenomenon. However, given that this is the first study of its kind into wheelchair configuration for sport it should serve as an extremely useful foundation for any future research to build on.

In conclusion, this investigation has demonstrated that experienced wheelchair athletes have a strong and relatively united understanding of how making "general" modifications to areas of wheelchair configuration affects their performance. However, it was noticeable that establishing in more detail where optimal settings were located was a very complex process that athletes found difficult to quantify. Therefore, it is essential that future quantitative research attention is undertaken to help optimize areas of player's wheelchair configuration, specific to the anthropometrics and disability of the individual. This should enhance player's awareness of the consequences of the selections they make when configuring a new wheelchair, as it was apparent that their selections are currently based on trial and error. Not only may these selections be limiting their performance, but they could be placing them at an increased risk of injury. The current investigation also helped to identify which areas of configuration are in need of the most urgent research attention. The effects of rear wheel camber on aspects of mobility performance, in particular, warrants further research as a result of the disparity amongst participants' subjective opinions as well as within the scientific literature (17–20).

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