ADAPTED PHYSICAL ACTIVITY QUARTERLY

Expert Users' Perceptions of Racing Wheelchair Design and Set Up: The Knowns, Unknowns and Next Steps

Journal:	*Adapted Physical Activity Quarterly*
Manuscript ID	APAQ.2016-0073.R2
Manuscript Type:	Original Research
Keywords:	wheelchair sport, qualitative inquiry, wheelchair athletics, research methology, paralympics

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Abstract:

This paper demonstrates how a qualitative methodology can be used to gain novel insights into the demands of wheelchair racing and the impact of particular racing chair configurations on optimal sport performance via engagement with expert users (wheelchair racers, coaches and manufacturers). We specifically explore how expert users understand how wheels, tires and bearings impact upon sport performance and how they engage, implement or reject evidence-based research pertaining to these components. We identify areas where participants perceive there to be an immediate need for more research especially pertaining to the ability to make individualized recommendations for athletes. The findings from this project speak to the value of a qualitative research design for capturing the embodied knowledge of expert users and also make suggestions for 'next step' projects pertaining to wheels, tires and bearings drawn directly from the comments of participants.

Keywords: wheelchair sport, qualitative inquiry, wheelchair athletics, research methodology, Paralympics

Introduction

Since wheelchair racing first emerged on the international scene in the 1980s, there have been considerable advances in the training and preparation of the athletes (Goosey-Tolfrey, Mason, & Burkett, 2013). There has also been a concurrent evolution in the design, configuration and manufacturing of the equipment and the racing chairs on the track today bear little resemblance to their predecessors (Cooper & De Luigi, 2014). The combined effect of these developments has been an overall improvement in the performance standards with today's wheelchair racers achieving times that would have been inconceivable three decades ago (see Figure 1).

[Insert Figure 1 about here]

Sport scientists working in this area recognise that the sport performance of wheelchair athletes is dependent on three factors: the athlete, the wheelchair and the interaction between athlete and chair (Mason, van der Woude, Goosey-Tolfrey, 2013). Although there is a robust body of research focused on the physiology of wheelchair racing athletes (Bhambhani, 2002; Campbell, Williams, & Lakomy, 2004; Goosey-Tolfrey et al. 2013) and some studies on the ergonomics of racing chairs (Fuss, 2009; Masse, Lamontagne, & O'Riain, 1992), the third factor – the interaction between athlete and racing chair – has received less attention. Articles by Cooper (1990a) and Cooper and De Luigi (2014) have highlighted some of the key areas of wheelchair racing design and typical ranges within which athletes currently configure these areas of design, such as wheel size and push-rim diameter etc. However, very few studies have quantified the effect of such manipulations on the subsequent performance of wheelchair athletes. To the authors' knowledge, only the effect of seating position (Walsh, Marchiori & Steadward, 1986; Masse, Lamontagne & O'Riain, 1992; Vanlandewijck, Verellen & Tweedy, 2011) and different push-rim to wheel size ratios (Woude, Veeger, Rozendal, van Ingen Schenau, Roth &

van Nierop, 1988; Costa, Rubio, Belloch & Soriano, 2009) have been investigated with respect to athletic performance. Indeed the research that does explore this interaction is largely focused on 'court sports' (i.e. wheelchair basketball, wheelchair rugby and wheelchair tennis) where the chairs and the demands on the athletes differ considerably from wheelchair racing (Mason, Porcellato, van der Woude, & Goosey-Tolfrey, 2010; Vanlandewijck et al., 2011). Furthermore, one substantial gap yet to be addressed lies in understanding how athletes, their coaches and the manufacturers of racing chairs interpret, adopt, implement, modify or reject research pertaining to wheelchair racing. Do they, for example, find that some recommendations though correct in theory and proven in laboratories, are impractical to implement? While sport scientists work in closed conditions with limited variables to determine the 'optimal' design or set up of racing chairs, in practice, athletes, coaches and manufacturers weigh competing factors. These include the availability, cost and/or durability of equipment and materials and also individual factors such as the size and strength of the athlete, the nature of their injury or impairment, the level at which they are competing and also the demands of different events (sprint, middle or long distance). Understanding what athletes, coaches and manufacturers are looking for in a racing chair and how and why they make the decisions they do to use certain types of equipment or configure a racing chair in a particular way is a critical, yet often overlooked, step in understanding wheelchair sport.

The objective of this research was to address the aforementioned gap and use a qualitative research design to engage directly with expert users (defined for the purpose of this research as elite wheelchair racers, their coaches and the manufacturers of racing chairs) and discuss with them their perceptions of how different aspects of chair design and configuration impact upon athletic performance. This included conversations about the evolution of the chairs they personally use and/or manufacturer, their adoption or rejection of certain designs, their opinions of recent advances in materials, and their suggestions for future research based on their needs, those of the athletes they coach and/or their customers. Consistent with the qualitative approach, the research was underpinned by a subjective and transactional epistemology that seeks to understand the world from the perspective of the participants (Sparkes & Smith, 2014).

Method and Design

Participants

Maximum variation sampling was used to select athletes, coaches and manufacturers of racing chairs to target for recruitment. This method of sampling consists of the research team defining in advance the dimensions of variation in the population most relevant to the topic under investigation and then systematically contacting individuals who represent the most important variations of these dimensions (Patton, 2002; Sparkes & Smith, 2014). Maximum variation sampling “aims at capturing and describing central themes that cut across a great deal of variation” (Patton, 2002, p. 234-235) and was thus deemed an appropriate fit for this research where the dimensions of variation under consideration included: time involved in sport, competition class, sport event and gender. The final sample included five current athletes and four coaches (two were themselves retired elite wheelchairs racers) and two manufacturers of racing chairs. Collectively the athletes (current and retired) had competed in the following classes: T34 (n=1), T51 (n=1), T52 (n=1), T53 (n=3) and T54 (n=1). While some of the athletes specialised in particular events, all athletes were experienced competitors across multiple distances and had experience racing on both the track and the road. All athletes were competing at an elite international level and preparing for selection for Rio 2016. Likewise all of the coaches and both manufacturers had experience working with athletes competing in diverse classifications and at international events (Paralympic Games and/or World Championships). Seven of the participants were male and four were female and collectively the sample included individuals from Austria, Australia, Canada, the Netherlands and the United Kingdom. Time involved in the sport of wheelchair racing ranged from 3 to 20+ years.

Procedure

Rigour, in qualitative practice, is established by maintaining a clear and transparent link between the knowledge produced and the steps undertaken in the collection and analysis of the data (Tracy, 2010). It requires that the researcher(s) demonstrate their integrity and competence by (among other criteria) selecting methods appropriate to the goals of the project, spending prolonged time in the field and being attentive to the nuances and complexities present thus ensuring that the data collected supports the claims made (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006; Marshall & Rossman, 2006; Tracy, 2010). For this reason, in the section that follows, we outline steps undertaken in designing and carrying out the research and also the reasoning for decisions made.

A semi-structured interviewing method was adopted because it allowed for the exploration of topics identified *a priori* by the research team while still providing opportunities for participants to raise new subjects that they felt should be included in the research (Rubin & Rubin, 2011; Smith & Sparkes, 2014). The research team that developed the interview guide included two investigators with substantial knowledge of wheelchair sport and extensive experience designing and conducting physiological and biomechanical research in this area and one investigator who is very experienced in qualitative research design and has experience coaching and volunteering in para-sport programmes. To further ensure the completeness of the guide and also that the terminology used would be familiar to athletes and coaches, it was reviewed and revised by a wheelchair racing coach with over 25 years experience coaching elite wheelchair racers. The final version of the guide included questions about: the components of racing chairs (bearings, compensators, footrest, frame, push rims, seat, steering, tires and wheels), aspects related to the set-up of the chair (fit and positioning of athlete in chair), and the processes involved in selecting, ordering, being fitted for and/or manufacturing a new chair. Gloves, though not strictly related to chair design, were also included because they are deemed integral to the interface between the athlete and the racing chair (Cooper, 1990b; Rice, Dysterheft, Bleakney & Cooper, 2016). Finally, before commencing the interviews, the first author spent several hours observing wheelchair racers training at a nearby facility and having casual conversations with athletes and coaches during their breaks. She also visited a wheelchair manufacturer at their main facility where she was able to familiarize herself with different models and designs and ask questions about the manufacturing process. This project received approval from the host institution's research ethics review board.

All interviews were conducted by the first author in person (n=6) or by Skype (n=5) and were audio recorded. They ranged in duration from 42 minutes to 119 minutes for a total of 849 minutes of recording. All participants signed consent forms, were guaranteed their responses would remain anonymous and were informed of their right to terminate the interview at any stage. When possible, athletes were asked to bring their racing chair to the meeting so that they could reference specific elements. One of the interviews with manufacturers was carried out at their facility where racing chairs were on display. It is worth reinforcing that the guide was semi-structured and purposely created to permit for considerable flexibility on the part of the interviewer. While all topics were addressed in each interview, the style of the interview was highly conversational and participants were encouraged to talk broadly about racing chair design and set up with the interviewer prompting if the participant did not address particular components of the chairs. Often the athletes' racing chairs were used as prompts with the interviewer asking the athletes to explain different components that she could see had been modified or that were different from chairs she had previously encountered. Furthermore, because the aim was to explore the topic from the participants' viewpoint, the interviewer avoided making responses that could be interpreted by participants as agreeing and/or rejecting their statements, instead the first author used follow-up 'probes' (Rubin & Rubin, 2011) with the goal of better understanding how or why the participants had formed their opinions and impressions.

Analysis

All interviews were transcribed verbatim and imported to NVivo 10 software. They were analysed using an iterative hybrid thematic analysis framework (Braun & Clarke, 2006; Fereday & Muir-Cochrane, 2006). Fereday and Muir-Cochrane (2006) describe this form of analysis as highly rigorous in that the research team engages in an iterative and reflexive process that is "guided, but not confined, by the preliminary codes" (p. 88). In this instance, we selected this form of analysis because it permitted us to include codes that had been identified *a priori* by the research team (based on their own experiences of working in disability sport and researching the mechanics and physiology of wheelchair sport) and yet placed a strong emphasis on ensuring the final findings are 'data-driven' and reflect the perspectives and priorities of the interview participants. Our analysis ultimately included the use of deductive nodes identified during the design of the project, inductive nodes that arose during the course of interviewing (derived from the first author's field notes) and other nodes identified during the reading and rereading of the transcripts. In total, 16 nodes were used during the coding process. These nodes were subsequently placed into five groupings. Group 1 included components related to the frame of the chair (compensator, footrest, frame, seat and steering). Group 2 addressed the process of 'fitting' an athlete for a chair (fit, ordering and positioning). Group 3 addressed the differences/similarities in chair design set up across diverse events (sprint, middle and long distances, track and road) and also as it pertained to different types of athletes (in terms of classification, gender, size, experience, racing style, etc.). Group 4 included all aspects related to the wheels (bearings, tires, and wheels) and Group 5 included gloves and push rims. The final code that addressed the weight and stiffness of various components was not included in a single group but instead intertwined in the discussion pertaining to all groups (NOTE: Weight and stiffness were originally created as separate nodes but during coding it became apparent that these two topics were almost always raised together and the two nodes were collapsed into one).

As previously stated, the objective of the research was to explore how expert users assess, implement or reject evidence-based research recommendations pertaining to the optimal configuration of racing chairs with regard to optimizing sport performance. It was also intended to identify areas that the users perceive to be in need of further research. Furthermore, the epistemological and ontological framing of the project focused on seeking to understand these topics from the participants' perspective. To answer these questions, in analysing the interview data, we developed the themes of 'knowns', 'unknowns' and 'next steps.' If participants spoke of a specific aspect of racing chair configuration or design as having generally known qualities, an impact on sport performance that was widely accepted by users, or made comments such as 'everyone knows that' or other statements that suggested their views were widely held and beyond debate, these responses were coded as 'knowns.' For example, when discussing push rims with participants, all participants expressed very similar understandings of how changing the size of the push rim would impact upon an athlete's top speed and their ability to accelerate and thus this was deemed to be a 'known.' In contrast, the theme 'unknowns' consisted of instances when participants themselves questioned or speculated how different components, designs or materials would impact athlete performance. This included, for example, challenging claims made by manufacturers, questioning the equipment choices of other athletes or the advice of coaches, or quite simply stating that they were unsure of how changing a particular element on their chair would impact upon their sport performance. The final theme, 'next steps,' was used when participants made comments indicating that they felt further research (either lab-based or 'real world') was needed in order to definitively understand the impact a change would have on sport performance and/or suggested specific avenues for future research pertaining to the set-up and design of racing chairs.

Findings and Discussion

The focus of this paper is on the knowns, unknowns and next steps from Group 4 (wheels, tires and bearing). This group was selected for more in-depth consideration for several reasons. First, wheels and related components were identified by athletes and coaches as the area where they were able to make the most changes and could thus have the most influence over their sporting performance. For example, while having the right chair frame was seen as essential to an athlete's performance, there are few modifications that can be made to a frame once it is manufactured and delivered. This, combined with the expense of purchasing a new frame and lag time between ordering and delivery, meant that athletes and coaches have few opportunities to try out different frame set ups and configurations or to compare athlete performance when switching between frames. In contrast, switching out a set of wheels, changing a set of bearings, or buying new tires, while still potentially expensive, are far easier processes. Athletes frequently replace these items because a component is damaged or worn or because they are looking for a performance gain. Thus the research team identified Group 4 as containing the nodes with the richest data and the most novel insights into how expert users assess, make decisions, and weigh existing research evidence.

Wheels

Knows and unknowns of wheels.

There are three broad types of wheels used on racing chairs. 'Spokes' have a rim and a series of spokes that connect to a hub in the centre of the wheel. These are the original type of wheels used on racing chairs (and indeed on most non-sport day chairs). ‘Discs’ consist of a solid disc shaped piece of carbon with no holes or spokes. ‘Quad spokes’ or ‘Four spokes’ are based on the carbon disc wheel but with four cut-outs in the disc. While there is some variability in the cost of the wheels, at the time of writing a set of spoke wheels (Figure 2a) purchased in the UK would cost approximately £300 while quad spokes (Figure 2b) or discs (Figure 2c) cost in the range of £1100 to £1400.

[Insert Figure 2 about here]

When discussing wheels with the participants, a few areas were consistently raised as the ‘knowns’ of wheels. It was agreed by all interviewed that disc wheels were the heaviest but also the most rigid and most aerodynamic of the wheel designs. Quad spokes were not as heavy as discs, still pretty stiff, but not as aerodynamic as discs. Spoke wheels were the lightest type of wheels but were also the least aerodynamic and the least stiff. It was also agreed that spokes were “sort of for the beginner and someone who is starting out [in the sport]” (*Participant quote*). Furthermore, this quote also gives some insight into how the participants perceived these ‘knowns’ to impact upon optimal sport performance. The assumption underlying the participants’ comments was that the wheels that were the most aerodynamic and stiffest were also the fastest and were therefore used by wheelchair racers competing internationally. In contrast, spokes, the least aerodynamic and the least stiff, were not believed to be as fast and therefore the purview of beginner athletes. No scientific investigations have yet explored the effects of wheel stiffness on performance specific to wheelchair racing, although this has been a topic of recent interest in the wheelchair court sports (Mason, Lemstra, Woude, Vegter & Goosey-Tolfrey, 2015). However, although differences in wheel stiffness were reported between the wheel investigated by Mason and colleagues, no meaningful effect on physiological demand or sprinting performance specific to the wheelchair court sports were reported.

Although there was consensus among all the participants regarding the defining characteristics of different types of wheels and also agreement that stiff, aerodynamic wheels were needed to achieve fast times, the users differed in their evaluations of how the weight of the wheel impacted sport performance. For example, although participants consistently stated that discs were the heaviest of the wheels, there was considerable speculation during the interviews about ‘how heavy was too heavy?’ Participants also had diverse responses when asked about the circumstances in which the aerodynamic advantages of the disc wheels would be outweighed by the disadvantages of having a heavier piece of equipment. One concern repeatedly raised during the interviews was that the extra weight of the discs made them more difficult to get moving (slower acceleration off the start line). That was the rationale provided by one of the athletes for his choice of quad spokes over discs. As a specialist in the 100m event, he contended that his ability to accelerate quickly off the line was tantamount and said:

> You tend to see more guys in the 100m [using quad spokes] because of the extra weight [of discs] and getting that extra weight rolling from nothing in 100m race - that’s big…. In 100m you want to get the chair rolling as quickly as possible.

Accordingly, the race distance at which the disadvantage of having a slower acceleration off the start line was outweighed by the advantage of having a higher top speed and a more aerodynamic design was classified as an ‘unknown.’ Some participants, like the athlete quoted in the previous paragraph, commented that they believed quad spokes were preferable for 100m and 200m races but for 400m and longer there was an advantage to be gained by using discs. However, the exact point at which the balance shifted in favour of disc was something that many participants actively questioned. This would seem a worthy area for future investigation, as although not restricted to the mass of the wheels, Fuss (2009) indicated through mathematical modelling that decreasing wheelchair mass would have a greater impact on wheelchair racing times than both rolling resistance and aerodynamic drag.

Related to this same unknown were questions about whether or not athletes needed to reach a certain minimum speed in order to capitalise on the aerodynamic advantage of the disc wheel design. To elaborate, athletes in the T54 class are the 'most able' of wheelchair racers; their impairments are limited to their lower extremities and they typically have full use of their abdominal muscles. In contrast, athletes who compete in the T51 class have impaired function in all limbs and are not able to use their abdominal muscles. The difference in the functional ability between the groups is reflected in the top speeds athletes in these classes are able to achieve. For example, the current world record for T54 class in the 100m is 13.63s for the men and 15.64s for the women (average speeds of 26.41 km/h and 23.02 km/h respectively) whereas the 100m world records for the T51 class are 20.47s for the men and 25.77s for the women (17.59 km/h and 13.97 km/h) (see Table 1). While none of the participants were able to give an exact speed at which the aerodynamic advantage of disc wheels 'kick in', many were of the opinion that most female athletes, regardless of their class, and most male athletes in the T51 and T52 classes, would not benefit from the use of discs. One coach interviewed, who was a former wheelchair racer, said:

> I have this belief that if you are not any bigger or faster than me then you shouldn't be pushing on discs. I think they are sort of designed for a power athlete. They are heavier and they are more rigid and they do work really well but because of how heavy they are, I think you need to be able to generate the amount of power to overcome the disadvantage.

[Insert Table 1 about here]

Another athlete who also coached in a program for developing athletes confirmed this opinion stating that:

> For the moment none of my athletes really run the discs in competition because I don't think they are particularly strong enough to get them going…. You know for a longer event maybe it is better for them to use the disc wheel because once you get them going – you know it's a nice wheel. But at the moment for them to get away and stay with the pack – it will be easier pushing on the quad spokes. That's what they do at the moment.

However, while some of the coaches and the more experienced of the athletes interviewed understood that disc wheels would provide an advantage only to *some* athletes (and even then only in *some* events), the younger and less experienced athletes included in this project were less clear on how they should personally decide which wheels to purchase and use. For example, an athlete who was entering his third international season and preparing for his first Paralympic Games selection trials had just purchased disc wheels. In this quote he describes his decision:

> I've started to get bigger, stronger. I sat down with [my coach] in January – and wheels still confuse me – which ones you are supposed to use. They know the disc in theory take longer to get up to speed because they are a little bit heavier and a lot stiffer but… For the time being I am on discs and I'm trying to get my starts to where they were on the quads. But I think there is a 2-mile difference in my top speed [with the discs]. There is a 2-mile difference in my top speed between my quad spokes and the disc. So for the 400 – the fraction that I lose at the start I make up by having a 20-mile hour top speed compared to an 18 [mile

> hour] top speed. It makes sense. And some people say that because I am quite a big lad I don't feel it as much even though they are a bit heavier.

This athlete also revealed that his decision to try the discs was very much influenced by his conversations with his coach but also by watching the world leading athletes in his event. These athletes were all pushing on discs and he was worried that if he did not emulate them he would not be competitive. Additionally, all three groups interviewed, athletes, coaches and manufacturers, referred to the 'psychology' of wheels and reported that many athletes, particularly those who are starting out in the sport and who are still learning their own strengths and weaknesses, will make decisions regarding equipment based on what they see other athletes using. As one coach stated:

> I think there's a lot of psychology with these wheels. Because at speeds of maybe 20-25 km/h for quads [athletes in the T51 and 52 classes], air resistance doesn't play a big role… The paras [athletes in the T53 and 54 classes] are going 50 km/h or more then it's starting to be important to have wheels with little air resistance. But it's really the psychology. If you know you have good materials, if you know you have the best – it only makes maybe a 0.1 percent but you feel good because you have that material. And if you are building your confidence, it's more than 0.1 per cent – it might be 5 percent.

Another female athlete interviewed had this to say:

> People fall in love with discs. And I'm not talking about the big guys. I think the big guys need discs anyway because they need a more rigid wheel because they are just that strong. But a lot of the people who are in the midrange, so girls and guys who aren't amazing yet – they just want them because they look cool when

> they are pushing. And that's stupid reasoning. Are they actually a benefit? And when are they a benefit?

Finally, there were also some circumstances where athletes felt they knew which disc would be most beneficial to them in terms of sport performance but that practical considerations prevented them from capitalizing on this information. For instance, one athlete interviewed competed in the T51 class and specialized in sprint events. He was convinced that he would benefit from quad spoke wheels because they were lighter than discs – an important consideration for an athlete in a short event and also given that T51 have less strength and travel at slower speeds than athletes in the T53 and T54 classes. However when asked why he was not using quads when he knew they would be faster he said it was the risk of injury that determined his decision:

> I would like to used quads because they are lighter and easier to get going but because I haven't got good control of my arms, my hands go in the holes. It doesn't happen when you first start training but as soon as your arms get tired and you miss that push rim – some of the guys [in the T51 class] use them and they get away with it but I've caught my hand twice now and just got it out so I don't use them.

This athlete's explanation of why an athlete in the T51 class (a class defined as having impairment or limited function in all four limbs) would steer away from adopting quad spokes despite the potential performance gains once again points to the need for more individualisation when recommending particular set ups for athletes.

Next steps – wheels.

As explained in the previous section, the expert users had a very clear understanding of the properties of various types of wheels. They knew which wheels were the heaviest, which were the most rigid, and which were the most aerodynamic. They also felt that they understood the impact these properties would have on sport performance in theoretical contexts. What they perceived to be the next step was developing an evidence-based research agenda that would enable them to recommend a particular type of wheel for an individual athlete competing in a specific event.

Tires

Knowns and unknowns of tires.

As was the case with wheels, tires were an aspect of racing chair set up over which users had an enormous amount of control in that they are easily changed and there exists a large range of tires on the market at different price points and from different manufacturers. However, when it came to talking about the impact of tires on sport performance, the participants did not speak about types of tires but instead focused on tire pressure. They stated that tire pressure could impact an athlete's speed and was a performance issue whereas the selection of a specific tire was more an issue of personal preference. In several cases, athletes reported selecting tires based on the terrain they personally trained on and looked, for example, for tires that were less likely to puncture when training on roads or tires that performed well in wet conditions. Furthermore, because tire pressure is variable over time (tires naturally lose pressure over time, have to be deflated for travel, and/or expand or contract due to temperature and other environmental factors), athletes and coaches constantly have to check their tire pressure and pump tires to the pressure they deem optimal for performance.

The participants were unanimous is agreeing that tire pressure had an impact on a wheelchair racers performance and was a more important consideration than the actual make or type of tire used. However, further discussion about the topic revealed that there were very divergent opinions among the participants as to what constituted optimal tire pressure. For athletes, the issue of tire pressure was a ‘known.’ They consistently stated that high tire pressure was desirable and that the harder the tire, the better it would perform. For example, one athlete said, “you’ll get less drag on a rock hard tire than you will on a tire that is a little big saggy. So yeah - I quite like my tires hard because I feel that’s where they roll best.” Moreover, the athletes cited the sport of cycling as the source of this knowledge, acknowledging that there was little research in this area specific to wheelchair racing but they were using the same tires as cyclists and were of the opinion that the principles were transferable. The only literature conducted specific to wheelchairs has highlighted how under-inflated tires can have a detrimental effect on the physical strain and technique of everyday wheelchair propulsion (de Groot, Vegter & Woude, 2013). Although this highlights the importance of maintaining tire pressure, it does not help establish optimal tire pressures and how these may differ for different athletes on different surfaces in different conditions. Similarly, athletes consistently reported that higher pressure was better, however, there was still variation when they were asked how high they ran their tires. The range of pressures the athletes reported extended from approximately 125 psi to 220 psi. For example, one athlete replied:

> I like my tires rock hard no matter what track I’m on. Whether it’s a soft track or a rock hard one – 170 [psi] is like –I don’t like going below 170. Anything under that and I get a bit cautious that I’m losing [speed].

Another replied he took his tires “to the max. 200, 220 [psi] whatever the tire can handle.

For coaches and manufacturers, the issue of optimal tire pressure was an ‘unknown.’ In contrast to the athletes, the coaches and manufacturers revealed that they were starting to question whether the issue was really so clear cut. For example, one manufacturer had this to say when asked about optimal tire pressure for wheelchair racing:

> You can get a lot out of the bike wheel on that. Because in the past they [wheelchair racers] have always gone for as narrow a profile and as hard as possible and that was a little bit like what the bike wheel was doing at the time as well. But the bike wheel has changed to more width and up to an optimum pressure, not a ridiculously high pressure.

Other coaches were also aware of this shift in cycling towards wider tires and lower pressure and were starting to think of how this might be applied to wheelchair racing. However, when it came to implementing this knowledge, the coaches felt they faced two barriers. The first was that some coaches reported that athletes themselves were reluctant to makes changes and the second was that they themselves were unsure of what recommendations to make. While the trends in cycling convinced them that it would be worth exploring lower pressures (or at least mid-range pressures), they still lacked the information to be able to recommend a specific pressure to an athlete. This echoed what previous research from the wheelchair court sports has indicated. Although wheels with a higher pressure have been shown to minimise physiological demand, no direct benefit in acceleration and sprinting performance was observed during research specific to the wheelchair court sports (Mason et al., 2015). It was purported that there becomes a point where high pressure becomes too high and that sufficient friction with the surface is lost and performance can be compromised. Unfortunately the exact pressure where this takes place for individual athletes remains unknown.

The second 'unknown' that coaches and manufacturers raised pertained to the interaction between tire pressure and Mondotrack. As previously stated, the tires most athletes are manufactured for cycling and the testing that has been carried out in cycling has been done on roads and velodromes or using similar surfaces in laboratories. But the majority of racing chair events are contested on an outdoor track. 'Mondo', the surface that covers most of these tracks, is designed for athletics running events[1]. As one manufacturer described it: "Racing on running track – you've [got] Mondo. And it's specifically for absorbing energy. It's designed to be comfortable to run on. And it's absolutely not what you want to be pushing a racing chair on." As another coach was quick to point out, not only is Mondo not ideal to push on, it does not have the same material properties as a road or velodrome raising questions about whether research from cycling really is applicable to wheelchair racing:

> When you are on an asphalt track you have to put in as much air as you can because asphalt doesn't deform. But when you are on a Mondo track – Mondo will deform and so you have to choose whether you deform the Mondo or deform the tire.

In short, the coaches and manufacturers involved in this project were aware that wheelchair racers might be working off of a faulty premise when they make the decision to pump their tires to higher pressures. The athletes were concerned that if the tires were not hard enough they were losing speed because their energy is going into deforming the tire and the air inside the tire and this would indeed be the case if they were competing on a harder surface such as asphalt or a velodrome. What the athletes were not considering is that by pumping their tires to avoid deforming the tire, they may be creating a situation where they are deforming the Mondotrack instead, potentially slowing them down even more. As one coach observed: "If you are deforming the track, if your tires are pressing into the track then you are increasing the rolling resistance and you are decreasing speed."

[1] The Italian company 'Mondo', a world leader in track surfaces and the official track of the 2008, 2012 and 2016 Olympic and Paralympic Games produces 'Mondotrack'.

However, though coaches and manufacturers were in agreement that Mondo had different properties to other surfaces on which cycling tires are commonly used, once again they were faced with an unknown – if they are not able to apply evidence-based research from cycling, how should they be determining the optimal tire pressure for wheelchair racers? Furthermore, the coaches and manufacturers were starting to speculate about what other factors they should be taking into consideration – asking, for example, if the combined weight of the athlete and their chair needed to be taken into account and if different tire pressures should be recommended for variously sized athletes. They also knew from experience that individual tracks have different properties – though 'Mondotrack' is a commonly used term, it is actually a proprietary name and some tracks use different materials. Moreover, Mondotrack (and other materials) deteriorates over time and thus new tracks might be harder (less likely to deform) than older tracks or, conversely, older tracks may start balding, becoming smoother and harder over time. One coach summarized the situation saying:

> The thing you have to consider with tire pressure is the hardness of the track but also the weight of the athlete in their chair. So a lighter athlete in a lighter chair is going to dig in less to the same hardness track as someone who is heavier with a heavier char. I guess the general rule is that with the super hard track then you can afford to have the tire pressure higher…. Ultimately I want to be able to say 'with this hardness of track this is the tire pressure we need.'

That same coach went on to say that, for the moment, the best she was able to do was encourage the athletes she works with to try different tire pressures on different tracks, consider how it felt, track their performances in those conditions, and then to try to transfer that information to other tracks of a similar 'hardness.' For example, at the time of the interviews, the athletes she coached were preparing for a competition in Doha and the team had identified a local track that they felt had similar properties to the track in Doha.

Some athletes were also starting to come to the realisation that there may be different optimal pressures for different surfaces and indeed for different athletes, but few felt confident in adjusting the pressure in their tires according to the circumstances. Instead they tended to default to the higher pressure at which they were most comfortable. As one athlete stated:

> I've done different tests myself. But I can't test different athletes. Softer is better – softer tires on a softer track, harder tires for a harder track. But it depends – like what air pressure is it exactly? 70 psi? 140 psi? Or are you changing from 100 to 150 – I don't know…. I just go with 140 just because….

Another athlete asserted that this was a potential issue for larger athletes who could deform the track with their weight, but that for her, a smaller female athlete, it was not a consideration:

> As long as the track is a fairly good surface then I believe harder is better. But again that's never been tried. I know a lot of bigger guys will adjust their pressure according to the track but I've never found – I don't feel that I'm that heavy and I've never found that having less pressure in my tires felt like it was helping me over having them pumped up.

Next steps - tires.

Similar to what was reported in the previous section on wheels, the 'unknowns' that the participants faced generally had to do with how to interpret existing evidence-based research so that it could be made more specific to wheelchair racing and more specific to individual athletes. While there are clearly some commonalities between cycling and wheelchair racing, there are also some critical differences that will impact upon the transferability of the research. While Mondo may indeed be a surface created primarily for runners, it is indeed used by wheelchair athletes. Thus it follows that the next step is research that specifically explores how tires (originally designed for roads and velodromes) perform when being pushed on Mondotrack, (originally designed for a runner's footfall). These investigations must account for both the pressure of the tire but also the combined weight of the athlete and their racing chair.

Bearings

Knowns and unknowns of bearings.

The final components of racing chairs captured in Group 4 are bearings. Though racing wheels are typically sold with bearings (each wheel has two), there are a number aftermarket bearings available to purchase as upgrades. Bearings also wear at different rates and typically have a shorter lifespan than the wheel as a whole. As with tires, this means that athletes have decisions to make about when to replace bearings and/or which bearings to purchase. Though steel bearings have long been the industry standard, recently ceramic bearings have entered the market. There is considerable diversity in the grade of ceramic bearing available for purchase but a few have emerged as industry leaders including the 'CeramicSpeed low friction' bearings available from Draft Chairs (we reference these because they were familiar to most of our participants and frequently referenced during the interviews). To provide some context, the CeramicSpeed low friction cost £85 per bearing (£510 per chair), the next grade CeramicSpeed bearing cost £42 per bearing (£248 per chair), and top line steel bearings retail for £12 per bearing (£72 per chair)

Compared to wheels and tires, bearings were discussed less extensively by interview participants. With only three exceptions, the athletes we interviewed stated that they used the bearings that came standard with their wheels and felt there was little to be gained from purchasing an aftermarket upgrade. As an example of a typical response when questioned about bearings, one athlete had this to say:

> I don’t know. It's just the default bearing that they put in. I know that you can get bearings aftermarket and Draft even posted a video of some of their highest bearings where they just spun the bearing and it spun forever. But I mean these bearings [points to his current wheels] are old but they still spin quite freely when you just touch it. I don’t think there is much per cent there that you’re going to be chasing.

As was the case with this athlete, all the racers we interviewed were aware of the claims being made about various types of bearings. However, the ‘unknown’ for the athletes was how much effect the bearings had upon performance. As seen in the above quote, they questioned what percentage gain could be made by purchasing new bearings. Even amongst the three athletes we interviewed who had purchased ceramic bearings, the impact that this purchase would have on their performance was very much still an ‘unknown.’ One athlete who had recently started using ceramic bearings made this comment:

> I don’t want to say they made the difference. I don’t know if I put the others [steel bearings] back in if I’d know. But it rolls nicer [with ceramics] and I think sometimes it’s in your head as well.

The second athlete to have purchased ceramic bearings but who had not yet used them (he was waiting for the arrival of a new racing chair) also questioned how noticeable the change would be: “I got some that I will put into the chair. So it will be interesting to see if there is a difference that the [ceramic] bearings make. But we are getting down to the fine… {sentence left unfinished}” All three athletes stated that they thought it possible that the hype around ceramic bearings was unjustified and the only advantage that this purchase would provide would be purely psychological (or a ‘sugar pill’ as one participant termed it). Yet despite acknowledging that the evidence in support of ceramic bearings was minimal, these athletes stated that they had made the purchase in anticipation of competing at the Rio Paralympic Games and on the premise that even a minute gain in speed would be worth the expense in this all-important year.

Coaches also described the potential impacts of bearings on sport performance as an ‘unknown.’ As with the athletes, they were aware of the hype surrounding the latest ceramic bearings and were even prepared to say that ceramic bearings did perform better than steel bearings in controlled testing. One coach explained:

> I was with [Athlete 1] and [Athlete 2] one night and we were checking three different bearings. [Athlete 1] actually had the best ones that Draft have got – their CeramicSpeed [low friction] bearings. And he also had the next ones down – so they are not £400 – they are £200 for a set of wheels. And then we had another athlete who refuses to spend £400 – this person is the best in the world - and we were spinning them. And this one would spin – and you could hear it grinding – it was awful. And then the next one – and then the most expensive ones – you just spun them and they went on and on and on. It makes such a difference.

However, the coaches were quick to point out that most testing of bearings has not been carried out in situ in racing chairs and there was little evidence that athletes would be able to achieve faster starting times, higher tops speeds or expend less energy during long races by using ceramic bearings. This, combined with the high cost of the purchase, made them wary when advising athletes on which bearings to purchase.

The manufacturers responses to questions of bearing were, as one would expect, tempered by their own loyalty to the brands and types of bearings that they distribute. However, while the manufacturers may have a certain bias towards a particular type of bearings, they did agree that convincing athletes to invest in high-end bearings (and convincing coaches to recommend particular bearings) would require more evidence-based research. They acknowledged that, as of this moment, athletes had not wholeheartedly adopted the ceramic bearings because they remained unconvinced that it would provide them with a competitive advantage.

Next steps – bearings.

With regard to next steps, there are two areas pertaining to the 'unknowns' of bearings that the expert users identified as in need of further research. The first is a relatively simple comparison, in situ, of how different types of bearings, made of different grades of steel and ceramic perform in regards to initial acceleration, top speed, and energy expenditure. The second area for further research has to do with how bearings perform in racing chairs over time taking into consideration the deterioration and wear of different types of bearings and also the potential gains/losses related to cleaning and maintenance of bearings. Unfortunately no literature currently exists to help inform these decisions. All that is known is that internal friction is a key contributing factor to the overall resistance experienced by users and that the type of bearing and maintenance will impact upon this (Woude, Veeger, Dallmeijer, Janssen & Rozendaal, 2001).

Concluding Comments

In this paper we illustrated how a qualitative research project, shaped by a transactional and subjective epistemology, used semi-structured interviews and thematic analysis to gain novel insights into the current state of research on racing chair design. Though the use of qualitative methods to study wheelchair sport is not in and of itself novel, qualitative methods have predominately been employed to investigate socio-cultural or psychological aspects of wheelchair sport (cf. Hardin & Hardin, 2004; Huang & Brittain, 2006; Page, O'Connor, & Peterson, 2001; Williams & Taylor, 1994). We position this study as part of a small, but emerging body of research where qualitative methods are being used to explore the technical aspects of the sport. Collectively these works offer new ways of understanding how key participants (most notably athletes but also coaches and others) develop and acquire expertise that can subsequently be used to inform advances in the field of disability sport science (Hambrick, Hums, Bower, & Wolff, 2015; Mason, van der Woude, & Goosey-Tolfrey, 2009). By engaging directly with athletes, coaches and manufacturers we were able to identify what expert users felt were the knowns, unknowns and next steps pertaining to racing chairs. We then delved into the data from Group 4 and addressed in more detail how the participants understood wheels, tires and bearings to impact upon sport performance. This enabled us to identify areas where the expert users believed the existing evidence was insufficient to support the claims being made (i.e. bearings) and also areas were they felt more information was needed before they could put research recommendations into practice (i.e. prescribing a particular wheel for a particular athlete in a particular event or understanding how to set a tire pressure specific to the athlete and the track). These contributions from expert users are very valuable because they provide insights that can be used to streamline and focus the expensive and time-consuming trial and error model commonly used to determine optimal racing chair design or set up (Walsh et al., 1986). Additionally, while the focus of this paper was on wheels and tires, our conversations with expert users suggested to us many possible avenues for future work. This includes areas where wheelchair racers and coaches feel they require scientific support from practitioners and/or researchers to further maximise their performances. In brief, studies investigating the impact of wheel stiffness and mass on acceleration performance for short duration events and propulsion economy for longer duration events would seem a priority. Other areas to explore could include investigations into the optimal tire pressures required to minimise rolling resistance on different surface types and the use of different glove types and glove material in diverse environmental conditions (rain, heat and humidity). Moreover, we would propose that future projects with similar designs engage with other wheelchair sports including basketball, rugby and tennis in the goal of identifying the research priorities of these communities and also areas where knowledge might be transferable between wheelchair sports and areas unique to each sport.

This research was novel for several reasons. When athletes are involved in research on racing chair design, they are most commonly assigned the role of 'test subjects.' They are instructed to perform different tasks, for example, trials over set distances using different types of wheels. Their outputs are quantitatively measured and used to substantiate claims about 'the fastest wheels', 'the lowest friction bearings', etc. Rarely are the athletes invited to take on more meaningful roles in the research process, contributing, for example, to identifying the research questions or participating in the interpretation of results. As we have demonstrated, the advantage of adopting research designs that seek to engage athletes differently is that wheelchair athletes derive their knowledge of racing chairs from their own embodied use of the equipment. As such, they are able to provide a perspective on the complex interaction between athlete and equipment that is entirely unique and based on their own direct experiences of using the equipment day in, day out and in varying conditions. Likewise, coaches and manufacturer have the advantage of having worked with a number of athletes over long periods of time, they have developed an expertise and an understanding of what will work in practice that cannot be duplicated.

The aim of this paper was not to disparage existing research on racing chairs, quite the contrary. Rather it is intended to shine a light on the current status of research in wheelchair sport and signpost a way for moving forward. As was stated in the introduction, it has long been acknowledged that understanding the sport performance of wheelchair athletes means developing knowledge about the athlete, the wheelchair and the interaction between chair and athlete. However, in practice, much of the research has focused on these factors in isolation and/or privileged quantifiable measurements of the interface between athlete and equipment. It is our view that there is much to be gained from bringing a qualitative perspective to the topic. First, through interviews and other qualitative methods, expert users are able to comment on the practicality of implementing certain evidence-based recommendations. For instance, as mentioned earlier, an athlete raised the issue that while athletes in the T51 class might benefit from the lightness of quad spoke wheels, many used disc wheels because of the danger of catching their hands between the gaps on a quad spokes. Secondly, expert users can play a crucial role in identifying future areas for research. This was seen when coaches and manufacturers raised the issue of tire pressures and Mondotrack. In short, by engaging with expert users to identify research questions and by drawing on qualitative research designs, we can ensure that our research agendas are aligned with the immediate needs of the populations they are intended to benefit thus enhancing the probability that our research findings will have impact.

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Figure Legends

Figure 1 – Illustration of the winning times at the London marathon for the male and female events since 1983 taken from taken from https://en.m.wikipedia.org/wiki/List_of_winners_of_the_London_Marathon

Figure 2 – Racing wheelchairs configured with a) spokes b) quad spokes and c) disc main wheels

Table 1 – Average speeds (km/h) for the current world record times in wheelchair racing events.

		Event							
		100m	200m	400m	800m	1500m	5km	10km	Marathon
	Classification								
Men	T32	15.48	15.38	15.86					
	T33	21.87	24.03	24.85	25.60	20.66			
	T34	24.08	26.98	28.78	28.74	27.13	24.27		
	T51	17.59	19.22	18.33	17.98	17.91	17.88	16.74	17.69
	T52	21.87	23.98	26.09	25.64	25.74	23.78	23.09	25.29
	T53	25.41	28.49	30.41	30.50	30.94	30.35	30.24	31.56
	T54	26.41	29.78	31.95	31.61	30.94	30.35	30.24	31.56
Women	T32	9.56	8.72	8.50					
	T33	18.10	20.55	20.53	20.16	18.25			
	T34	20.80	23.60	24.23	23.42	22.33	22.35		
	T51	13.97	16.30	13.38	12.05	11.25			
	T52	19.28	21.69	22.20	22.72	20.42	20.28		19.86
	T53	22.19	24.89	26.33	26.80	27.94	27.09	24.63	25.81
	T54	23.02	26.16	27.75	28.04	27.94	27.09	24.63	25.81

NOTES:

[1] World Record times as of 8 June 2016 retrieved from International Paralympic Committee website (https://www.paralympic.org/world-records/athletics)

[2] The T53 and T54 classes are combined for the 1500m, 5km, 10km and Marathon events.

[3] Blank fields indicate there is no current World Record for the event or this event is not regularly contested in international competition.

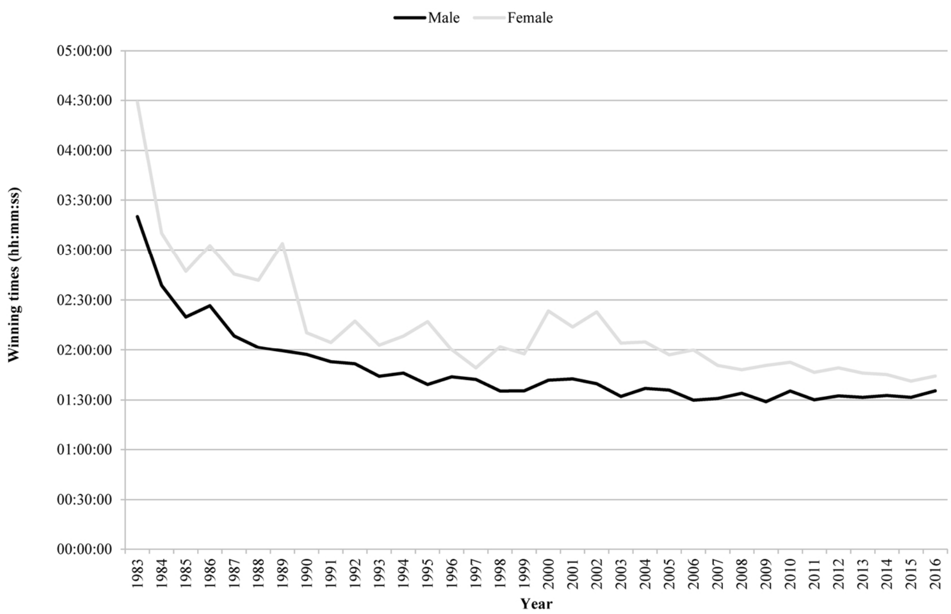

Figure 1 – Illustration of the winning times at the London marathon for the male and female events since 1983

149x98mm (300 x 300 DPI)

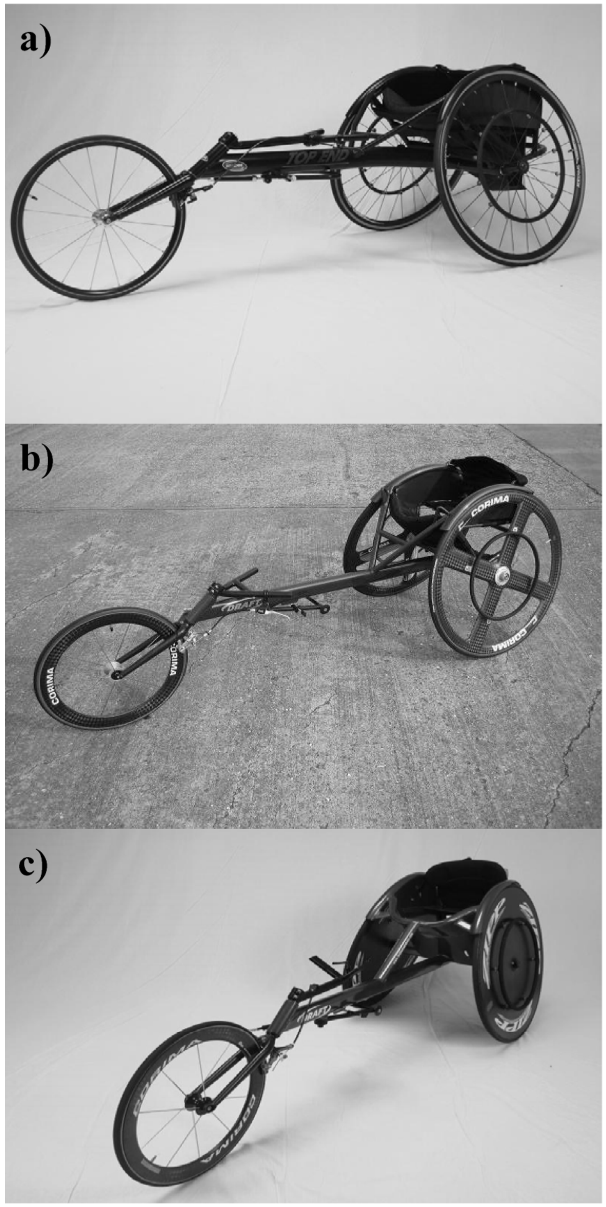

Figure 2 – Racing wheelchairs configured with a) spokes b) quad spokes and c) disc main wheels

192x386mm (300 x 300 DPI)