Understanding Fatigue and Stamina Management Opportunities and Challenges in Wheelchair Basketball

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ABSTRACT
Wearable fitness devices have demonstrated the capacity to improve overall fitness and athletic performance. Previous research has identified a need for these technologies to take into consideration a broader range of abilities to create more inclusive fitness communities. The adaptive sports community offers opportunities to explore technology use within a specialized community wherein physical activity is central to its identity. In this paper, we explore the current use and future potential of fitness technologies for stamina and fatigue management in wheelchair basketball, a team-based sport originally created for paraplegic athletes. We present findings from observations, seven interviews, and a survey (76 responses) with wheelchair basketball players and coaches. We present findings relating to their experience with and interest in automatic tracking of fatigue and stamina related metrics for themselves and their players.

CCS Concepts
• Social and professional topics~People with disabilities

Keywords
Wheelchair Basketball; Wearable; Fitness; Stamina and Fatigue Management; Adaptive Sports;

1. INTRODUCTION
Wearable technology continues to thrive and be a popular and controversial topic today. Recently, there has been a growing interest in the development of wearable fitness technologies which are suitable for people with a broader range of attributes and abilities. While many fitness devices still function primarily for able-bodied individuals, some consumer devices, such as the Apple Watch 2, have taken deliberate action to develop features specifically for users with disabilities. In addition, research projects have targeted the design and development of mobile and wearable fitness technologies for use by people with disabilities [3],[11],[17]. However, more research is needed to understand the role that wearable devices can serve for wheelchair sports to build more inclusive fitness communities.

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Figure 1. Wheelchair Basketball is one of the world's most popular adaptive sports. It is a team sport that incorporates multiple roles and is designed to be inclusive of people with differing abilities.

Adaptive sports provide an opportunity to explore physical activity within a context where there is a baseline of physical activity relating to participation in a sport. For team sports, like wheelchair basketball, there are formally defined roles, a structure of activities (e.g. training, practice, competition, etc.), and multiple people who have both individual and shared goals. Wheelchair basketball incorporates different competition levels, and people with a range of functional abilities. The sport is also structured to support inclusion of these different functional and competitive levels, in part, through their use of a functional classification system. This makes wheelchair basketball an ideal sport to study.

Quantification has been shown to contribute positively to performance and training for sports [21]. Stamina and Fatigue are an important aspect of team and player/athlete management in all competitive sports. The US Women's soccer team uses Polar heart rate monitors during their training to provide insight to coaches and develop athlete-specific training routines. Also, the World Champion German Men's Soccer team described their use of the Adidas miCoach platform and its contributions to their success in the 2014 World Cup. We use fatigue and stamina management to focus our investigation and contextualize the results among other technologies used in competitive athletics.

In this paper, we investigate the current use and potential of wearable fitness technologies for stamina and fatigue management

in the sport of wheelchair basketball. We conducted an interview study with five wheelchair basketball players and two wheelchair basketball coaches to understand habits, practices, and opportunities for fitness tracking technologies. Following the interviews, we conducted a survey with 76 wheelchair basketball players and coaches to learn about their interest in automatically tracking fatigue and stamina related metrics for themselves and their players.

Research Question. We aim to answer the following research question:

1) How can we design mobile and/or wearable technologies for wheelchair basketball players to support stamina and fatigue management?

To answer our primary research question, we must also consider the context in which this technology would be used. Thus, we also address the following questions:

a) What is wheelchair basketball and how does it differ from "stand up" basketball?
b) Who are the stakeholders involved in stamina and fatigue management in wheelchair basketball?

2. RELATED WORK

2.1 Automatic Tracking and Fitness Technologies

Pedometers have been used to record step counts and have been used to improve participation in physical activities[5],1]. Today's wearable fitness devices often build on this and can capture this information and more. Many of the commercially available wearable fitness devices, such as the Fitbit[1], can track information such as step count, calorie expenditure, and overall physical activity by tracking motion. Morris et al.'s [12] Recofit system used an armband to capture repetitive motions for strength training which makes it possible to count repetitions when lifting weights or stretching. The commercially available Microsoft Band[2] can measure many details such as distance, calories burned, motion activity, sleep activity, heart rate, steps taken, and skin temperature from a single device. In contrast, people also may use multiple devices to track these features.

Quantified Self (QS) describes the social and technical movement surrounding tracking data about one's habits and using that objective data to learn and understand one's habits [14]. MacLeod et al. [10] explored the motivations and opportunities for personal informatics to be used by people with chronic illnesses. They described the disparity between presumed and actual motivations for self-tracking and behavior change. In this case, having an understanding and control over their data motivated participants to self-track.

Whooley et al. [23] described the integration of multiple data sources to identify correlations between actions such as sleep and cognitive performance. Through the process of reflection and reintegration, the data can be used in many more ways than simply direct measurement. In addition, Rooksby et al. [18] discussed how people use tracking data from different sources. A single tracker may not give a full representation of a person's activity. They also point out that reviewing and sharing data with others can create new connections and provide a platform for sharing experiences. For this research, we explore and build on these ideas and capabilities to identify opportunities for wearable fitness devices to support wheelchair basketball players.

[1] http://www.Fitbit.com/

[2] http://www.microsoft.com/microsoft-band/

2.2 Stamina and Fatigue Management in Competitive Sports

In professional and collegiate sports, managing the health of the athletes is essential to the success of the team. Athletes are expected to perform at the peak of their ability whenever they compete and to improve they are routinely asked to perform at or beyond the edge of their abilities. Over time, performance will inevitably decrease, but strategies can be implemented to understand and reduce the performance impact. This constant boundary pushing puts a strain on the body and if not properly managed can lead to fatigue and/or injury.

Several strategies have been employed for stamina and fatigue management in competitive sports. The most effective methods involve detailed analytics, constant assessment, and are multi-faceted interventions including detailed exercise programs, nutrition regimens, mental training, and rest [1],[1][1]. Often these programs involve a significant mental training and awareness component where athletes must learn about their own bodies and abilities. Technology has been used as an effective tool to support physiological awareness and learning about one's body.

2.3 Fitness Devices for People with Disabilities

Specifically, this work focuses on fitness devices for people with motor impairments. Researchers have begun to identify a research agenda and illuminate important implications for the design of mobile fitness technologies for people with disabilities. However, more research is needed to understand the potential for wearable fitness devices among people with disabilities.

Currently, the Apple Watch with watchOS 2.0 update is the only consumer-available wearable fitness device with features to specifically address wheelchair use. It offers a wheelchair mode, which enables the ability track pushes instead of steps, and converts some exercises to be more appropriate for someone using a wheelchair.

Few research projects have explored fitness tracking for people with motor impairments. Carrington et al. [3] and Malu and Findlater [11] introduced several accessibility challenges relating to the design of fitness devices for people with motor impairments. Both Carrington et al. and Malu et al. took a general perspective on the accessibility of wearable fitness devices for people with motor impairments to identify accessibility challenges associated with using wearable fitness devices, in general. This paper identifies opportunities for the use of automatic tracking particularly for wheelchair basketball players.

3. OBSERVATIONS OF WHEELCHAIR BASKETBALL AT THE NWBT

The National Wheelchair Basketball Tournament (NWBT) attracts hundreds of athletes, annually. It is managed by the National Wheelchair Basketball Association (NWBA) We attended the tournament for the past two years (2016 and 2017) to observe the community and learn more about wheelchair basketball, the NWBA, and the rules and practices of the sport.

In 2016, we observed interactions within the community and had informal conversations with community members, players, coaches, and tournament staff. These observations informed the design of our future interviews observations at the tournament in 2017.

Participants in the fitness technology interviews mentioned that different factors of the games including game speed, scheduling, and availability of substitute players impacted their management of fatigue. During the 2017 tournament, we looked for examples of these factors and recruited for the survey and other future studies.

Competition Levels. At the NWBT, there are three levels of competition for adults: Division I, Division II, and Division III. All three of these divisions are co-ed. The NWBA also governs a collegiate division, with Men's and Women's teams, and manages the US National Wheelchair Basketball Team. Division I through III are based on the level of competition with I being the highest and III being the lowest. Players in the collegiate division may also play on a division I, II, or III team, or the national team. Elite players from any division may be selected for the National team.

Game Speed and Competition Level. We observed that Division I level games moved at a faster pace because players tended to move at higher speeds. We also observed that Division I games tended to also have a lot of time when the clock is stopped for different in game events, timeouts, fouls, and short pauses. These in-game events allow the athletes to pause for a moment before resuming the high-intensity activities of the game. This also occurred in Division II and III games, but with longer pauses and overall the pace of the games was slower.

Functional Classification and Inclusive Competition. The functional classification system is used to group players into categories based on their physical ability to execute fundamental basketball movements (Table 2). Each player is assigned a class from 1.0 to 4.5 based on their abilities. This classification is used to ensure every player has an equal right and opportunity to be an integral member of a team. According to NWBA rules, each team is allowed a maximum of 15 points total for the five active players on the court at any given time. This ensures a balance of the total functional abilities for each team.

The functional abilities of players can vary significantly and not all wheelchair basketball players used a wheelchair when they were not playing. At the end of a game, some people will roll to the sideline unstrap from their chairs and walk away. It is difficult to tell what a player's functional classification might be unless you are trained to do so. For instance, one may confuse a physical limitation for fatigue or a fatigue-related response. The classification process involves watching and interviewing individual players by a panel of classification reviewers to receive an official classification. This is one of the other roles that the NWBT serves for this community. All classifications are verified during the registration process for the tournament to ensure that no team has an unfair advantage.

Fatigue Related Incidents. At the tournament, there is a medical staff onsite in case of injuries or other emergencies. Most of these incidents involved cuts or other physical injuries. However, there were also a few instances where people received medical treatment due to fatigue, overheating, or fainting. While we observed very few of these events, it is one extreme situation relating to fatigue that could be prevented with the right prior information. These observations informed this work and the idea for automatic tracking of this information.

4. FITNESS TECHNOLOGY INTERVIEWS

We conducted semi-structured interviews with five wheelchair basketball players and two wheelchair basketball coaches. The interviews focused on understanding the opportunities for using fitness tracking technologies for wheelchair basketball.

4.1 Participants

Participant details are in Table 1. Participants were volunteers and were recruited through the National Wheelchair Basketball Association, via email, and by word of mouth. All participants in the interviews were compensated for their time.

4.2 Interview Structure

The semi-structured interviews were approximately 30 minutes and consisted of the following sections.

4.2.1 Background (~5 minutes)

This section covered demographic information about the participants, their amount of experience with wheelchair basketball, and roles they have on their wheelchair basketball teams. For players, we also covered information about their basketball wheelchair and official classification.

4.2.2 Experience with Mobile Tracking (~5 minutes)

We asked participants to describe any previous experiences they have had with mobile or wearable fitness tracking technology. We asked about their overall impressions of the devices and the experience of using them.

4.2.3 Current and Desired Tracking and Training Activities (~15 minutes)

We asked participants about the activities that they are currently tracking with respect to their individual training, team practices, and competition. These activities included sport specific statistics, drills, metrics, performance assessments, as well as fitness related activities. We also asked about desired or potential activities that participants would like to automatically track using mobile or wearable technologies.

4.2.4 Ideal Mobile Tracking Solution (~5 minutes)

In this section, we asked participants to describe their ideal mobile tracking solution or device and its capabilities. We asked participants to describe the potential benefits of this proposed technology. We also asked questions about any existing restrictions that might limit the use of such a technology in training, practice, or during competition.

4.3 Analysis

Each interview was transcribed and coded. We used a thematic analysis approach to code the interview data and identify relevant themes based on the interview transcripts and field notes from observations. Resulting themes included device requirements, fatigue management, past experiences, wheelchair basketball routines, tracking behaviors, and desired information.

4.4 INTERVIEW FINDINGS

The findings from the preliminary interviews will be presented in the following subsections based on the structure of the interview provided above.

Table 2. Description of the functional classification system. Adapted from NWBA functional classification descriptions http://www.nwba.org/page/show/2023335-functional-classification.

Class	Description
1.0	No active movement of the trunk in the vertical, forward or sideways plane.
1.5	Has characteristics of a class 1.0, but more trunk stability
2.0	Has active use of upper trunk in the vertical and forward planes, able to rotate the upper trunk while upright in both directions, able to hold the ball forward with both arms extended, able to lean the trunk into the forward plane about 45 degrees with control and return to the upright sitting position, able to actively bring upper trunk off the backrest of the chair, and uses hands to return to upright of trunk if no thighs-unless knees are significantly higher than the hips.
2.5	Has characteristics of class 2.0, but able to lean forward and return to upright sitting position possibly with difficulty
3.0	Displays active use of the upper and lower trunk in the forward and vertical planes: Can lean forward 90 degrees, placing chest on thighs and return to upright with ease without knees significantly higher than hips, can hold the ball with both hands outstretched in front of face without loss of stability, can rotate upper and lower trunk as a unit not supported by wheelchair backrest, rotation of the trunk occurs at the level of the pelvis not the waist, unable to maintain stability leaning sideways, and works within a 'Cylinder'
3.5	Has characteristics of a class 3.0, but able to move partially out into the sideways plane and return to upright sitting, able to remain upright in hard contact situations forward, able to sit with hips higher than knees, often raises and lowers trunk with each push, able to generate some power in legs with pushing, able to retrieve a ball with two hands on the floor slightly to the side and return to upright position, can lean to the side but remains within his base of support, plays within a WIDER cylinder than a Class 3.0 player, does not have full volume of action to either side.
4.0	Displays the ability to move the trunk maximally in all planes of movement with weakness to one side, has one strong side and one weaker side, can hold the ball with outstretched hands in front or overhead without loss of stability even in contact situations, no need to counterbalance even in contact situations unless contact is forceful and directed into the weaker side.
4.5	Displays the ability to move the trunk maximally in all planes of movement with no significant weakness in any direction, full volume of action in all planes, displays ability to lean to either side during shooting, passing, contesting a shot or trying to intercept a pass.

Table 1. Demographics and Background of Participants

ID	Age	Gender	Years Exp.	Class	Occupation
P1*	ND	Male	25	N/A	Coach
P2	26	Male	15	1.0	Academic Advisor
P3*	31	Female	3	N/A	Adaptive Sports Coordinator
P4	26	Male	14	1.0	Engineer
P5	34	Male	20+	2.5	Receptionist
P6	38	Male	7	1.0	Recreational Director
P7	23	Male	<1	3.0	Accountant

*This participant was a coach

4.4.1 Previous Experience with Tracking

Participating in organized competitive wheelchair basketball exposed each of our participants to some aspect of tracking or quantifying their performance. However, for the purposes of this research we focused on automatic tracking using some type of mobile or wearable device. Three of the five players had experience using a mobile or wearable fitness tracker.

P2 used a Fitbit but did not have a great experience with it:

"I have tried a Fitbit for a little bit, for a little while…but I had troubles with it actually tracking how much activity I had. I mean like I don't take steps of course but I got to the end of the day and it had 500 steps for example. or umm the actual miles. all the calculations seemed roughly quite off. umm I don't know it just doesn't recognize movements the same way… but it definitely wasn't correct…"

"I tried it for 2...2 weeks I think. [I got it because] I liked the idea behind the accountability you could have with other people. umm to kind of push each other. for me it didn't do a whole lot for me." -P2, Player

P4 also used a Fitbit but had a better impression and still uses the device:

"I have a Fitbit… um it tracks it does track my steps and heart rate and calories burned and all that sorta stuff. um I just have the simple version of the Fitbit I don't have the fancy one with the touch screen and all that…Yeah, I find it useful I like it. It does keep track of things pretty well I feel like. so I do like it…I've had it for a little over a year now…" –P4, Player

P5 owns an Apple Watch and likes what it currently does for him, but would like it to do more:

"I do have an Apple Watch. That I use… I think it works pretty well you know there's a few things that I don't that I don't necessarily care for like it doesn't. It keeps track of your pushes but it doesn't keep track of the miles you know so it will tell you you've done 2000 pushes but I'm like ' well how far is that?' but I guess it's kind of push is different for everyone"

– P5, Player

The remaining two players did not have direct experience with automatic tracking but had either seen or heard of others using fitness devices.

4.4.1.1 Summary of Previous Experience

Participants had mixed experiences with fitness tracking devices. Three players had direct experience with a device either a Fitbit or Apple Watch. Two participants were not satisfied with the information provided by their devices. One participant stopped using the device because of this. The other participants had not used a device themselves.

4.4.2 Current and Desired Tracking and Training Activities

Current Activities. Participants mentioned several activities that they currently track as part of their training and preparation:

P4 described how he wears his Fitbit, measures the time it takes for him to perform different exercises, and his shooting percentages:

"When I have been training, I like to like time certain exercises in terms of agility and speed and that sort of thing. And then in terms of shooting just kind of count uh percentage wise say I shoot 50 shots form a spot um just kind of keep track of how many makes and a percentage." – P4, Player

P5 mentioned using his Apple Watch to track his activities in practice:

"I use it when I work out. just uh when I'm playing basketball I'll war it at practice and stuff just to know how far I've gone or whatever, you know, as far as pushes and you know burning calories it keeps track of that and you know your heart rate and all that fun stuff too." – P5, Player

Coaches Perspective

P1 described how as a coach measuring and assessing performance is part of the regular routine for training:

"We do preseason testing...testing for med ball throws, chin ups, bench press, baseline to free throw sprint and then 20meter sprint, with and without the ball…[We measure] time and power output…We have laser timers for all of our sprint work.

We'll do 30-minute drill every day and they have to complete it and give us their time. So for beginners they'll come in and it'll take them the whole 30 minutes. Our guys that have been here 3-4-5 years they can now complete it in 18-21 minutes. So, we use that kind of as a bench mark for fitness." – P1, Coach

Desired Activities. In addition, participants expressed an interest in tracking the following metrics and activities:

P2 was interested in tracking the distance travelled as well as speed and acceleration:

"I don't know if you ever see an NFL game I think it would be interesting to see the distance travelled. Some people might go straight down the court and back. other people are picking, and they're um hand on the ball and going around all sorts of people., you know they might travel twice as far in the same vertical distance." –P2, Player

"I think uhh different speeds like a top speed or acceleration track could be measured. or like stopping distance. Like somebody is flying down the court and they they power stop how quickly do they stop. a deceleration over a long range?"

–P2, Player

P4 described his desire for having something to give warning signs for fatigue before it becomes a problem:

"Instead of waiting to actually feel tired and waiting for that fatigue to actually set in if this technology can like give you a sign beforehand. like hey you're running low or you're slowing down type of thing. um that could kind of be proactive and prevent that. that fatigue from setting in." – P4, Player and Coach

He also mentioned that heart rate could be beneficial for measuring fatigue:

"I think heart rate would be beneficial. I don't know what else I don't have a great medical background in terms of signs and stuff for fatigue that would be useful for that."

– P4, Player and Coach

Coaches Perspective

In addition to individual metrics described by and for individual players, coaches were also interested in determining the position of players on the court at different times:

"Their movement their position um where they are and let's say a certain player you can pull that up and say look on this play you were over here whereas maybe you should have been in this position type of thing." – P4, Player and Coach

4.4.2.1 Summary of Current and Desired Tracking

Players and coaches engaged in tracking different activities currently. Two players described using their existing devices to track their physical activity during practices. Coaches also described their measurement and tracking routines. They also described desired tracking activities, providing individual metrics of interest such as distance travelled, heart rate, player movements, and positions.

4.4.3 Ideal Mobile Tracking Solution

Participants suggested locations on the wheelchair to attach devices and sensors. P2 suggested a location under the seat of the chair would be a safe place:

"There's like a cross bar under there um that doesn't have direct contact with other wheelchairs so if you fall down you're not going to crunch it. If there was a way to secure it to that I think that would be the probably safest point." – P2, Player

He also suggested that wearing something on the body might also be permitted:

"I mean yeah you could wear a head band or a sleeve, an arm band...I don't know if you could integrate it into one of those...I don't see any reason why a ref would tell you to take it off." – P2, Player

P4 also suggested that wearing a chest strap for respiration might be desirable. P5 described his desire for something that could attach to his chair but also something that might contact the body:

"You could possibly use it if it was attached to the chair someway for sure. and it wasn't so big and bulky you don't want it to be heavy. but like a wrist band would work. and then also we have like a click strap which are basically like ski straps that clench down into your chair. If you could figure out most people have wrist bands that they put over the clicky part to keep you from, you know getting jabbed by it if you fall on them, so something in there could work. If you could figure that out, it'd be a good place for something." – P5, Player

The descriptions of an ideal mobile tracking solution seemed to be as much about what to track as how and when it is tracked. Participants identified important considerations for both personal

preference and adherence to the rules, regulations, and practices of people who play the sport.

"Everybody pushes harder in games. everybody goes harder in games. um you may not get the same effect in practice when maybe you're not going at 100% or you're not in that high speed environment of a game. so, I think it would be more beneficial in game." – P4, Player

P7's discussed how a device that detected movement and speed information might useful at the national level of competition:

"I think probably to have like a national level it would probably apply the most. I don't see why you wouldn't want to do that if you're at the national level and if I were them I would already be doing that. I just think at that point its one way to measure yeah measure any type of show or perform with it. and I just think from a health perspective there some way to kind of motivate." – P7, Player

He also described that such a device might also be useful for people at every level but would likely be too expensive for newer players, like him, to make that kind of investment. Three other participants also mentioned that tracking information like this might be most useful at elite or national levels, since they are more likely to use that type of "analytical information".

Coaches Perspective

Coaches confirmed possible form factors by were generally interested in having more information about their players. One coach described the lack of options out there and the opportunity for improvement:

"It is a wide-open space. There's nothing out there but we definitely need information if were gonna maximize our training with our athletes just like with the able-bodied athletes." – P1, Coach

4.4.3.1 Summary of Ideal Mobile Tracking Solution

Participants described that a solution for mobile tracking might involve attaching sensors or devices to the wheelchair. These devices would need to be attached in such a way that they would be shielded or out of reach from collisions or contact with other players. On-body sensing devices would need to take on the form factors of existing, approved, athletic equipment. This includes headbands, hats, a chest strap or fabric. Both coaches and players were interested in new information regarding their performance. However, given that few people use devices every day, participants especially one coach felt that there is an unmet need for more information.

4.5 Summary of Fitness Tech Interviews

Participants in the interviews had some experience with automatic tracking for fitness but, as expected, all were concerned with their performance and assessment of their goals or team's goals. Specific metrics such as heart rate, number of pushes, and speed were mentioned as well as several different basketball related activities or situations for when this information might be useful. These interviews were used to focus our observations and survey questions. The results from the interviews informed the design of the survey questions including desired metrics and activities.

5. NWBT SURVEY

We conducted a survey to learn more about wheelchair basketball players' and coaches' interest in automatic tracking for stamina and fatigue management. Specifically, we were interested in the following questions:

1) How interested are players and coaches in automatic tracking for fatigue and stamina management?
2) What are players' and coaches' motivation for automatically tracking stamina and fatigue related data?
3) What are the potential benefits of collecting this information?
4) What concerns do players and coaches have with automatically tracking this kind of data?
5) What form factor preferences do players and coaches have for devices to automatically track this data?

5.1 Survey Design

The survey consisted of 19 questions and took approximately 10-15 minutes to complete. We designed the survey to be short so it could be completed during breaks at the tournament, while allowing an opportunity for participants to take part in future interviews. The survey was divided into 2 main sections, one for players and the other for coaches. If a person was a player, but had no experience with coaching, they were not presented with the section for coaches, and vice versa. Each of the two sections consisted of ~9 questions asking about the following:

- Levels of competition (National, Division I,II,III)
- Functional classification (Table 2)
- Overall Interest in Automatic Tracking of S&F
- Interest in- Stamina and Fatigue related metrics (derived from interviews)
- Open-ended questions about motivations, potential benefits, and concerns related to automatic tracking

The survey was administered online through Google Forms and available for two weeks following the start of the tournament.

5.2 NWBT Survey Results

The survey link was shared with all players and coaches who registered with an adult team at the 2017 NWBT (48 teams). There was a total of 94 responses. We checked the responses for erroneous data (entering short answers to numerical questions etc.) and incomplete responses (blank sections, multiple skipped questions, etc.) and removed those entries. We ended with a total of 76 responses representing 59 players, 7 coaches, and 10 who were both players and coaches. Each of the five adult competitive divisions and eight functional classes are represented in the sample (Table 3 and Table 4). The results of the survey are summarized in the following subsections.

5.2.1 Interest in Automatic Tracking

Participants were asked to indicate their level of interest in automatic tracking both overall and their interest in specific metrics on a 5-point scale from "Not Interested" to "Extremely Interested". Overall, the results of the survey confirm that there is interest from both players and coaches in automatically tracking this kind of information. More than 85% of players and more than 97% of coaches indicating that they were at least "Somewhat Interested" in tracking. The distributions of overall interest levels are shown in Table 5. Coaches were extremely interested in automatic tracking because of the benefits it could provide their team in the form of information.

Table 3. Highest Competition levels for Players and Coaches.

Players		Coaches	
(Inter-) National	6	**(Inter-) National**	2
Division I	15	**D1**	2
Division II	20	**D2**	3
Division III	20	**D3**	5
College	8	**College**	2
		Varsity	3
Total	69	**Total**	**17**

Table 4. Functional Classification of Survey Participants

Classification	Number of Players
1.0	10
1.5	4
2.0	8
2.5	11
3.0	9
3.5	4
4.0	9
4.5	10
Not Provided	4
Total	**69**

Table 5. Overall Interest in automatic tracking of stamina and fatigue for Players and Coaches.

	Players (n=69)*	Coaches (n=17)*
Extremely Interested	18.8%	43.8%
Very Interested	24.6%	18.8%
Somewhat Interested	42.0%	31.3%
Slightly Interested	13.0%	6.3%
Not Interested	1.4%	0.0%

***These sample includes 10 responses from players who were also coaches. These responses were counted for both groups.**

We also asked participants to rate their interest in specific metrics that were identified through the interviews. Those metrics included "Number of pushes", "Movement/Speed", "Heart Rate", "Distance Travelled", and "Respiration". Only coaches were given the option for "Position of players" due to an interest expressed during an interview. Coaches wanted to know whether players are in correct the positions, or locations, at different times. The results are summarized in Table 6 and Table 7.

Table 6. Distribution of level of interest in individual metrics of players about themselves.

	Extremely Interested	Very Interested	Somewhat Interested	Slightly Interested	Not Interested
Number of Pushes	20.3%	31.9%	34.8%	7.2%	5.8%
Movement/ Speed	34.8%	37.7%	17.4%	7.2%	2.9%
Heart Rate	26.1%	36.2%	26.1%	8.7%	2.9%
Distance Travelled	29.0%	24.6%	34.8%	8.7%	2.9%
Respiration	30.4%	36.2%	24.6%	8.7%	0.0%

Table 7. Distribution of level of interest for individual metrics of coaches for about their players.

	Extremely Interested	Very Interested	Somewhat Interested	Slightly Interested	Not Interested
Number of Pushes	52.9%	29.4%	5.9%	11.8%	0.0%
Movement/ Speed	82.4%	11.8%	5.9%	0.0%	0.0%
Heart Rate	52.9%	35.3%	11.8%	0.0%	0.0%
Distance Travelled	47.1%	23.5%	11.8%	5.9%	11.8%
Respiration	64.7%	23.5%	11.8%	0.0%	0.0%
Position of Players	52.9%	17.6%	29.4%	0.0%	0.0%

5.2.2 Device Form Factor Preferences

Survey participants were asked to indicate their preferred form factors for a device by choosing from four options shown in Table 8. Each participant could cast multiple votes for multiple options. For players (91 total votes), "something that could attach to either" receiving the most votes, followed by "part something you wear and part something attached to the chair", then "something that attaches to your chair", and finally "something you wear on your body". The results for coaches (23 total votes) were similar. However, there were equal number of votes for "something that attaches to your chair" and "part something you wear and part something attached to the chair". Form factor results are summarized below in Table 8.

Table 8. Summary of form factor preferences indicated by survey participants.

Form Factors [Something worn on]	Players (For Self)	Coaches (For Players)
Body	12	3
Chair	19	5
Either, Body OR Chair	34	10
Both, Body AND Chair	26	5
Total	**91**	**23**

6. DISCUSSION

6.1 Fatigue Management – Self vs Team

Overall, fatigue and stamina management are important to playing the game of wheelchair basketball and being competitive. However, there is an interesting transition from different levels of competition. One of the most important distinctions to make is that of the player and the coach. First, players are interested in automatic tracking primarily for self-management of their own performance. In contrast, coaches are interested in their players' information primarily to manage the team, and secondary to manage individual players.

There were several central ideas relevant to the discussion of fatigue management that we noticed through the observations, interviews, and survey.

Awareness. One such idea is this concept of awareness. Four players were interested in learning more about themselves and having a better sense of their bodies. All three coaches expressed interest in improving their awareness of their players. As stated by one player and two coaches, managing fatigue is often a shared responsibility between player and coach.

There is a difference between what a player may want for their own self-management and what that same person may want when assuming the role of a coach. This appears to be related to the idea of awareness. As a coach, your job is to manage the team and thus rely on information to make informed decisions and plan strategy.

Management of Individual Training. Two coaches and three players described the benefits of knowing more about individual players, to better tailor training programs to individual needs and set better individual goals. As demonstrated by the Olympic soccer teams' example[3,4], this can make a huge difference when preparing for intense competition and keeping players healthy. This idea has been explored briefly through a pilot study which provided a data set relating to player activities in rugby and basketball [21]. The researchers suggested that the dataset might be useful in replicating game conditions during practice sessions. Our findings also support this use case for automatically tracked information. In addition to game information, players may take advantage of recorded metrics to compare their performance across practices or for assessment purposes.

Management of Team Strategy. Two coaches and one player described the coach's responsibility of managing team strategy and substitutions. Given the functional classification requirements for active players, it is important to make smart decisions when substituting players. Coaches in the survey mentioned one of the potential benefits would be if the automatic tracking would be able to assist with managing their line-ups. A participant in the interviews also mentioned this idea of making smarter substitutions based on automatically tracked real time information.

6.2 Movement and Biomechanics

Athletes and coaches were excited about the idea of automatically tracking motion and muscle activity as they related to the biomechanics of the different motions they make. For instance, one participant was intrigued by the idea of being able to better understand his muscle activity as he performed pushes in different situations to ensure he was getting the most power that he could out of every push. One survey participant also mentioned their motivation would be to learn to "push smarter, not harder". This is important to the management of fatigue because it allows players to make efficient movements. Improving the efficiency of movements improves a player's ability to maintain their performance for longer periods of time.

As P1 pointed out, it is important to understand how each person is moving to make sure you are doing what is right for them. Given the varying degrees of motor impairment and function it is important to understand each individuals' potential and challenges.

"I would like to know how each athlete is generating power so that we can see actually what functionally they have access to, and how we can help them maximize their functional capacity." – P1, Coach

This information would allow coaches to intervene more effectively:

"You could uh identify it early enough to not get into some of the bad habits. Are they using the hip flexors or are they using the triceps or lats? What are they using to generate power in their push or their stops? Umm…I think to be able to see that in their training and can use that to teach stroke mechanics and maximizing their stroke technique. That would be mean more to me…" – P1, Coach

6.2.1 Injury and Fatigue Prevention

Shoulder pain is a common condition among wheelchair users especially for wheelchair basketball players. A study conducted by Curtis and Black [8] described the prevalence of shoulder pain among female wheelchair basketball players. They also describe movements in wheelchair basketball involving the upper body that lead to upper body soft tissue injuries. Shoulder injury is very prominent among wheelchair basketball players and has been studied in relation to other factors [24][20].

6.3 Form Factor and Device Preferences

The interview and survey results confirm the opportunity for a device to be used to support wheelchair basketball players and teams. Interview participants described characteristics of existing devices that they liked including common form-factors like wrist-worn devices, chest straps, or ankle-worn devices. There were also some other devices that people were interested in using such as a smart basketball:

"You know they have like the basketball that like knows your form or whatever and knows the rotation of the ball and something to incorporate that into your training would be nice. To have some kind of wearable technology that knows the angle of your shot or where you release it or something like that." – P5

Participants also mentioned how feedback might need to be interpreted by coaches. P4 said:

"The coach would have to be trained in terms of what those that information that you're receiving back really means. So, I don't know if any coach would be able to be like oh this person's level of oxygen or whatever is low. take them out or whatever so I mean there would necessarily need to be some training involved." – P5, Player

[3] https://www.sporttechie.com/u-s-womens-national-team-training-polar-wearables/

[4] http://www.geekwire.com/2015/german-national-soccer-team-used-wearable-technology-win-world-cup/

6.3.1 Wheelchair-Attached Sensing

From the survey, we confirmed that having an option or combination of locations (on-body and/or wheelchair-attached) for devices would be preferable. This is consistent with findings from related work suggesting the use of the wheelchair to deliver solutions [3]. Players suggest utilizing the space around and under the seat to attach devices. The reason for this suggestion is to avoid direct contact between the device and other players. Due to the nature of the sport, it is important that devices are out of the way for the safety of the wearer as well as other players they encounter during a game. Sporner et al. [21] utilized a miniature data logger (MDL) to collect quantified measurements of activity for wheelchair users. This approach has been used in other settings to learn about everyday characteristics of manual wheelchair use among veterans[22] and children[7]. The MDL requires processing of the data after the activity is completed. Given the advancement of current and emerging fitness tracking technologies and sensing, more real-time or near-real-time feedback is expected from participants.

6.4 Community Characteristics

The wheelchair basketball community is structured to allow competition at multiple levels and to incorporate people with different abilities at all levels. The functional classification system allows someone who might have low functional motor abilities to compete at all levels based on their basketball skill. Also, there is a strong commingling of people who play professionally, internationally, and recreationally across different teams and levels of competition. While a minimum documented disability is required to play the sport officially, this is not a requirement for coaches or people who want to play recreationally. Thus, the sport itself while adaptive is not closed to people who would be considered "able-bodied". Informally, an able-bodied person would receive a classification of 4.5 to keep the teams balanced.

7. Limitations and Future Work

Some limitations of the survey were that the data discussed here is ordinal data and may not provide a consistent scale between options on the 5-point scale. In addition, given the small samples and uneven groupings of participants by class or competition level, we would be unable to perform proper between-group comparisons for their preferences.

For future work, we intend to collect additional data to explore comparisons by competition level and functional classification. We also intend to more deeply explore the interface requirements for the proposed class of devices to support the unique and shared needs of players and coaches at all levels.

8. Conclusions

This research explores the development of mobile and wearable devices for automatic tracking of stamina- and fatigue-related information for the sport of Wheelchair Basketball. In this paper, we described an exploration into how automatic tracking might be used by wheelchair basketball players and coaches to support stamina and fatigue management. We conducted an interview study to identify potential metrics and uses for automatic tracking. We presented the results of a survey with 76 people, including 69 wheelchair basketball players and 17 coaches, to validate our interview findings and capture a more general sense of the interest in stamina and fatigue management.

This research provides new insight for mobile and wearable technology designers to improve existing solutions and to create new systems that provide relevant feedback for this population of athletes. We intend to expand this research to include other adaptive sports. Our goal is to create more versatile mobile and wearable technology solutions that are useful in different active situations.

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