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WheelPower: Wheelchair Sports and Data Science Push It to the Limit

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Abstract

Paralympic wheelchair athletes solely depend on the power of their upper-body for their on- court wheeled mobility as well as for performing sport-specific actions in ball sports, like a basketball shot or a tennis serve. The objective of WheelPower is to improve the power output of athletes in their sport-specific wheelchair to perform better in competition. To achieve this objective the current project systematically combines the three Dutch measurement innovations (WMPM, Esseda wheelchair ergometer, PitchPerfect system) to monitor a large population of athletes from different wheelchair sports resulting in optimal power production by wheelchair athletes during competition. The data will be directly implemented in feedback tools accessible to athletes, trainers and coaches which gives them the unique opportunity to adapt their training and wheelchair settings for optimal performance. Hence, the current consortium facilitates mass and focus by uniting scientists and all major Paralympic wheelchair sports to monitor the power output of many wheelchair athletes under field and lab conditions, which will be assisted by the best data science approach to this challenge.

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1 Project overview

Paralympic wheelchair athletes solely depend on the power of their upper-body for their on-court wheeled mobility as well as for performing sport-specific actions in ball sports, like a basketball shot or a tennis serve. Wheeled mobility is dependent on power output

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and can be measured in a standardized lab environment and to a certain extend during training and competition. Wheelchair athletes adhere to very intense training programs, but they until recently lacked sport-specific tools for objective monitoring of power production, essential to performance [5]. Moreover, different wheelchair sports are performed by a relatively small group of athletes with a plethora of different impairments due to trauma or disease (Paralympic.org). This has resulted in limited and scattered scientific knowledge directly applicable to their sports practice [1]. For instance, only recently the extra peak power necessary to propel the wheelchair, while simultaneously holding a tennis racket, was shown [3]. Hence, little is known about the biomechanical and physiological demands of the wheelchair sports, impeding the possibility to provide coach and athlete with essential feedback to achieve both individualized and team performance optimization through training, wheelchair design and fitting, and game strategy.

Fortunately, The Netherlands already has a strong research history on the use of manual wheelchairs by multiple knowledge partners, like VU Amsyterdam, TU Delft, University op Groningen and The Hague University of Applied Sciences. Together they approached the Paralympic Wheelchair Sports, represented by NOC*NSF and their individual sports federations. Together we opened the discussion and formulated the correct research questions, endorsed by all parties. Multiple sessions were organised with all stakeholders invited. Bringing together the needs of all partners and understanding each other has been one of the challenges already before, but also during the project. For example, the needs of coaches and players must be balanced with time that was asked for participating in structural measurements over the season, leading up to big tournaments. Therefore, seeing the immediate benefits and feeling that it improves their preparation was and is critical to the project.

More discussions and improved mutual understanding have already been benefits of the WheelPower project and have helped to make a stronger connection between Science and wheelchair sports. Given the strength of having multiple Paralympic wheelchair sports (wheelchair-basketball, -tennis, -rugby, -racing and paratriathlon) buy-in on this project, it became also more interesting to our commercial partners, who saw opportunities to improve their commercial products based on the expected generated knowledge. Similarly, the rehabilitation centers perceived the projects" possibility for knowledge translation to patient rehabilitation as very useful and became consortium partner. In total 17 partners signed the consortium agreement, which was a major effort, but has been instrumental to the strength of the project.

2 Problem addressed

The objective of WheelPower is to improve the power output of athletes in their sport-specific wheelchair to perform better in competition. To achieve this objective the current project systematically combines the three Dutch measurement innovations (WMPM, Esseda wheelchair ergometer, PitchPerfect system) to monitor a large population of athletes from different wheelchair sports resulting in optimal power production by wheelchair athletes during competition. The data will be directly implemented in feedback tools accessible to athletes, trainers and coaches which gives them the unique opportunity to adapt their training and wheelchair settings for optimal performance.

The main research question is: what are the performance indicators for optimal power production by wheelchair athletes during competition and how are they improved using continuous performance monitoring, combined with direct feedback? The sub-questions are:

1. How do the power demands, monitored during training and competition, compare to the maximum measured power production capabilities of wheelchair athletes?
2. What is the biomechanically optimal technique for efficient power transfer from the upper-body into the wheelchair-sport specific goals? For instance, how does timing of subsequent rotation of (upper-)body segments affect the efficiency of power transfer when pushing the hand rims, or when hitting the ball with the racket during wheelchair tennis?
3. How does direct feedback on the performance indicators for power production in wheelchair sports actions improve the competition performance of wheelchair athletes?

Multiple reasons explain the barriers that have caused wheelchair sports to fall behind in performance monitoring relative to other (wheeled) sports. First, upper-body cyclic physical activity is fundamentally different from lower-body tasks such as cycling, hampering knowledge translation from able-bodied sports [9]. Unlike the legs, the arms are essentially equipped for apprehension and 3D-manipulation of objects rather than heavy work such as load bearing. Therefore, the arms need constant joint stabilizing muscle activation, while the diversity of small muscle units has a low total muscle mass and thus power output, making them more injury prone [16]. Second, the mode of hand rim wheelchair propulsion is categorically different from any other form of ambulation, since during each propulsion cycle both hands need to bimanually couple to rotating rims outside the visual field in a discontinuous propulsion mode [17]. Third, the wheelchair design and sport-specific nature make the use of regular power sensors (e.g., Powertap [18], SRM [2]) as used in cycling, unfeasible. In addition, force instrumented hand-rims (e.g., SmartWheel [10], Optipush [6]) as used in more fundamental wheelchair research, are bulky and have too much impact on the mass and inertia of the light-weight sports wheelchair. Last, as stated earlier, the heterogeneity of wheelchair athletes – among others due to variation in impairments – has previously limited quantitative large sample size studies that generalize research insights to the whole group of wheelchair athletes.

The above-mentioned gaps of 1) monitoring power output in the lab and on the field in a 2) large sample of wheelchair athletes are addressed in WheelPower as follows. From different perspectives the Dutch research groups have shown leadership in the development of new technologies applicable to wheelchair sports to obtain objective performance measures, such as external power output in the field and in the lab (Figure 1). First, the Wheelchair Mobility Performance Monitor (WMPM) is an Inertial Measurement Unit (IMU)-based field solution to measure the overall on-court power demands during training and competition [14]. Second, the Esseda wheelchair ergometer is a high-resolution measurement tool to analyse how power is optimally delivered by an athlete under standardized repeatable conditions in their personal sports wheelchair [4]. Third, the PitchPerfect system is also an IMU-based tool, originally developed for pitching in baseball but also employable in wheelchair sports, to provide coaches and athletes of feedback on motion timing and power production through the kinetic chain in throwing and hitting [11]. In this project, the methodology of the PitchPerfect will provide insight in upper extremity movements and joint angles during propulsion and other wheelchair sport related upper-extremity activities. By implementing these three new technologies in all five Paralympic wheelchair sports, power output will be monitored in a large group of wheelchair athletes.

In conclusion, the current consortium facilitates mass and focus by uniting scientists and all major Paralympic wheelchair sports to monitor the power output of many wheelchair athletes under field and lab conditions, which will be assisted by the best data science approach to this challenge.

Figure 1 Figure 1: The Wheelchair Mobility Performance Monitor (WMPM) is an Inertial Measurement Unit (IMU)-based field solution to measure the overall on-court power demands during training and competition. The Esseda wheelchair (WC) ergometer is a high- resolution measurement tool to analyse how the power is optimally delivered by an athlete under standardized repeatable conditions in their personal sports. Third, the PitchPerfect system is also an IMU-based tool, originally developed for pitching in baseball but also employable in wheelchair sports, especially wheelchair tennis, to provide coaches and athletes feedback on motion timing and power production through the kinetic chain in throwing and hitting.

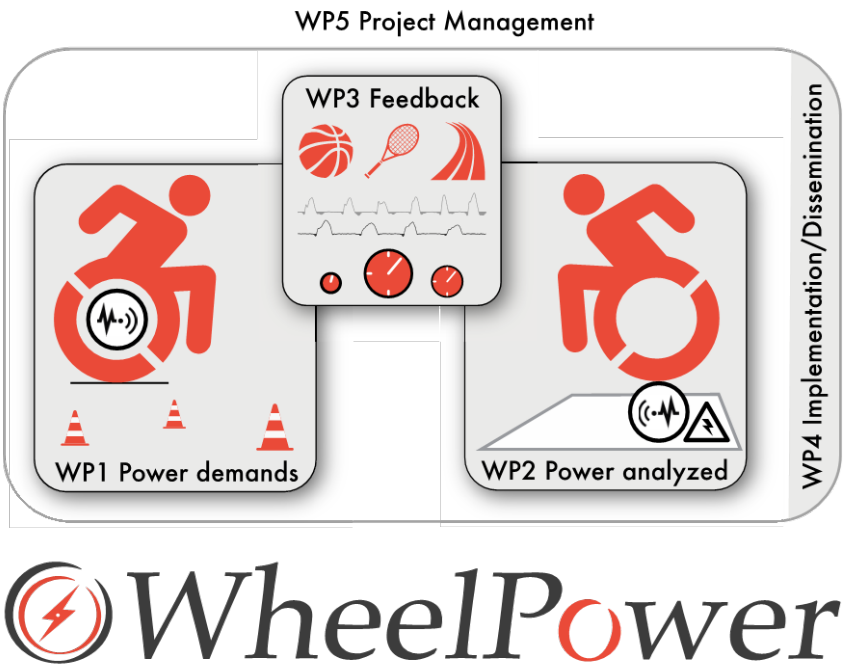

Figure 2 Figure 2: The WheelPower work packages (WP) as part of the consortium design.

3 Project consortium

Three main work packages form the core of the project (Figure 2). One Post-doc-and two PhD researchers are the main persons executing the research, i.e., perform the measurements and write scientific paper as well as provide feedback of the outcomes and discuss these with coaches, players and embedded scientist. They all function within the specific consortium teams with assigned work package leaders. To coordinate the whole project a three weekly meeting structure has been put in place with an alternating big and small team assembly. In the small team the project-leader talks with the three main researchers and their daily supervisors, while the other meeting assembles everybody involved from the research partners.

To maintain good communication with all people involved, a yearly meet-up is organised, with additional discussion with the strategic partners from the different Paralympic sports. For a wider audience a regular newsletter is maintained coupled to our website (`www.wheelpower.online`). Social media through Instagram, Twitter and LinkedIn have been very active and well followed. Especially athletes sharing their measurements through Instagram has been a strong addition to the visibility of the project and has helped to motivate other athletes to participate. Twitter and LinkedIn have been very useful for international visibility and making new connections to interested parties. The partners formalised in the WheelPower consortium have also extended and intensified their formal collaboration around Paralympic Science Support, not only for wheelchair sports, but now for alle Paralympic disciplines. This consortium now has a dedicated coordinator positioned at Kenniscentrum Sport en Bewegen and will help strengthen what was gained through the WheelPower project.

Regarding knowledge sharing and implementation we adhere to Open Science principles. All scientific papers are open access available, as well as most of the data analyses tools (`https://pypi.org/project/worklab/`).

4 Key results

The main outputs of WheelPower are (1) the addition of the power output to the WMPM (used in training and competition), (2) the development of test protocols to measure the (an)aerobic capacity of elite wheelchair athletes and (3) the applications of the WMPM during competition.

The first work packages add the estimation of power output to the already existing WMPM (Figure 3). This project started in a lab environment on an extra-large treadmill and several measurement devices were combined to objectively measure the power output produced by the individual. Based on these "golden standard" measurements, three IMU sensors (on the wheel, frame and trunk) were trained with machine learning and provided an accurate estimate of the power output. With the addition of power output to the WMPM, it becomes possible to monitor the training load of the players throughout the season to prevent injuries and perform maximally during major competitions [15].

The second work package ensures the successful implementation of wheelchair-specific anaerobic and aerobic exercise testing in all five Paralympic wheelchair sports. The standardized, yet individualized test protocols to test these maximal (an)aerobic capacities have been developed in WheelPower (Figure 4). First, an extensive literature review was written that provided an overview of all studies that addressed the wheelchair-specific anaerobic and/or aerobic exercise capacity [7]. After that, these different test protocols were synthesized into a test protocol that can assess the exercise capacity in a diverse group of wheelchair athletes, using a standardized, yet individualized way [8]. After validating these test protocols, they have been used for regular monitoring of Dutch athletes from the five Paralympic wheelchair

Figure 3 Figure 3: Wheelchair racing measurements on a treadmill for sensor-based power estimations.

sport disciplines. For example, the elite wheelchair tennis players monitor their (an)aerobic performance bi-annually and in cooperation with trainers, embedded scientists and coaches, training of the athlete is optimised. Another example can be found in the wheelchair set-up: a wheelchair rugby athlete improved his seating and asymmetry with a different seating position and a wheelchair triathlete is now wheeling with a different size of hand rim. The implementation of these test protocols worked because WheelPower closely collaborated with coaches and embedded scientist from the national teams.

The third work package implemented the WMPM for daily monitoring during important competitions (Figure 5 and 6) [13, 12]. To improve the evidence-based classification system of wheelchair rugby, measurements have been conducted at the World Championships of wheelchair rugby. Several athletes from different national teams performed standardized field tests and were monitored during the actual competition. By combining these two, we aim to get more insight in the relation between coordination impairments and performance. For instance, the role of muscle strength on wheelchair tennis performance is investigated to improve athlete classification, in collaboration with the International Tennis Federation. Lastly, in cooperation with Basketball Experience NL, a feedback system is developed which makes it possible to present live performance feedback from the IMU sensors directly to the audience or as a live-stream overlay during a match.

5 Further steps

Multiple future steps for the results and products of the WheelPower project are foreseen.

The first is making sure that the products and knowledge of the WheelPower project have a sustainable future in the sports they were developed for. To that end, Sports Data Valley is an important automation partner that will help secure the infrastructure and analyses tools. That way, in the future every athlete, coach, sports-professional and research will have a privacy-proof platform where the performance portfolio is stored, maintained and accessed to keep profiting from participation.

Secondly, the addition of more athletes from the same sports and other wheelchair sports (like wheelchair handball), are foreseen, to help them profit themselves from the analyses, but also to extend the database for research. More questions about for instance talent development and longitudinal performance and injury pathways still need to be answered.

Additionally, the step to rehabilitation and activities of daily living seems straightforward. Like Formula-1, the Paralympic athletes are prime examples of the physical and mental potential of manual, wheelchair users. Translation of results and methods to other populations

Figure 4 Figure 4: The standardized and individualized test protocols to test maximal (an)aerobic capacities on an instrumented ergometer.

Figure 5 Figure 5: Wheelchair mobility performance measurements during the Wheelchair Rugby World Cup in Veijle.

Figure 6 Figure 6: Sensor placement in the wheel for capturing performance data.

will help persons in wheelchairs to become independent, participate in society and stay physically active and healthy. In principle every manual-wheelchair user is an upper-body athlete in need of the best training facilities.

In summary, WheelPower developed tools to measure power output during training and competition and to assess the maximal (an)aerobic capacities in a standardized environment. By adding the power output to the WMPM app, we can quantify the training load of players throughout the season and relate these to the maximal achieved (an)aerobic power output. Performance measures are gathered in a "Performance Portfolio" which is fed back to the trainers, coaches and embedded scientists. The "Performance Portfolio" will be gradually filled with relevant performance facilitators and performance killers so that athletes can optimise their wheelchair settings and/or training guidelines to perform maximally during competition. Furthermore, gathered performance data and research could aim in more evidence informed classification guidelines, to enhance the fairness of wheelchair sports, which is a key topic in Paralympic sports development.

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