

## Verplichte bijlage uitgewerkte aanvraag Sport en Beweging 2018

### 1. Dutch lay summary (optional)

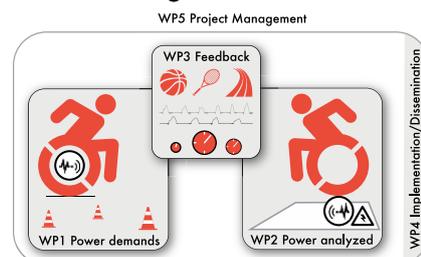
Met vier gouden, drie zilveren en twee bronzen medailles presteerden de Nederlandse rolstoelsporten uitermate goed op de Paralympische spelen in Rio 2016 (rolstoelbasketbal, -tennis, -atletiek, -triathlon en -rugby). Om deze positie te behouden en zelfs te versterken in dit snel professionaliserende veld is meer kennis nodig over hoe het vermogen (Watt (W)) van atleten in een rolstoel geoptimaliseerd kan worden om hun wedstrijdprestatie te verbeteren. Daarvoor is niet alleen nieuwe kennis nodig op basis van objectieve meetgegevens van trainingen, testen en wedstrijden, maar is *met name ook* een directe terugkoppeling van de geanalyseerde data naar atleet en coach noodzakelijk om zo de training, rolstoelafstelling en wedstrijdprestatie te optimaliseren. Om dit te bereiken is de reeds productieve samenwerking tussen sportbonden, NOC\*NSF, Chef-de-Mission Esther Vergeer, en wetenschappers geïntensiveerd rond de thema's 'beter presteren' en 'data science' in rolstoelsport.

Het doel van het WheelPower project is dan ook het verbeteren van de prestaties door het optimaliseren van het vermogen dat atleten leveren tijdens trainingen en wedstrijden. Door het continu monitoren van vermogen tijdens trainingen en competitie, gecombineerd met directe feedback hierop, kunnen de rolstoelatleten en hun coaches de resultaten van objectieve lab- en veldtesten direct gebruiken. Op basis van deze vermogensgegevens en wetenschappelijke kennis, kunnen trainingsrichtlijnen ontwikkeld worden, rolstoelactiviteiten worden geoptimaliseerd, wedstrijdstrategieën worden verfijnd en kan de rolstoel technisch worden verbeterd en individueel afgesteld. Op deze wijze kunnen atleten zich gedurende de competitie beter voorbereiden voor een topprestatie tijdens de wedstrijd.

Een historisch sterk consortium werkt samen in dit project, bestaande uit drie universiteiten (Groningen, Delft en Amsterdam), een hogeschool (Den Haag), NOC\*NSF, de vijf betrokken sportbonden, vier sportinnovator centra (Groningen, Papendal, Delft, Amsterdam), twee revalidatiecentra (Reade en Basalt) en twee toonaangevende commerciële partners op het gebied van bewegingsanalyse en ergometrie (Lode en ProCare). Delft Data Science en Sport Data Valley zijn als data science partners betrokken voor de big-data analyse en infrastructuur.

Twee promotieonderzoekers en een postdoc werken de onderzoeksdoelen uit aan de hand van vijf werkpakketten. De focus van de eerste onderzoeker ligt op het continu monitoren van de rolstoelprestatie en het vermogen tijdens training en competitie *in het veld*. Met een recent ontwikkelde methode met versnellingsensoren, gecombineerd met een data science benadering, worden de kritische prestatie-indicatoren bepaald. De tweede onderzoeker zal in *het lab* het maximale (an)aerobe vermogen van de atleten analyseren en optimaliseren door o.a. de kinetische keten te verbeteren. De postdoc zorgt voor de integratie van de resultaten van de twee onderzoekers door het vormgeven van de 'Performance Portfolio' als basis voor directe feedback voor het optimaliseren van training en rolstoeltechnologie.

De resultaten leiden tot nieuwe wetenschappelijke kennis over het optimaal leveren van vermogen in een (sport)rolstoel. Deze innovatieve kennis wordt in dit project geïmplementeerd middels directe feedback aan atleet en coach en zorgt voor een continue verbetering van het prestatievermogen van de rolstoelatleten.



*De combinatie van veld en lab testen gaat leiden tot optimale feedback om wedstrijdprestatie te verbeteren*

## 2. Research proposal (MAX 6 PAGES A4, SINGLE SIDED)

### 2a. Research aim

#### *Current (international) status/background*

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 metabolic (an)aerobic power output, mechanical efficiency and mechanical frictional losses (i.e., rolling, internal and air resistance) and should be measured in a standardized lab environment as well on court during training and competition. Wheelchair athletes adhere to very intense training programs, but they currently lack sport-specific tools for objective monitoring of power production, essential to performance<sup>1</sup>. Moreover, different wheelchair sports are played 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<sup>2</sup>. For instance, only recently the extra peak power necessary to propel the wheelchair, while simultaneously holding a tennis racket, was shown<sup>3</sup>. 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.

#### *Current state-of-art, gaps in scientific knowledge*

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<sup>4</sup>. 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<sup>5</sup>. 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<sup>6</sup>. Third, the wheelchair design and sport-specific nature make the use of regular power sensors (e.g., Powertap<sup>7</sup>, SRM<sup>8</sup>) as used in cycling, unfeasible. In addition, force instrumented hand-rims (e.g., SmartWheel<sup>9</sup>, Optipush<sup>10</sup>) 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.

#### *How the proposal fills these gaps*

The above-mentioned gaps of 1) monitoring power output in the lab and on the field in a 2) large sample of wheelchair athletes can be filled as follows. From different perspectives the Dutch research groups have shown leadership in the development of a new technology applicable to wheelchair sports to obtain objective performance measures, such as (an)aerobic power output in the field and in the lab (fig 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<sup>11</sup>. Second, the *Esseda wheelchair ergometer* is a high-resolution measurement tool to analyze how the power is optimally delivered by an athlete under standardized repeatable conditions in their personal sports wheelchair<sup>12</sup>. 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<sup>13</sup>. 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 very detailed 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 a large number of wheelchair athletes under field and lab conditions, which will be assisted by the best data science approach to this challenge.



Fig1: 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 analyze 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.

### *Objectives*

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.

### *Research questions*

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?

## 2b. Research design / strategy

WheelPower consists of five work packages (WPs), of which three WPs focus on the scientific work (WP 1-3) and two WPs (WP 4-5) are supportive.

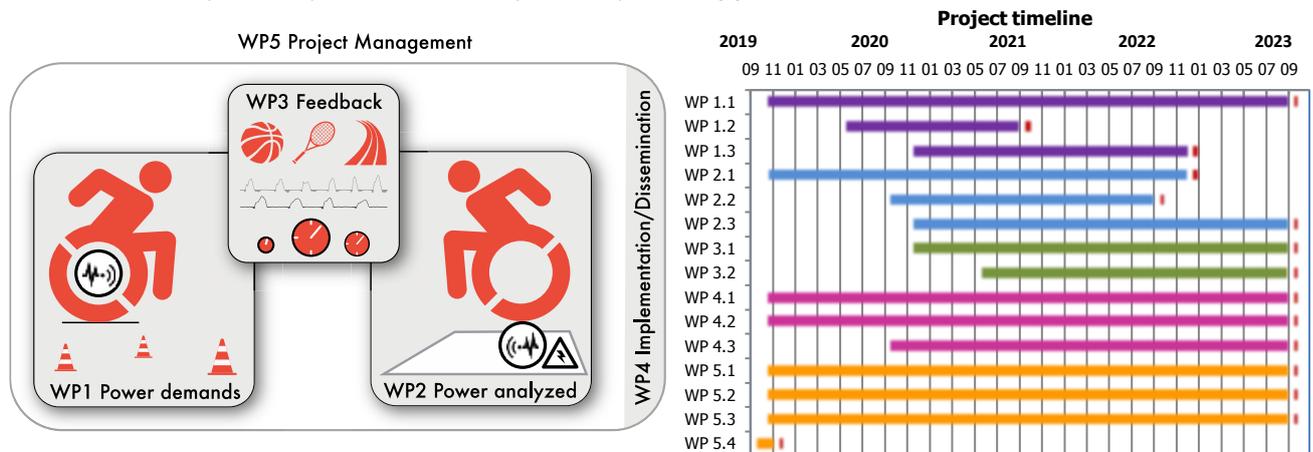


Fig2: Schematic overview of the interrelated work packages and their respective timelines.

<b>WP 1 ON-COURT POWER DEMANDS (PhD)</b>	<b>WP LEADER TU Delft, Prof .dr. Veeger</b>
<p><b>Objectives:</b> The objective is to connect all elite wheelchair athletes to the Wheelchair Mobility Performance Monitor (WMPM) and meanwhile extend the WMPM with more athlete activity-based output, such as trunk motion and push characteristics. Furthermore, measures like heart rate, but also subjective measures like the rate of perceived exertion will be added to monitor training load. In addition, the PitchPerfect system will be adapted for use in specific wheelchair-sport activities, the process of which has already been initiated within the ongoing NWO Perspective program Citius Altius Sanius, in for instance (able bodied) tennis. This WP allows for a direct start with data collection, combined with lab-based measurements, so that individual Performance Portfolios are filled immediately.</p>	
<p><b>WP 1.1 Implementation of the WMPM over five wheelchair sports (Basketball, Tennis, Racing, Triathlon, Rugby)</b></p>	
<p><b>M1.1</b> During standardized valid field tests  <b>M1.2</b> During (selected) training sessions  <b>M1.3</b> During (simulated) competition</p>	<p><b>D1.1</b> Report on WC settings-performance relationship across sports  <b>D1.2</b> Report on Performance Portfolio with WMPM training feedback  <b>D1.3</b> Report on Performance Portfolio with WMPM competition results</p>
<p><b>WP 1.2 Implementation of the PitchPerfect over the wheelchair sports (Basketball, Tennis, Racing, Triathlon, Rugby)</b></p>	
<p><b>M1.4</b> Selected sports actions in the field, e.g. serving and ground strokes in wheelchair tennis</p>	<p><b>D1.4</b> Report on the mechanics of the kinetic chain of power production in the selected sports actions with guidance for improvement</p>
<p><b>WP 1.3 Datascience and feedback (with WP2 and WP3)</b></p>	
<p><b>M1.5</b> Relating WMPM to ergometer  <b>M1.6</b> Data science approach to the big data set of WMPM, PitchPerfect and athlete data, to appoint performance indicators</p>	<p><b>D1.5</b> Report about the on-court power-estimate of the WMPM (D2.5/3.5)  <b>D1.6</b> Performance facilitators and performance killers, captured in a personalized Performance Portfolio with monitoring, feedback and support tools based on the WMPM, WC-ergometer and PitchPerfect (D2.5/3.5)</p>
<b>WP 2 WHEELCHAIR POWER ANALYZED (PhD)</b>	<b>WP LEADER UMCG, Prof. dr. van der Woude</b>
<p><b>Objectives:</b> The objective is to perform detailed standardized lab measurements of (an)aerobic power output (W) and physiological responses on the wheelchair ergometer and add these data to the Performance Portfolio. Detailed biomechanical analyses on the kinetic chain (i.e., skill) will be performed to optimize the power flow for producing optimal power outputs. These outcomes together with the field-based outcomes of the WMPM and PitchPerfect system are the big data foundation for the data science approach and subsequent Performance Portfolio. This will ensure an optimal knowledge translation pipeline between the knowledge partners and the professionals of each of the sports disciplines involved.</p>	
<p><b>WP 2.1 Physiological &amp; biomechanical testing on ergometer</b></p>	
<p><b>M2.1</b> Physiological exercise testing  <b>M2.2</b> Biomechanical exercise testing  <b>M2.3</b> Addition of the WMPM &amp; PitchPerfect on WC ergometer</p>	<p><b>D2.1</b> Physiological profile report of individual athletes  <b>D2.2</b> Biomechanical profile report of individual athletes  <b>D2.3</b> Integrated dataset of all three measurement modalities</p>
<p><b>WP 2.2 Decision making on a number of wheelchair design avenues</b></p>	
<p><b>M2.4</b> Testing the effect of different sport specific configurations</p>	<p><b>D2.4</b> List of pointers for optimal wheelchair configuration</p>
<p><b>WP 2.3 Datascience and feedback (with WP1 and WP3)</b></p>	
<p><b>M2.5</b> Relating WMPM to ergometer  <b>M2.6</b> Data science approach to the big data set</p>	<p><b>D2.5</b> Report about the on-court power-estimate of the WMPM (D1.5/3.5)  <b>D2.6</b> Performance facilitators and performance killers, captured in a personalized Performance Portfolio with monitoring, feedback and support tools based on the WMPM, WC-ergometer and PitchPerfect (D1.5/3.5)</p>

<b>WP 3 THE POWER OF FEEDBACK (Postdoc)</b>		<b>WP LEADER HHS, dr. van der Slikke</b>	
The objective is to integrate WP1 & WP2 by combining all the collected data, perform data science on the underlying relationships and consequently develop and implement feedback systems via the Performance Portfolio to provide athletes and coaches with essential information on the athlete's performance.			
<b>WP 3.1 Development of the Performance Portfolio</b>			
<b>M3.1</b> Server-based individual feedback		<b>D3.1</b> Personalized Performance Portfolio for all participating athletes	
<b>M3.2</b> Addition of player characteristics and subjective factors.		<b>D3.2</b> A set of pointers regarding training load and wheelchair setup	
<b>M3.3</b> Proper infrastructure (Sport Data Valley/Delft data science)		<b>D3.3</b> Privacy preserving database accessible for athletes & scientists	
<b>WP 3.2 Datascience and feedback (with WP1 and WP3)</b>			
<b>M3.4</b> Relating WMPM to ergometer		<b>D3.4</b> Report about the on-court power-estimate of the WMPM (D1.5/2.5)	
<b>M3.5</b> Data science approach to the big data set		<b>D3.5</b> Performance facilitators and performance killers, captured in a personalized Performance Portfolio with monitoring, feedback and support tools based on the WMPM, WC-ergometer and PitchPerfect (D1.5/2.5)	
<b>WP 4 IMPLEMENTATION &amp; DISSIMINATION</b>		<b>WP LEADER Reade dr. De Groot</b>	
<b>Objectives:</b> Implementation is key to the success of the WheelPower project. Therefore, this WP ensures knowledge transfer and implementation of all generated knowledge and infrastructure throughout the duration of the project and beyond.			
<b>WP4.1 Direct implementation in the sports</b>			
<b>M4.1</b> Organise user-group meetings		<b>D4.1</b> Minutes of yearly user-group meetups	
<b>M4.2</b> Showcase of Performance Portfolio		<b>D4.2</b> A full working demo available for interested parties	
<b>M4.3</b> Translate feedback from the users		<b>D4.3</b> Report of modifiable factors for improvement of Performance Portfolio	
<b>WP4.2 Knowledge sharing</b>			
<b>M4.4</b> Facilitation of academic communication		<b>D4.4</b> Scientific papers describing research findings	
<b>M4.5</b> Communication of progress & results to wider audience		<b>D4.5</b> Articles in popular and non-academic media outlets	
<b>WP4.3 Wider implementation into grassroot sports, activities of daily living &amp; Rehabilitation</b>			
<b>M4.5</b> Make use of implementation partners		<b>D4.6</b> Active involvement (e.g. attendance workshops/ symposia) of Sportinnovator- & Rehabilitation-centers	
<b>WP 5 PROJECT MANAGEMENT</b>		<b>WP LEADER UMCG, dr. Vegter</b>	
<b>Objectives:</b> Efficient and effective project coordination is critical for the proper execution of the WheelPower project. The PM is responsible for the daily management of the project, oversees the overall progress, and is the primary contact between ZonMw and the WheelPower project. PM is responsible for (i) the overall management, (ii) preparation of the meetings, (iii) timely collection and preparation of reports.			
<b>WP 5.1 Progress monitoring of WPs and quality management</b>			
<b>M5.1</b> Check on reaching milestones		<b>D5.1</b> List of reached milestones and appropriate actions	
<b>M5.2</b> Check & organise timely meetings and lead steering committee		<b>D5.2</b> Report on meetings & collaboration (incl. Mid-term & Final report)	
<b>WP 5.2 Data management, including preparation of data management plan</b>			
<b>M5.3</b> Coordinate data management plan between all partners		<b>D5.3</b> Data management plan	
<b>WP 5.3 Coordination of administrative project management including reporting, and monitoring finances.</b>			
<b>M5.4</b> Coordinate proper administrative duties		<b>D5.4</b> Financial conduct of all partners	
<b>WP 5.4 Coordination of non-WMO ethical approval for the whole programme</b>			
<b>M5.5</b> Coordinate program for UMCG non-WMO approval		<b>D5.5</b> non-WMO programme approval	

*Potential hurdles that may inhibit successful completion of this project.*

The partners in this consortium already have a long-lasting partnership and are strongly embedded in sports practice. Therefore, only a limited number of potential risks for unsuccessful completion of the project are foreseen and accounted for. Firstly, the goal of WheelPower is to include a large number of wheelchair athletes from the different wheelchair sports, which makes the continued willingness and enthusiasm of the athletes and sport-professionals very important. Currently, we have the commitment from the different sports, but keeping them motivated is of prime interest. To that end, the activities of the embedded scientist wheelchair sports, regular user-group meetings and adequate project management are key components to keep the lines of communication open between science and practice for effective implementation of research results within the daily sport practice.

Secondly, the novelty of WheelPower lies for a large part in the integration of results from lab and field measurements into the Performance Portfolio. Therefore, WP3 serves to safeguard the collaboration between the field (WP1) and the lab (WP2). The project management (WP5) will emphasize this collaboration and makes sure the communication between WP1, WP2 and WP3 will keep running smoothly and potential hurdles will be proactively negotiated.

Finally, the most important deliverable is the implemented working Performance Portfolio that will be gradually filled with the relevant performance facilitators and performance killers so that athletes can benefit from the monitoring, feedback and support tools based on the WMPM, WC-ergometer and PitchPerfect. Therefore, the active participation of not only the researchers, but also the other consortium partners are a prerequisite and will again be safeguarded by the project management including the work package leaders in the steering committee (see 2d). Fortunately, NOC\*NSF is an important stakeholder in the project and, through the involvement of their embedded scientists, performance managers and chef-de-mission, the important link from science to practice will not be overlooked.

## 2c. Data science

This project aims at providing a data-based tailored performance advice, to that end the data science partners Sports Data Center (SDC) and Sports Data Valley (SDV) play a crucial role in development & implementation of innovative performance analytics. For the first time in wheelchair sports, the easy to use versatile measurement methods allow for large scale data collection, in turn providing the basis for big data analytics in a stepwise approach.

Firstly, a data science approach is used to expand the set of features extracted from the WMPM, Esseda wheelchair ergometer & the PitchPerfect system and consequently perform variable selection to reduce it to the most performance relevant outcomes for athlete feedback<sup>14</sup>. Data of simultaneous performance measurements with ergometer and WMPM, could be employed to improve the quality of extracted features, both in accuracy as well as their potential for athlete feedback. The ergometer for example allows for detailed power calculation, but only in a straight sprint and disregarding trunk movement, whereas the WMPM only allows for power *estimations*, yet in ecologically valid conditions. The combined measurement across wheelchair sports enables feature optimisation for both methods. The optimized features are directly fed into the athlete feedback dashboard of WP3.

The second data science step relates performance data to wheelchair-athlete specific information, collected alongside the performance data. Common data on training status, training response and wheelchair settings will be added, allowing the model to take this information into account, in the search for performance indicators and performance killers. For example, which wheelchair mobility performance is associated with the best match performance and what training load preceded a shoulder overload injury? These indicators extracted with neural networks and predictive analytics will be fed back into the feedback dashboard of WP3, to support athletes in attaining the highest performance level and warn athletes for potential risks based on performance monitoring.

In this data science approach, there is a strong relationship with the Citius Altius Sanius (CAS) P2 project, where a real-time decision-support system is set up for able bodied sports. Furthermore, since the CAS project also incorporates multiple sports, the developed methodology and knowledge gained, could be used to quantify (wheelchair-)sport specific **training load** and **training status** in a similar way.

The data collection will start straight away, providing direct basic feedback to athletes and coaches. Since the sensor setup will stay the same, data-science based improvements in feature extraction could be applied to both new and existing measurements. The raw sensor data and processed performance outcomes will be stored by Sports Data Valley (SDV), who will build a dedicated data loader. SDV stored grassroot data will be accessible for feature

extraction to generate performance reports, that will be stored in SDV as well. The privacy preserving database will be accessible for individual athletes to view their own data, for coaches to view team data and for researchers to access data only in anonymised mode. Given the competitive nature of sports, special attention will be given to privacy and security issues. This is a mutual responsibility of all consortium partners, but will primarily be handled by the SDV and its data stewards, also involved in similar sports related projects. Although the primary aim is to facilitate elite athletes during this project, the application for amateur sports and daily wheelchair users is taken into account in the design of the data storage and feedback pathway.

## 2d. Project members and consortium

A strong multidisciplinary team is created of all relevant national partners regarding this topic. Their strong knowledge base and research experience, combined with the Paralympic wheelchair sports, commercial & rehabilitation partners have a true sustainable impact on the power performance of the athletes, and can translate these findings to a broader scope of wheelchair users.

Knowledge partners: RuG/UMCG Groningen (dr. Vegter, prof. dr. Van der Woude, dr. De Groot), TU Delft (prof. dr. Veeger), VU Amsterdam (dr. Hoozemans) and THUAS Den Haag (dr. Berger, dr. Van der Slikke) have a long common research history, recently most clearly visible in the successful 2013 awarded RAAK-Pro project on the perfect sports wheelchair. This consortium is now complemented with Sport Data Center (prof. dr. Jongbloed) for the datascience analyses and Sport Data Valley (A. Damstra) for the proper infrastructure.

Paralympic wheelchair sports: wheelchair basketball (Van der Linden), tennis (Sporrel), athletics (Mul), triathlon (de Bruin) & rugby (Pot) are involved through their own sports federation, together with the Netherlands Olympic Committee (NOC\*NSF, Vergeer, Van der Rijst, Maase).

Commercial partners: for the technological innovation Lode (Rademaker) and ProCare (Baas) are the main project partners. Moreover, the Sportinnovator centers Groningen (Prof. dr. Lemmink), Papendal (Veerbeek), TU Delft (Prof. dr. Van der Helm) and Amsterdam (Dr. Vervoorn) are present to guard the knowledge implementation and continuation after the funding period.

Rehabilitation centers: Basalt (van Vree) and Reade (de Groot, Janssen) together with Sportcentrum Papendal will serve as important testing hubs and as important stakeholders for the continuation and translation of the project results to a wider audience of daily wheelchair-users and rehabilitation practice.

### *Describe the organisation of the consortium:*

For the execution of the project WheelPower, a dedicated **Steering Committee** (SC) is set up. The SC makes all strategic, long- and medium term and tactical decisions and is responsible for the daily management of the project. The SC is the only decision-making body in the WheelPower project. SC members have the authorisation to discuss, negotiate and agree on decisions or provide recommendations within the frame of their responsibilities. Decisions are made by voting and are taken either at regular or extraordinary meetings or through email and/or teleconference. All WP leaders are included as a member of the SC. The SC meets bi-annually at the consortium meetings to discuss progress and specific issues that need attention. Representatives of the partner organisations are invited to participate in the bi-annual consortium meetings.

The **Project Manager** (PM) dr. Riemer Vegter, oversees the overall progress. He is supported by experts at UMCG for coordination of financial and legal matters and secretarial support is available to run the project. The PM and financial expert meet in person at least every three months. The legal expert is consulted on an *ad hoc* basis. The participation of users is stimulated by organising bi-annual user-groups meetings to collect and implement feedback of the end users.

### 3. Relevance (MAX 3 PAGES A4, SINGLE SIDED)

#### 3a. Societal impact and participation

The Dutch Paralympic team performed exceptionally well at the Paralympics in Rio 2016 with a 7th place in the international medal table. The wheelchair athletes (tennis, basketball, rugby, wheelchair racing and paratriathlon) won four gold, three silver and two bronze medals. As stated in the National Knowledge Agenda Sport and Exercise: “Dutch elite sport wants to rank in the international top 10. However, more medals can only be obtained with more scientific knowledge.” If the Netherlands aims at continuation or, preferably, expansion of our current success rate in the wheelchair sports, measures to maintain our position are needed.

In preparation to this project proposal, two expert sessions with coaches from wheelchair sports and (embedded) scientists were organized and a round of semi-structured interviews was held with athletes, embedded scientists and coaches. From these efforts, a number of research questions were synthesized, with the aim to attain focus and mass around a commonly shared topic: optimizing power output in athletic wheelchair use.

Different coaches stressed (see coach quotes below) that a major improvement in further professionalization of wheelchair training and support programs would be the development and implementation of evidence-based training guidelines. These guidelines do as yet not exist and the coaches and athletes ask for scientific support on developing these guidelines. By using objective data, innovative technology and instrumentation for monitoring performance, and consequently providing direct feedback tools, training and performance can be objectively evaluated and evidence-based guidelines can be developed in time.

This comprehensive performance monitoring is a critical factor missing in wheelchair sports. Also, the cross-over of training techniques, management methods or wheelchair innovations between wheelchair sports is minimal. The same applies to the integration of novel technological developments such as the wheelchair sports performance monitor (WMPM), the wheelchair ergometer and the PitchPerfect system (for timing of body segment rotations). By improving this, a major step towards a higher level of training and coaching will be taken. Thus, in the current call we aim to successfully combine lab- and field-based data collection, analyses and interpretations. These features are generally identified top items on the wish list of all coaches and technical directors. Now, in 2019, all building blocks and expertise are available and therefore this opportunity should be seized. Moreover, there is still a clear knowledge gap on upper-body power production during Paralympic sports. Findings of able-bodied sports often cannot be translated to the impaired Paralympic athletes, because of differences in muscle function, exercise physiology and coordination. The large group of motivated wheelchair athletes within the WheelPower project will be of great importance in understanding all aspects of upper-body physical activity for people with a disability, hence the eager participation of the rehabilitation centers within the project.

#### *Coach quotes:*

> Esther Vergeer (Chef-de-Mission Paralympics NOC\*NSF): ‘To gain new insights more focus and mass are necessary. This call is an excellent opportunity to bundle the ‘rolling’ disciplines and realize a strong innovation team.’

> Gertjan van der Linden (Head coach Wheelchair Basketball): ‘In the ‘Perfect Sports Wheelchair’ project we saw the added value of measurements with the sensors. But direct feedback of the data is a requirement and that step has to be made quickly.’

> Arno Mul (Head coach Wheelchair Racing): ‘The detailed measurements of sprint power and propulsion technique on the wheelchair ergometer will give us the competitive edge, therefore, we are co-initiator of the wheelchair ergometer development’.

### 3b. Scientific impact

Short- & long-term scientific impact: large-scale data collection across multiple wheelchair sports is essential for the science of athletic wheelchair use. Typically, research on wheelchair sports is scattered and sparse, thus these studies lack statistical power for a proper quality of the evidence (Heyward et al 2018). As a consequence, the power demands of the different wheelchair sports are currently not well understood, which is why proper guidelines for the optimization of training and wheelchair setup are lacking. Several important scientific implications of the WheelPower project will help to achieve this knowledge.

1. The results will lead to a better understanding of the external power demands and the consequent internal power production of the athlete-wheelchair combination. This will impact the field of Paralympic Sports Science, but also of rehabilitation, since both need to optimize the wheelchair-user combination for an optimal performance.
2. The continued monitoring of training and competition will help relate the training load to both successful (e.g. personal best) and adverse events (e.g. overuse injury), thus making it possible to understand these relationships with a big-data approach.
3. The successful implementation of feedback on the power performance of athletes is of important scientific value to a broad field of sciences. During the project different forms of feedback at different stages of training will be tested to see which is the most effective.
4. The legacy of the project will be the continued implementation of the developed methodology by the professionals in the field, leading to an ever-growing dataset that will become invaluable over time, and will be used for different scientific research questions such as talent identification, athlete health and performance and the improvement of athletic achievements.

#### 3 Scientific disciplines:

- 1 Human Movement & Sport Sciences Groningen (UMCG/RUG) and the Faculty of Behavioural and Movement Sciences Amsterdam (VU) are involved for the biomechanical and physiological testing of the athletes (e.g. wheelchair ergometer, kinetic chain).
- 2 Biomechanical Engineering (TU Delft), Human Kinetic Technology (THUAS, Den Haag) and the Faculty of Behavioural and Movement Sciences Amsterdam (VU) are involved with the engineering, implementation and analysis of the IMU sensors in the field (WMPM and PitchPerfect).
- 3 Sports Data Center and Sports Data Valley are important partners, to help with the big data analyses and ensure the proper design and infrastructure of the feedback.

#### Innovative project:

The project builds on exciting recent innovations that have yet to come together as a whole. The project delivers a unique integration of state-of-the-art lab techniques, continuous training and competition monitoring, combined with the direct feedback to the athletes and coaches. The broad collaboration of the wheelchair sports is an innovation in itself and will help achieve a unique mass and focus between wheelchair sports. Therefore, the results will lead to important new scientific insights that can be directly implemented to have impact for the sports, as well as for wheelchair users during and after inpatient rehabilitation.

### 3c. Focus and Mass

> *'Beter Presteren'* & *'Data science'*

From the aim: 'to improve the power output of athletes in their sport-specific wheelchair to perform better in competition' it becomes clear that the WheelPower project directly has a meaningful impact on the theme 'Beter presteren'. Reaching this aim will for a large part depend on successful 'data science' approaches. To that end, Sport Data Center and the use of Sport Data Valley are of critical importance.

> *'Focus and mass'*

One of the explicit strong points of the WheelPower project is the collaboration with all the different Paralympic wheelchair sports, to gain enough national mass to really focus on the central theme of power production by the athlete-wheelchair combination. This will ensure high quality science leading to tangible end-products that will help the sports perform better.

> *Expertise of the consortium partners.*

# With over 250 publications, the consortium has a large scientific track record in the field of wheelchair use in rehabilitation and sports. We have shown international leadership by organizing the conference 'Rehabilitation: mobility, exercise & sports 2018' and the Paralympic Vista conference in 2019. Moreover, we have vast experience in managing large ZonMW funded multi-center/ multi-disciplinary spinal cord injury research programs like the Umbrella project and ALLRISC and like the RAAK-PRO program 'De perfecte sportrolstoel'. Furthermore, our research also led to implementation projects such as the Wheel-I project (De Groot et al 2014) and three Sportinnovator awards with wheelchair basketball and wheelchair tennis. The strength of the consortium is further exemplified by the 19 letters of commitment with a strong emphasize on non-academic partners as well.

# The WheelPower project follows up on the previous rounds 'Sport & Beweging 2012 and 2017' (Performance enhancement in elite (talented) wheelchair and handcycling athletes (2012) and Rolling to Tokyo (2017)). The most recent project was very well assessed by the international reviewers, but they suggested to extend the project to four years. The structural collaboration between all national partners has been key for the current proposal.

# Dr. Riemer Vegter, the main applicant, has a leading role in international collaboration on Paralympic wheelchair sports, as reflected by his additional roles as research fellow at the Peter Harrison Center for Disability Sports (Loughborough, UK), his teaching position at the International Master Adapted Physical Activity (KU Leuven, BE) and as chair of the 6th RehabMove Congress. As active member of the Sportinnovator Centrum Groningen he has been actively involved with Sports Data Valley and making the link between Science and adapted sports practice.

# NOC\*NSF together with Chef-de-Mission Esther Vergeer and the Paralympic wheelchair sports (wheelchair basketball, tennis, athletics, triathlon and rugby), play an important role in articulating needs (e.g., addition of subjective measures to the Performance Portfolio) as well as the implementation of the results and thus are strong partners to warrant the true impact of the findings.

# The Sportinnovator centers Groningen, Papendal, Amsterdam and Delft are important partners for the communication, application and valorization of the results.

# Lode and ProCare are strong leading Dutch commercial manufacturers and distributors of exercise equipment and measurement solutions. Their involvement will greatly benefit the further development of the equipment and their commercial success.

# The rehabilitation centers Reade and Basalt form strong clinical partners with great expertise on upper-body functioning in relation to the impairment of the athletes. Moreover, they are important implementation/dissemination partners to advocate the wider use of the deliverables from the WheelPower project

# The participation of Sports Data Center and Sports Data Valley not only ensure state-of-the-art data science, but also the incorporation thereof in a proper infrastructure for direct feedback based on objective data, which will be key to the success of the WheelPower project.

> *WO/HBO Collaboration*

The Hague University of Applied Sciences forms the bridge between science and practice and thus plays an important role in the application of the scientific knowledge in the field of the Paralympic wheelchair sports. The collaborative success between the partners is illustrated by dr. Rienk van der Slikke. As teacher at Human Kinetic Technology he has attained his PhD on wheelchair field testing at TU Delft and is currently also appointed as Embedded Scientist at NOC\*NSF/TU Delft.

#### 4. KNOWLEDGE TRANSFER AND IMPLEMENTATION (MAX 1 PAGE A4, SINGLE SIDED)

Implementation is one of the strong suits in the current proposal, since the equipment, data-science infrastructure and newly developed knowledge will all be made available for continued use, through a series of pre-planned actions by the different consortium partners. This will ensure the usability and reproducibility of the deliverables after the project.

First, the professionals of the sports (coaches, embedded scientists, performance managers) will be educated on using the equipment (WMPM, ergometer & PitchPerfect) in combination with the developed test protocols and feedback systems. Therefore, they can profit from the continued use of the developed Performance Portfolio for data informed training and wheelchair setup. To that end, the yearly consortium meetup will also have workshops on how to use and interpret the different key elements of WheelPower. Furthermore, the prolonged use will lead to a longitudinal database giving rise to new data science questions and creating reference values on physical capacity, training load and the effect of wheelchair setup.

Second, all developed knowledge on the beneficial and limiting factors for optimal power production during wheelchair use will be implemented in the Performance Portfolio. Sports Data Valley will facilitate the uploading of performance data and the accessibility by means of a Performance Portfolio. The online reports will contain important performance indicators with easy to understand explanations of these values, translated from the produced scientific papers by the PhDs and Postdoc. These will also be distributed openly as White papers and through dedicated Dutch professional outlets such as 'Sportgericht', 'Moving Matters', 'Dwarslaesie Magazine', Dutch Journal on Rehabilitation Medicine (NTRG) and other news outlets of the Sportinnovator centers, the Rehabilitation centers and (applied) universities.

Third, the consortium partners consist of two types of important stakeholders for the implementation outside the realm of elite Paralympic sports. On the one hand, the Sportinnovator centers have as primary mission to capitalize on the WheelPower innovations and apply them to a wider field of (recreational) wheelchair sports. On the other hand, the rehabilitation centers see a very clear parallel to the training of new wheelchair users, maximizing the chances for participation without risking overuse injuries. They will be continuously involved as partners of the user group alongside representatives of the athletes and patient association (Dwarslaesie Organisatie Nederland). Further dissemination will be achieved through symposia during a number of Dutch societal and professional meetings like, 'Supportbeurs', and the yearly conferences of the professional societies 'NVDG', 'VRA', 'VvBN', 'ISPO', 'SMALLL' and 'Sportinnovator'. As such, results of WheelPower will also be transferred to other wheelchair users than the Paralympic athletes and thus be implemented in society.

A number of risks for implementation are foreseen and accounted for. First and foremost, all future users need to feel ownership of their data and the freedom to retract permissions if they feel that need. To that end Sport Data Valley assures the proper ethical approach (in accordance with the GDPR but based on FAIR principles) to the design of the database and (non WMO) ethical approval is requested beforehand. Moreover, any data science depends on the proper input of sound collected data. To prevent the misuse or misinterpretation, proper education and valid inertial sensors are necessary. From the knowledge partners these are currently available during the project. To turn these into a low cost widely available product we will discuss with interested commercial partners, while safeguarding the IP of the Performance Portfolio.

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