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Initial Maximum Push-Rim Propulsion and Sprint Performance in Elite Wheelchair Rugby Players

Abstract

Wheelchair rugby (WR) is an increasingly popular Paralympic sport; however, the evidence base supporting the validity and reliability of field tests to assess the physical condition of WR players is in its infancy. Therefore, here, we aimed to evaluate the intrasession reliability of the initial maximum push-rim propulsion (IMPRP) test and the sprint test, and to determine the relationships between IMPRP mechanical outputs and sprint performance variables. We studied 16 Spanish WR players (aged 33 ± 9 years). The maximum single wheelchair push from a stationary position and the sprint performance (i.e., times for 3, 5, and 12 m, and the maximum velocity) of elite WR players were measured in this study. The intraclass correlation coefficient, coefficient of variation, and standard error of measurement for IMPRP variables were >0.85, <10.6%, and <16.76, respectively; the corresponding values for a linear sprint were >0.97, <3.50%, and <0.15. In relation to IMPRP mechanical outputs (i.e., acceleration, maximum acceleration, force, maximum force, power, and maximum power) and sprint performance (i.e., times for 3, 5, and 12 m, and the maximum velocity), significant and large associations were observed in the WR players (r ± confidence limit = −0.78 ± 0.17 to −0.90 ± 0.11; 0/0/100, most likely; $R^2 = 0.613–0.812$; $p < 0.001$). These tests provide simple and reliable methods for obtaining accurate mechanical pushing capacities and sprint performances of WR competitors (the 61.4–80.1% variance in sprint performance was explained by the IMPRP variables). These relationships indicate a need to implement specific strength exercises in WR players with the aim of improving the IMPRP and therefore improving sprint capacity.

Introduction

Despite the growing interest in Paralympic sport, the evidence base supporting wheelchair-based sporting performance is still in its infancy compared with that for able-bodied sport ([21]). Wheelchair rugby (WR) is a team sport for male and female athletes ([16]) with impairments that affect all 4 limbs: it is a mixed sport for quadriplegic athletes. These include those with cervical spinal cord injuries, multiple amputations, polio, cerebral palsy, and other neurological disorders ([21]). Wheelchair rugby teams are formed of 4 players ([19]), whose total point score must not exceed 8 at any given time (all players are classified in 7 groups based of their functional ability, ranging from 0.5 [most impaired] to 3.5 [least impaired]). Wheelchair rugby is played on an indoor basketball court (15 × 28 m) over 8-minute quarters using a "game-clock," whereby the time is stopped when a goal is scored or a fault is committed. Teams have 40 seconds to score a goal once the ball has been inbounded and must advance past the half-way line within 12 seconds; otherwise, possession is conceded ([25]). The team scoring the most goals by the end of the game is declared the winner ([2]).

In recent years, many studies have analyzed the internal load ([22]) and external load ([10,26,30]) of WR players using objective methods and have established that WR is a sport characterized by intermittent, but frequent, high-intensity accelerations and decelerations ([22]). Although the match requirements are increasingly understood in WR, little is known of the physical condition of players. Along with factors such as athletic profile, equipment, competitive environment, and interventions, understanding physical condition is important for performance outcomes in wheelchair court sports ([21]). Therefore, the physical condition of athletes has been widely studied in wheelchair team sports, such as wheelchair basketball (WB) ([5,9,13]). However, there are few studies of the physical condition of WR players ([1,14,29,33]).

Sprint and strength capacity have previously been identified as key performance factors in wheelchair sports ([4,5,13,18]). In WB, sprint capacity has been widely analyzed over 5, 12, and 20 m ([5,6,13]). For example, de Witte et al. ([6]) analyzed sprint capacity during real games by means of separate activities consisting of a 12-m sprint, a rotation with a curve (circumference) of 12 m (clockwise/counterclockwise), and a turn on the spot (clockwise/counterclockwise). However, in WR, although the size of the court is the same as in WB, no studies have used the 12-m sprint time to measure physical fitness. Specifically, in WR, the ability to accelerate quickly from standstill seems to be key to reposition oneself before the opponent ([17,32]); thus, push-rim propulsion is one of the determining factors of performance in WR. Although there are reports of aerobic capacity, sprint performance, and trunk strength ([1,14,29,33]), little is known of the upper-limb kinematic parameters of push, strength, acceleration, and sprint performance ([12,29]). The first-push parameters have been removed from every measurement of sample data, thereby excluding the different kinematic parameters of initial maximum push-rim propulsion (IMPRP), where large amounts of strength are required. To the best of our knowledge, no study has analyzed the reliability of different devices (i.e., encoder and radar) to determine these performance variables for players. Therefore, if we could ascertain whether the IMPRP and sprint tests are reliable in WR players, they could be used to provide useful information for coaches.

The relationship between strength and sprint capacity has been widely studied in able-bodied team sports ([11,27]). However, in adapted sports, we are only aware of analyses in

WB ([13,18,28]) and WR ([1]). In WB, improved linear sprint was reported after resistance (bench press) training ([28]), and a moderate inverse relationship was reported for both mean and maximum power (obtained in a Wingate test) compared with linear sprint velocity ([18]). These relationships were confirmed in research showing that handgrip, maximal pass, and medicine ball throw strength values were inversely correlated with the time in the linear sprint ([13]). In WR, a moderate inverse relationship was also shown between impaired forward trunk muscle strength (N) and 1-m sprint performance (seconds) ([1]). However, little is known about the contribution of specific IMPRP mechanical outputs (i.e., velocity, acceleration, force, and power) to linear sprint performance in WR.

Therefore, the aim of this study was to report IMPRP and sprint performance in WR players, in addition to evaluating the reliability (intrasession) of the IMPRP and 12-m sprint wheeling tests. To assess the involvement of strength in sprint capacity, the final aim was to determine the relationship between IMPRP mechanical outputs and sprint performance variables.

Methods

Experimental Approach to the Problem

A descriptive study design was used to describe mechanical outputs during IMPRP, which consisted of a maximal single wheelchair push from a stationary position, and performance over a 12-m wheeling sprint among elite WR players. To assess the reproducibility of the variables of interest from both IMPRP and 12-m wheeling sprint tests, the intraclass correlation coefficient (ICC), coefficient of variation (CV), and *SEM* were calculated. Moreover, to evaluate the association between IMPRP and 12-m wheeling sprint performance, correlational analysis was performed between the variables of interest.

Subjects

We included 16 Spanish WR players (age: 33 ± 9 years, body mass: 70 ± 15 kg, wheelchair mass: 16 ± 2 kg, total mass: 87 ± 15 kg, mean ± *SD*, and time since injury: 13 ± 8 years) with 2 ± 1 years' experience of WR training, who volunteered to participate. All the participants belonged to the Spanish Sports Federation for People with Physical Disabilities (FEDDF) and were classified in accordance with the Classification Committee of the International Wheelchair Rugby Federation (IWRF) (Table 1). The institutional research ethics committee of the Catalan Sports Council (No. 01_2017_CEICGC) approved this study. All participants provided written informed consent (in the case of 16-year-old players, their parents provided the written informed consent as well), after a detailed written and oral explanation of the potential risks and benefits resulting from participation, as outlined in the Declaration of Helsinki (2013).

Procedures

The battery of tests was performed during the national stage of the athletics season (February, 2017). Testing was conducted during the first session of the stage; so, players were instructed to refrain from strenuous exercise for 72 hours before testing and to avoid smoking and drinking alcohol, tea, and coffee on the day of testing. After a standardized warm-up ([9]) of continuous wheeling, joint mobility, and dynamic upper-limb stretching (pectoralis, latissimus dorsi, and deltoids; 6 repetitions each), players performed 3 progressive submaximal accelerations over 20 m ([8]) and also performed a specific 10-minute warm-up for both the IMPRP test and the 12-m wheeling sprint test. Testing was conducted with the participants using their personal sport wheelchair, including strapping, gloves, and required adjustments. The IMPRP and 12-m wheeling sprint tests were conducted on the basketball training court wooden surface. All the participants were familiar with the tests, which consisted of standard WR actions.

Initial Maximum Push-Rim Propulsion

The IMPRP test consisted of a single push, as powerful as possible, on the wheelchair rim from a stationary position and with a synchronous arm action (Figure 1A). Participants performed 3 repetitions of the test with a 15-second passive recovery between attempts, and they were verbally encouraged to perform each repetition maximally. Mechanical output was monitored using a linear encoder (Chronojump Boscosystem, Barcelona, Spain) (accuracy: ±1 mm, sampling rate: 1,000 Hz) ([3,24]). The tether of the linear encoder was hooked to the horizontal axis between the push wheels (Figure 1B), and the associated software (Chronojump v1.7.0.0) was configured to compute measurements in a linear plane inclined at 0°. The total mass (player's mass plus the wheelchair's mass) was fed into the Chronojump software and used to calculate the force. Each IMPRP repetition ended when the force production decreased to 0. The attempt with the highest maximum velocity was considered the best IMPRP repetition and used for correlation analyses. Displacement and time data for each IMPRP attempt were recorded and used to calculate mechanical outputs (e.g., mean and maximum velocity, acceleration, force, and power).

12-m Wheeling Sprint

Each participant completed 2 sets of 12-m wheeling sprints at maximum speed, with a 5-minute rest (1 minute of active recovery and 4 minutes of passive recovery) between sets. At the beginning of each test, players took position at the start line with the front wheels of the wheelchair on the line but with the trunk behind the line. After the starter gave a starting signal using the words "*when you want*," players were free to start pushing the wheelchair forward, and they were verbally encouraged to perform each repetition maximally. Times were recorded at 3, 5, and 12 m, and so was maximum velocity, in the same sprint by radar (Stalker ATS II, Plano, TX, USA) at a sampling rate of 48 Hz. The radar device was placed on a tripod 1.5 m behind the subjects at a height of 0.6 m, coinciding with the players' backs. Each velocity (v) to time (t) curve for the 3-, 5-, and 12-m sprint test was fitted post hoc by a monoexponential function using least squares regression:

After respective integration of v (t) (equation 1), the horizontal position (x) of the center of mass of the body can be expressed as a function of time, as follows:

Each velocity-time curve was analyzed using the R Studio Software, v0.99.489 (R Studio, Boston, MA, USA), and times at 3, 5, and 12 m were obtained from the modeled wheeling velocity, as was the maximum velocity over 12 m. The best attempt (best time taken to cover 12 m) was used for the correlation analysis.

Statistical Analyses

Data analysis was performed using IBM SPSS for Windows, Version 20.0 (IBM Corp., Armonk, NY, USA). The data were screened for normality of the distribution, and standard statistical methods were used to calculate the mean and *SD*. Reliability between trials for each test was assessed by ICC, CV, and *SEM*. Intraclass correlation coefficient values >0.90 were considered excellent, values 0.75–0.90 were considered good, and values <0.75 were considered poor to moderate (23). The *SEM* was calculated using the following formula: $SEM = SD \cdot \sqrt{1 - \mathrm{ICC}}$. The relationships between variables were assessed using Pearson's product-moment correlation (r) and the coefficient of determination (R^2). The following scale of magnitude was used to evaluate correlation coefficients: <0.1, trivial; 0.1–0.3, small; 0.3–0.5, moderate; 0.5–0.7, large; 0.7–0.9, very large; and 0.9–1.0, almost perfect (15). The CV for regression (V%) was derived by regression and calculated as follows: ([Standard error of the estimate/mean of the outcome measure] × 100) (34). A p-value ≤ 0.05 was considered to indicate statistical significance.

Results

Table 2 presents the mean results for the variables obtained by IMPRP and linear sprint at 3, 5, and 12 m. Typical measured and modeled velocities are shown in Figure 2A as a function of time, along with the exponential model (1) that accurately describes wheeling velocities (Figure 2B). Moreover, typical measured mechanical outputs, including velocity and acceleration, as well as force and power, are shown in Figures 3A, B, respectively.

Regarding IMPRP mechanical outputs, the ICC, intra-CV, and *SEM* were calculated for each variable: mean velocity (ICC = 0.58; CV = 9.7%; *SEM* = 0.1), maximum velocity (ICC = 0.91; CV = 4.25%; *SEM* = 0.1), mean acceleration (ICC = 0.88; CV = 9.2%; *SEM* = 0.14), maximum acceleration (ICC = 0.94; CV = 9.04%; *SEM* = 0.21), mean force (ICC = 0.85; CV = 9.69%; *SEM* = 15.23), maximum force (ICC = 0.96; CV = 8.5%; *SEM* = 16.76), mean power (ICC = 0.90; CV = 10.4%; *SEM* = 11.49), and maximum power (ICC = 0.93; CV = 10.6%; *SEM* = 12.5).

Regarding linear sprint, the ICC, intra-CV, and *SEM* were as follows for each variable: maximum velocity over 12 m (ICC = 0.99; CV = 2.13%; *SEM* = 0.07), and for split times at 3 m (ICC = 0.97; CV = 3.50%; *SEM* = 0.12), 5 m (ICC = 0.99; CV = 2.05%; *SEM* = 0.08), and 12 m (ICC = 0.99; CV = 1.46%; *SEM* = 0.15).

The correlations between IMPRP mechanical outputs and sprint performance variables are presented in Table 3. Significant and large associations were observed between IMPRP mean acceleration, maximum acceleration, and 12-m wheeling sprint performance (i.e., maximum velocity over 12 m and the times at 3, 5, and 12 m) in WR players ($r \pm$ confidence limit = -0.78 ± 0.17 to -0.90 ± 0.11; 0/0/100, most likely; $R^2 = 0.613$ to 0.812; $p < 0.001$). In addition, the relationships among IMPRP force and power (i.e., mean and maximum) and 12-m sprint performance (i.e., maximum velocity over 12 m and times at 3, 5, and 12 m) were also significant and large ($r \pm$ confidence limit = -0.78 ± 0.17 to -0.90 ± 0.11; 0/0/100, most likely; $R^2 = 0.614$ to 0.801; $p < 0.001$).

Discussion

There have been a few studies of the aerobic capacity, sprint performance, and trunk strength of WR players ([1,14,29,33]) but none assessing IMPRP and sprint performance using a linear encoder and radar. In this study, we not only evaluated the reliability of the IMPRP and sprint tests but also determined the relationship between IMPRP mechanical outputs and sprint performance variables. The variables for IMPRP (i.e., mean and maximum velocity, acceleration, force, and power) and wheeling sprint performance (i.e., maximum velocity over 12-m sprint and times at 3, 5, and 12 m) showed a high degree of reliability and low *SEM* values for the outcome values. Furthermore, very large correlations were observed between almost all the variables for the influence of IMPRP mechanical outputs over 12-m sprint performance, indicating a strong association.

Although previous studies of WB have analyzed push-rim propulsion during accelerative wheeling sprints over 12 m ([30]), there are no comparable studies in WR analyzing the mechanical outputs (i.e., mean and maximum velocity, acceleration, force, and power) of IMPRP. We show that the IMPRP had good to excellent reliability (ICC = 0.58–0.94) and low intra-CV (<9.7%) and *SEM* (<0.21) values for mean and maximum velocity and acceleration. The mean and maximum registered force and power also had good to excellent ICC values (ICC >0.85) but higher intra-CV (<10.6%) and *SEM* (<16.76) values. However, the inter-CV values were probably high (>18.38%) because of the influence of the different impairments and functional capacities of WR players ([8,31]). Thus, because there is minimal information on the differences in IMPRP performance in relation to the functional classification of the IWRF ([5]), more studies are necessary to provide coaches and physical fitness trainers with knowledge, especially given that large differences were previously reported in trunk strength ([1]) and the volume of activity profiles during WR matches ([22]). However, the IMPRP test we propose is a simple and reliable method that offers accurate information on the mechanical outputs of WR competitors' pushing capacities.

Recent studies have analyzed wheelchair linear sprints over different distances ([9,13,30]), but only one has analyzed linear sprint in WR ([29]). As expected, the performance of WR players was less over both 5 m (3.18 ± 0.81 seconds vs. <2.4 ± 0.2 seconds) and 12 m (6.02 ± 1.46 seconds) than that of highly trained WB players in the sprint test ([5,8,13]). Regarding the reliability of the trials, we are not aware of any study that has analyzed accelerative sprint in wheelchair sports by fitting the velocity-time curves as an exponential function. As previously observed in studies of able-bodied athletes ([7,20]), in which subjects performed running acceleration over different distances, the exponential function was used to describe the actual velocities. Our results show excellent ICCs for maximum velocity over 12-m sprint and times at 3, 5, and 12 m (ICC = 0.97–1.00; intra-CV = 2.46–3.05%; *SEM* = 0.07–0.15). In WB, good to excellent ICCs have been reported for wheeling sprint performance at 3, 5, and 10 m (ICC = 0.879–0.976) ([9]) with similar results and good reproducibility values (0.80–0.84) reported for 5-m sprint tests ([5]) and good and excellent ICC values (0.74–0.94) for endurance tests and change-of-direction ability ([7]). However, inter-CV values (23.3–31.40%) ultimately determined the differences in performance among players, probably because of the different impairments and functional capacities among WR players. The excellent ICC values and low intra-CV and *SEM* values in this study for linear sprint times over 12 m could allow for study without laboratory methods, thereby reducing time and financial costs during evaluations. The influence of strength on sprint ability in wheelchair sports has been studied in WB ([13,18,28]), where the involvement of strength in sprint performance was large ($r = -0.52$ to -0.77). However, strength was tested in one study through the bench press (without correlation analysis), the Wingate test (r = −0.52 and −0.56 for mean and maximum power), and simple tests such as medicine ball maximal pass and handgrip (r = −0.54 to −0.77, large) ([13]). By contrast, we used a more specific and ecologically valid test, which showed large correlations between mean and maximal acceleration, force, and power, as well as sprint performance (i.e., maximum velocity over a 12-m sprint and times at 3, 5, and 12 m). Regarding the coefficient of determination, 61.4–80.1% (V% = 10.73–32.34%) of variation in sprint performance could be explained by strength-related IMPRP mechanical outputs. These correlations indicate the need to implement specific strength exercises to help WR players improve their IMPRP. It might also be interesting to determine the influence of strength in sprint performance related to functional classifications, as has been done for WB ([20]). Hence, more studies are necessary to understand the IMPRP mechanical outputs in terms of functional classification and their relationship to sprint performance. In general, athletes engaged in activities requiring less physical capacity (low classification) adjust their wheelchairs to obtain a relatively low seat height that allows for prolonged and more powerful pushes ([30]).

The IMPRP and the 12-m wheeling sprint tests assessed in this study seem to be simple and reliable methods that offer accurate mechanical output data for the pushing capacities and sprint performances of WR players. Moreover, this is the first study to analyze the relationship between initial pushing strength and sprint performance variables, showing large correlations between IMPRP mechanical outputs and sprint performance variables. However, other issues have remained unsolved, such as which are the muscle groups that are most involved in initial pushing, so that they could be targeted to improve sprint performance and push-specific strength capacity in WR players.

Practical Applications

The IMPRP and the 12-m sprint wheeling tests are cost-effective, practical, and reliable tools for measuring the strength and speed of a given WR player. They are suitable for use by any strength and conditioning professionals to monitor the physical fitness of their players with a linear encoder and radar. In addition, the 61.4–80.1% variance in sprint performance (i.e., maximum velocity over 12 m and times at 3, 5, and 12 m) was explained by strength-related IMPRP mechanical outputs (i.e., mean and maximum force and power). Consequently, these relationships indicate a need to implement specific strength exercises in WR players, with the aim of improving the IMPRP and therefore improving the sprint.

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References

1. Altmann, VC, Groen, BE, Hart, AL, Vanlandewijck, YC, and Keijsers, NLW. Classifying trunk strength impairment according to the activity limitation caused in wheelchair rugby performance. Scand J Med Sci Sports 28: 649–657, 2018.

2. Braganc¸a, S, Castellucci, I, Gill, S, Matthias, P, Carvalho, M, and Arezes, P. Insights on the apparel needs and limitations for athletes with disabilities: The design of wheelchair rugby sports-wear. Appl Ergon 67: 9–25, 2018.

3. Brown, N, Bichler, S, Fiedler, M, and Alt, W. Fatigue detection in strength training using three-dimensional accelerometry and principal component analysis. Sports Biomech 15: 139–150, 2016.

4. Cavedon, V, Zancanaro, C, and Milanese, C. Physique and performance of young WB players in relation with classification. PLoS One 10: 1–20, 2015.

5. De Groot, S, Balvers, IJ, Kouwenhoven, SM, and Janssen, TW. Validity and reliability of tests determining performance-related components of WB. J Sports Sci 30: 879–887, 2012.

6. de Witte, AMH, Hoozemans, MJM, Berger, MAM, van der Slikke, RMA, van der Woude, LHV, and Veeger, D. Development, construct validity and test-retest reliability of a field-based wheelchair mobility performance test for WB. J Sports Sci 36: 23–32, 2018.

7. di Prampero, PE, Fusi, S, Sepulcri, L, Morin, JB, Belli, A, and Antonutto, G. Sprint running: A new energetic approach. J Exp Biol 208: 2809–2816, 2005.

8. Doyle, TLA, Davis, RW, Humphries, B, Dugan, EL, Horn, BG, Shim, JK, et al. Further evidence to change the medical classification system of the national WB association. Adapt Phys Activ Q 21: 63–70, 2004.

9. Ferro, A, Villacieros, J, and Pe´rez-Tejero, J. Sprint performance of elite WB players: Applicability of a laser system for describing the velocity curve. Adapt Phys Activ Q 33: 358–373, 2016.

10. Fuss, FK, Subic, A, and Chua, JJC. Analysis of wheelchair rugby accelerations with fractal dimensions. Proced Eng 34: 439–442, 2012.

11. Gonzalo-Skok, O, Tous Fajardo, J, Suarez Arrones, L, Arjol Serrano, JL, Casajus, JA, and Mendez Villanueva, A. Single-leg power output and between-limb imbalances in team-sports players: Unilateral vs. bilateral combined resistance training. Int J Sports Physiol Perform 12: 106–114, 2016.

12. Goosey-Tolfrey, VL, Vegter, RJK, Mason, BS, Paulson, TAW, Lenton, JP, van der Scheer, JW, et al. Sprint performance and propulsion asymmetries on an ergometer in trained high- and low-point wheelchair rugby players. Scand J Med Sci Sports 28: 1586–1593, 2018.

13. Granados, C, Yanci, J, Badiola, A, Iturricastillo, A, Otero, M, Olasagasti, J, et al. Anthropometry and performance in wheelchair basketball. J Strength Cond Res 29: 1812–1820, 2015.

14. Haydon, DS, Pinder, RA, Grimshaw, PN, and Robertson, WSP. Overground-propulsion kinematics and acceleration in elite wheelchair rugby. Int J Sports Physiol Perform 29: 1–7, 2018.

15. Hopkins, WG, Marshall, SW, Batterham, AM, and Hanin, J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc 41: 3–13, 2009.

16. International Wheelchair Rugby Federation (IWRF). Media Kit: A guide to Wheelchair Rugby. Delta, BC: IWRF Communications Committee, 2012.

17. Mason, BS, Van Der Woude, LHV, and Goosey-Tolfrey, VL. The ergonomics of wheelchair configuration for optimal performance in the wheelchair court sports. Sports Med 43: 23–28, 2013.

18. Molik, B, Laskin, JJ, Kosmol, A, Marszałek, J, Morgulec-Adamowicz, N, and Frick, T. Relationships between anaerobic performance, field tests, and functional level of elite female WB athletes. Hum Mov 14: 366–371, 2014.

19. Molik, B, Lubelska, E, Kosmol, A, Bogdan, M, Yilla, AB, and Hyla, E. Examination of the international wheelchair rugby Federation classification system utilizing parameters of offensive game efficiency. Adapt Phys Activ Q 25: 335–351, 2008.

20. Morin, JB, Bourdin, M, Edouard, P, Peyrot, N, Samozino, P, and Lacour, JR. Mechanical determinants of 100-m sprint running performance. Eur J Appl Physiol 112: 3921–3930, 2012.

21. Paulson, T, and Goosey-Tolfrey,, V. Current Perspectives on Profiling and Enhancing Wheelchair Court Sport Performance. Int J Sports Physiol Perform 12: 275–286, 2017.

22. Paulson, TA, Mason, B, Rhodes, J, and Goosey-Tolfrey, VL. Individualized internal and external training load relationships in elite wheelchair rugby players. Front Physiol 6: 388, 2015.

23. Portney, L and Watkins, MP. Foundations of Clinical Research: Applications to Practice. Hoboken, NJ: Pearson Education, Inc, 2009. pp. 63–115.

24. Ramos-Campo, DJ, Rubio-Arias, JA, Dufour, S, Chung, L, A´ vila- Gandı´a, V, and Alcaraz, PE. Biochemical responses and physical performance during high-intensity resistance circuit training in hypoxia and normoxia. Eur J Appl Physiol 117: 809–818, 2017.

25. Rhodes JM, Mason BS, Malone LA, Goosey-Tolfrey VL. Effect of team rank and player classification on activity profiles of elite wheelchair rugby players. J Sports Sci 33: 2070–2078, 2015.

26. Rhodes JM, Mason BS, Paulson TAW, Goosey-Tolfrey VL. A comparison of speed profiles during training and competition in elite wheelchair rugby players. Int J Sports Physiol Perform 12: 777–782, 2017.

27. Spiteri T, Nimphius S, Hart NH, Specos C, Sheppard JM, Newton RU. Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. J Strength Cond Res 28: 2415–2423, 2014.

28. Turbanski S, Schmidtbleicher D. Effects of heavy resistance training on strength and power in upper extremities in wheelchair athletes. J Strength Cond Res 24: 8–16, 2010.

29. Usma-Alvarez CC, Fuss FK, Subic A. Effects of rugby wheelchair design on output velocity and acceleration. Proced Eng 13: 315–321, 2011.

30. Van Der Slikke R, Berger M, Bregman D, Veeger D. Push characteristics in wheelchair court sport sprinting. Proced Eng 147: 730–734, 2016.

31. Vanlandewijck YC, Spaepen AJ, Lysens RJ. Relationship between the level of physical impairment and sports performance in elite WB athletes. Adapt Phys Activ Q 12: 139–150, 1995.

32. Vanlandewijck Y, Theisen D, Daly D. Wheelchair propulsion biomechanics: Implications for wheelchair sports. Sports Med 31: 339–367, 2001.

33. Weissland T, Leprêtre P-M, Bruere S, Troadec G, Terrefond M. Prediction of peak oxygen consumption from the multistage field test in elite wheelchair rugby players. Ann Phys Rehab Med 59: e54, 2016.

34. Winter EM, Hamley EJ. Submaximal oxygen uptake related to fat free mass and lean leg volume in trained runners. Br J Sports Med 10: 223–225, 1976.

Figure 1.: A) Placement of the linear encoder on the wheelchair. B) The tether of the linear encoder was hooked to the horizontal axis between the push wheels.

Figure 2.: A) Velocity of and acceleration applied to the wheelchair during initial maximum push-rim propulsion (IMPRP) by participant 10. B) Force, as a product of the participant's total mass and acceleration, and power, as a product of force and velocity, applied to the wheelchair during IMPRP.

Figure 3.: A) Actual (gray dot) and modeled (white dot) wheeling velocity ($m \cdot s^{-1}$) as a function of time at the onset of a typical 12-m wheeling sprint for participant 10. Actual wheeling velocity accurately fitted the exponential model (^{1}). B) Wheeling velocity given by the exponential model (^{1}), as a function of the actual wheeling velocity. The linear association, identity line, and 95% confidence interval (CI) are shown.