Original article

Title: **The role of power and kinetic asymmetry in differentiating elite vs. sub-elite wheelchair rugby sprint performance**

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**Abstract**

Wheelchair sprint performance varies by sports classification. Yet, it is unclear how spatio-temporal, kinetic and kinetic asymmetries of wheelchair sprinting differ among wheelchair rugby players of different performance standard. The study purpose was to examine the associations between 30s sprint performances and spatio-temporal, kinetic and kinetic asymmetries on a dual-roller ergometer in elite and sub-elite wheelchair rugby players (n=20). Kinetic differences between groups were investigated using statistical parametric mapping. Peak velocities were associated with the acceleration phase and higher peak power (r=0.62, P=0.003) and lower push times (r=-0.50, P=0.020). Greater distance travelled during the acceleration phase were correlated with lower asymmetries in peak power (r=-0.58, P=0.005). Overall, both peak velocity and total distance covered during the entire sprint was correlated with lower push times (r=-0.61, P=0.003 and r=-0.62, P=0.003) but greater peak power (r=-0.61, P=0.003 and r=-0.62, P=0.003). Elite players had lower power asymmetries between 1 to 15% and 95 to 100% of the push phase during the acceleration phase, accompanied by a lower initial contact asymmetry (P=0.011). While power is an essential feature of sprinting, our findings show that how it is applied, in terms of asymmetry and coordination might differentiate the performance in wheelchair rugby.

**Keywords:** Wheelchair sprinting, Paralympics, Asymmetries, Testing, Talent Identification.

## Introduction

Wheelchair rugby is a popular sport contested worldwide and has been included on the Paralympic programme since 2000. To minimise the impact of impairment on the match outcome, male and female players are classified into one of seven categories ranging from 0.5 (most impaired, low-point) to 3.5 (least impaired, high-point), with an on-court total of 8 points allocated between four players (Tweedy and Vanlandewijck 2011). Eligibility requires an impairment that affects both the arms and legs. Although originally developed for individuals with a spinal cord injury, players with a wide variety of physical impairments such as cerebral palsy, muscular dystrophy, congenital or acquired limb deficiencies and other neurological disorders are eligible to compete (World Wheelchair Rugby; WWR, 2020).

During wheelchair rugby game-play, players manoeuvre their chairs at low speeds which are interspersed with periods of high speed and/or sprint activity in response to the technical components of the game (Rhodes, Mason, Perrat, et al. 2015). Research indicates that higher-ranked teams not only engage in a greater number of these high-speed activities but also achieve higher peak speeds during competition (Rhodes, Mason, Malone, et al. 2015). This suggests an athlete's capacity to rapidly accelerate their chair (Mason et al. 2010; Van Der Slikke et al. 2016) and to attain and sustain a high maximal velocity are pivotal for success (Van Der Slikke et al. 2016; Paulson and Goosey-Tolfrey 2017). As a result, there has been increasing interest to understand the spatio-temporal and kinetic intricacies of sprinting in wheelchair rugby players, with recent studies exploring these parameters in elite players (Briley et al. 2023; Janssen et al. 2023; Haydon et al. 2018; West et al. 2014). Such characteristics of wheelchair sprinting differ between low-point and high-point wheelchair rugby players (Bakatchina et al. 2021), with high-pointers achieving ~15% faster sprint times than their low-point counterparts (Goosey-Tolfrey et al. 2018). Despite this, little is known about the specific factors influencing sprint performance. This limits a coach's ability to effectively develop sprint capacity, especially in less skilled wheelchair rugby players (sub-elite vs. elite level).

Due to the bilateral nature of wheelchair propulsion, symmetrical and synchronous pushing technique (where work is done by both arms to exert force in unison) is associated with greater power output and wheelchair velocities (Faupin et al. 2013; Lenton et al. 2009). Kinetic asymmetry contributes to the difference in the uneven development of performance or kinematic parameters between the left and the right-side during wheelchair propulsion. Various calculations, including instantaneously symmetry indexes, have been used to assess daily ambulation, such as propelling a wheelchair up slopes (Chénier et al. 2017) with greater asymmetries observes during outdoor propulsion (Hurd et al. 2008). Importantly, during an increase in grade during daily ambulation or when propulsion velocity is high within athletic propulsion, the likelihood of greater asymmetry increases (Soltau et al. 2015; Goosey-Tolfrey et al. 2018) which may increase energy cost and prevent the wheelchair moving in a straight line (Vegter et al. 2013). Briley et al. (2023) showed increasing kinematic asymmetry as a result of fatigue on a stationary ergometer, whilst Brassart et al. (2023) observed upper limb symmetry to be task- and wheelchair setup-specific. However, the effects of such asymmetries on sprint performance are not well understood. By elucidating this topic, we can equip coaches and athletes with targeted insights into the spatio-temporal and kinetic properties that underpin successful sprint performance, enabling them to prioritise the most crucial technique modifications to optimise sprint performance.

Therefore, the objectives of this study were twofold: i) to examine the association between spatio-temporal, kinetic and kinetic asymmetries and 30 s Wingate sprint performance on a wheelchair ergometer, and ii) to investigate the effect of wheelchair rugby performance standard (elite vs sub-elite) on wheelchair sprinting kinetics controlled by impairment, age and classification. It was hypothesised that elite wheelchair rugby players will display different spatio-temporal and kinetic patterns compared to sub-elite players, characterised by reduced kinetic asymmetries during a 30 s Wingate sprint performance.

## Materials and methods

*Participants*

Twenty international wheelchair rugby players (17 male and 3 females; age 27 ± 7 yrs; body mass 65 ± 13 kg) from a top five wheelchair rugby nation with a range of impairments (spinal cord injury; n = 9, cerebral palsy; n = 7, arthrogryposis multiplex congenita; n = 2, Limb deficiency; n = 2) provided written informed consent and completed a health screening questionnaire prior to participation. Experimental procedures were approved by the institution's ethics committee (review reference G07-P5), which were in line with the Declaration of Helsinki.

Athletes represented all WWR classifications from 0.5 to 3.5 (low point [LP]: n = 11, high point [HP]: n = 9), as seen elsewhere (Goosey-Tolfrey et al. 2018). The sample size calculation was based on anticipated correlations between spatio-temporal and kinetic parameters (e.g., peak force, peak power, and power asymmetry) and performance variables during wheelchair sprinting, with an effect size of $r$ = 0.56 derived from previous data (Briley et al., 2023). A two-tailed correlation analysis using a bivariate normal model was conducted in G*Power (3.1.9.2), with a significance level of $\alpha$ = 0.05 and power of 0.80, determining a minimum sample size of 20 participants.

*Experimental design*

Upon arrival to the laboratory, players were asked to void their bladder, and their body mass was recorded to the nearest 0.1 kg (Marsden Weighing Group Ltd, Henley- on-Thames, UK).

All trials were conducted in players own wheelchair rugby wheelchair (chair mass 17.5 ± 1.9 kg, wheel diameter 0.60 ± 11.5 m, and wheelbase 0.73 ± 0.43 m). Players wore their typical competition kit including gloves, strapping and abdominal binders. Tyre pressure was self-selected ranging 120 to 230 psi, depending on the player's tyre type and preference for competition.

All trials were performed on a dual roller wheelchair ergometer (WERG: Lode Esseda m988900, Groningen, Netherlands) which recorded at 100 Hz (Figure 1). The Lode Esseda ergometer measures spatio-temporal and kinetic parameters of wheelchair propulsion for each side (Figure 2) and provides good concordance with kinetics obtained from instrumented measurement wheels, and significant between trial reliability (ICC = 0.97 (0.71-0.99), $p < 0.001$: de Klerk et al. 2020). Once players were fixed to the ergometer, an automatic, individualised calibration was performed to ensure the resistance of the motor was adjusted for the mass of the wheelchair-user combination, the distribution thereof, alignment, and tension on the fastening straps (de Klerk et al. 2020). A relative rolling resistance was applied using a resistance coefficient which closely replicated propulsion on a competition court (Rick de Klerk et al. 2020). The participants then completed a standardised warm-up involving self-selected submaximal propulsion for a set distance equalling the length of two court laps (172m), followed by two 6 s sprints separated by 30 s to re-familiarise themselves with sprinting on the ergometer. All participants had previously completed a 30 s sprint on at least two separate occasions on the ergometer as part of their bi-annual screening. Following a 5-minute recovery period, participants performed an uninterrupted 30 s all out Wingate test. The Wingate test commenced with a rolling start (10 s) at a relative rolling resistance (9.8 ± 1.5 N; coefficient = 0.012), followed by a "go" command and a simultaneous increase in resistance. A relative increase in resistance was prescribed using a resistance coefficient (22.0 ± 3.3 N; coefficient = 0.027) to overcome excessive wheel velocities that are not compatible with the force-velocity curve (Janssen et al. 2023). Verbal encouragement was given to maximise participants' efforts during the Wingate trials.

***Insert Figure 1 Here***

*Data analysis*

All variables were derived using force and velocity outputs from the ergometer over the 30 s, in accordance with previous studies (Goosey-Tolfrey et al. 2018; Briley et al. 2022; Briley et al., 2023). An eighth-order Butterworth filter with a cut-off of 10 Hz filtered kinetic data with cut-off frequencies determined by residual analysis and in line with previous wheelchair sprinting research (Briley et al. 2023; Winter 2009). Two phases of the sprint were selected for analysis: acceleration and overall. The acceleration phase was represented by the first three pushes with overall representing the full 30 s Wingate sprint (Briley et al. 2023). Sprint performance outcome parameters were peak velocity and total distance (Figure 2). The following spatio-temporal and kinetic parameters were push time, push frequency, force and power in accordance with previous studies (Briley et al. 2020; Goosey-Tolfrey et al. 2018; Vegter et al. 2013). Fatigue index (FI) was calculated as minimum power attained following peak power divided by peak power, multiplied by 100 (Eq 1). Inter-limb asymmetries were calculated for each spatio-temporal and kinetic parameter of wheelchair sprinting using the symmetry index (SI) (Eq 2; Bakatchina et al. 2021; Goosey-Tolfrey et al. 2018). The SI reports asymmetry as a percentage whereby, 0% denotes perfect symmetry.

$$FI = \frac{min\ power}{peak\ power}\ x\ 100 \qquad \text{(Eq. 1)}$$

$$SI = \frac{|DOM - NDom|}{DOM}\ x\ 100 \qquad \text{(Eq. 2)}$$

Note: min power = minimum power, SI = Symmetry index, Dom = Value from the dominant limb, NDom = Value from the non-dominant limb.

***Insert Figure 2 Here***

*Statistical Analysis*

All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS version 27, IBM Corporation, New York, USA). Pearson's product moment correlations were utilised to examine the strength of any relationships between performance variables and the spatio-temporal and kinetic parameters of the sprint. Correlation magnitudes were interpreted as: *large* ≥ 0.5, *Moderate* = 0.3 – 0.49, *small* = 0.1 - 0.29, very small < 0.1 (Cohen 1988). Statistical significance was set at P = 0.05.

Pair-matched (impairment type, classification and body mass) comparisons of seven elite players (Paralympic team) and seven sub-elite players (pathway team) were used to further investigate spatio-temporal, kinetic and performance differences based on playing level. Matching based on impairment type, classification, and body mass, enabled greater confidence in establishing if any differences observed in performance and biomechanical variables are attributed to training, experience, or other inherent capabilities. Independent t-tests (α = 0.05) were used to compare sprint performance and relevant discrete kinetic and kinematic parameters between elite and sub-elite players. Effect sizes (ES) and 95 % confidence intervals (CI) were calculated to determine the magnitude of any effects, which were classified as small (d = 0.2), moderate (d = 0.5) and large (d = 0.8) (Cohen et al. 1988). Statistical Parametric Mapping (SPM) two-tailed independent t-tests (α = 0.05) were used to compare kinetic waveforms across the push phase (identified as the period where the WERG roller torque trace exceeded 1 Nm (Goosey-Tolfrey et al. 2018; Vegter et al. 2013)) between pair-matched groups of elite and sub-elite players. SPM analyses were conducted using open-source MATLAB code with theoretical underpinning provided elsewhere (Pataky et al. 2013; SPM1d, v.M0.4.5, www.spm1d.org).

## Results

Sub-elite players had a lower playing time compared to elite players (4.9 ± 1.6 yrs vs 12.3 ± 5.7 yrs respectively, *P* = 0.006).

### *Spatio-temporal and kinetic relationships with sprint performance*

A positive correlation was observed between peak velocity and peak power and a negative correlation between peak velocity and push times during the acceleration phase of sprinting (Table 1). Furthermore, distance travelled during the acceleration phase was negatively correlated with peak power asymmetries. Overall, both peak velocity and total distance covered during the sprint was negatively correlated with push times, but positively correlated with peak, mean, minimum power, power drop (maximum – minimum) and fatigue index (Table 1). Peak velocity was positively correlated with fatigue index.

***Insert Table 1 Here***

In the pair-matched comparison elite players covered a greater distance during the acceleration phase (4.2 ± 0.7 m vs. 3.4 ± 0.7 m, *P* = 0.002, ES = 1.2, 95% CI: 0.04 to 2.31) compared to sub-elite players. Elite players also attained a greater distance overall (104.4 ± 16.4 m vs 85.8 ± 20.1 m, *P*= 0.029, ES = 1.1, 95% CI: -0.05 to 2.19). Peak velocity during the acceleration phase and overall were not different between groups but effect sizes were considered large (P = 0.054, ES = 0.90, 95% CI: -0.22 to 1.97) and P = 0.056, ES = 0.88, 95% CI: -0.22 to 1.97), respectively).

SPM independent t-tests revealed elite players display lower power asymmetries during the acceleration phase of the 30 s sprint (Figure 3). Specific differences occurred between 1 and 15% and 95 to 100% of the push phase. Power was not different during either the acceleration phase or maximal velocity phase of sprinting nor did power asymmetries differ between elite and sub-elite players during the maximal velocity phase of sprinting. Further, elite players displayed a lower initial contact time asymmetry ($p$ = 0.011), suggesting that hands contacted the wheel at similar times compared to sub-elite. No differences were reported in contact time during release of the wheels ($p$ = 0.765).

***Insert Figure 3 Here***

## Discussion

The current study investigated the spatio-temporal and kinetic aspects of wheelchair rugby performance during a 30 s Wingate test on a WERG among elite and sub-elite players. Key findings revealed a strong correlation between peak velocity during acceleration and peak power, alongside shorter push times. Longer sprint distances were associated with reduced peak power asymmetries, while greater peak velocity and sprint distance were linked to lower push times, higher peak and mean power and greater power drop. Additionally, we observed a relationship between peak velocity and fatigue index. Elite players covered greater distances during both the acceleration phase and overall sprint. Notably, power asymmetries were more pronounced in the sub-elite players during initial and final 5% of the push phase, indicating potential areas for targeted training.

Enhanced acceleration capacity provides an advantage in gameplay, where rapid changes in pace and direction are vital for successful performance. The acceleration phase emerged as a critical determinant of overall sprint performance, consistent with previous studies (Mason et al. 2010; Van Der Slikke et al. 2016). Elite players covered greater distances during this phase, which correlated with higher peak velocities and shorter push times. Such associations emphasize the importance of rapid force production, expanding previous findings (Haydon et al. 2018; Goosey-Tolfrey et al. 2018). Goosey-Tolfrey et al. (2018) reported significant differences in propulsion cycles between high- and low-point players during short sprints contributing to enhanced acceleration performance. Indeed, kinematic differences between classification groups as a result of impairment have been identified (Haydon et al. 2018). Therefore, the need for future research to explore kinematic variations in conjunction with our provided biomechanical data is warranted. Despite this, in the context of force application, shorter push times and greater peak power outputs during acceleration as identified in the present study suggest that explosive force generation within each propulsion cycle is crucial. Our results also revealed a correlation between both peak velocity and distance covered during the overall 30 s sprint and reduced push times. Therefore, in agreement with Vegter et al. (2013) maintenance of a low push time throughout the sprint, despite increasing wheel velocity is critical for sustaining momentum.

Our findings revealed a negative correlation ($r = -0.58$) between acceleration distance and peak power asymmetry. Importantly propulsion asymmetry during straight-line movement on the court can influence steering, which may have implications for performance and control (Brassart et al. 2023). Elite players displayed smaller variability in power asymmetry compared to sub-elite players, indicating a more refined and consistent propulsion technique developed through training and experience (Briley et al. 2023; Janssen et al. 2023) which could explain the large effect sizes reported between groups for peak velocity. The asymmetry trends were particularly evident at the beginning (1–15%) and end (95–100%) of the push phase, which coincide with higher mechanical demands. These findings align with Franchin et al. (2020) who identified initial push and release transitions as critical points in propulsion. In the sub-elite players, greater variability in asymmetry during these phases may reflect biomechanical inefficiencies or impairment-related challenges, increasing veering (Vegter et al. 2013) and thus warranting further investigation into upper limb kinematics and coupling techniques (Van Der Slikke et al., 2016; Paulson & Goosey-Tolfrey, 2017).

A key observation was the relationship between higher peak velocities and greater fatigue indices. Players achieving higher peak velocities experienced a more substantial power drop. An increased reliance on type II muscle fibres and the concomitant increased glycogen metabolism to produce short, powerful contractions (Gollnick et al. 1973) is likely evident when reaching greater peak velocities. Thus, type II fibre-type specific degradation of glycogen stores in response to sprinting (Vigh-Larsen et al. 2022) may explain the significant power drop and fatigue index in players achieving greater velocities. This highlights the need to enhance explosive power, whilst augmenting fatigue resistance through targeted conditioning and recovery strategies.

Although the WERG delivered accurate data, its ecological validity has been challenged (Haydon et al. 2018) as a result of the potential differences in upper limb kinematics (Mason et al. 2014), suggesting future work should also consider quantifying kinetic and spatio-temporal asymmetries in real-world field settings. The application of inertial measurement units in future studies could allow for a more detailed analysis of steering dynamics. That said, the WERG's advantages, like its capacity for sensitive measurements of wheelchair-user configuration and accounting for asymmetries, as noted by Vanlandewijck et al. (2001), are clear but must be weighed against real-world applicability.

Despite our effort to pair-match players from elite and sub-elite teams, potential confounders related to motivation, training, and coaching quality between these groups might be present. Furthermore, while the inclusion of the 95% CI provides valuable context to the effect sizes, the large CI observed between pair-matched participants from elite and sub-elite groups may highlight a degree of uncertainty in the measures. However, this variability could be explained by the classification-specific differences in performance across various playing levels (Rhodes et al., 2015). Rhodes et al. (2015) observed differences in peak speed among higher classification groups between playing levels, with no such differences evident in lower classification groups. This suggests that classification and impairment play a crucial role in quantifying sprint performance across various playing levels, providing an area for further exploration.

*Conclusion*

In our study of wheelchair rugby players during a 30 s Wingate test, the acceleration phase was highlighted as pivotal for elite sprint performance. Effective force production, especially in the initial phases, and bilateral symmetry in propulsion are crucial. While elite players demonstrated greater distances during acceleration, sub-elite players displayed greater variability in power and asymmetries during key push phases. Though foundational power output is vital for wheelchair rugby sprint performance, its efficient application differentiates elite from sub-elite performances. A combined approach of enhancing bilateral power symmetry and push timing optimisation in combination with enhancing explosive power development is essential for top-level wheelchair rugby sprint performance. Such findings have significant implications for coaches working with developing wheelchair rugby players.

**Data availability statement**

The participants of this study did not give written consent for their data to be shared publicly, so due to the sensitive nature of the research supporting data is not available.

**Disclosure of interest**

There are no conflicts of interest associated with this research.

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## Tables (with captions)

Table 1. Relationships between sprint performance parameters and spatio-temporal, kinetic, and kinetic asymmetries of sprinting during 30 s Wingate sprint. Significant correlations are indicated by bold text.

| **Acceleration phase** | | | | | |
|---|---|---|---|---|---|
| | | Peak Velocity (m.s$^{-1}$) | | Distance (m) | |
| | | 2.63 ±0.38 | | 3.6 ± 0.6 | |
| **Variable (Units)** | **Mean ± SD** | r | P | r | P |
| Rel. Velocity (% max) | 79.3 ± 11.5 | -0.01 | 0.972 | -0.24 | 0.305 |
| Push time (%) | 50.4 ± 9.6 | **-0.50** | **0.021** | -0.26 | 0.258 |
| Pk. Force (N) | 108.2 ± 49.6 | 0.40 | 0.072 | 0.26 | 0.247 |
| Asymmetry pk. force (%) | 9.0 ± 4.8 | 0.05 | 0.821 | -0.55 | 0.009 |
| Pk. Power (W) | 331 ± 181 | **0.62** | **0.003** | 0.28 | 0.227 |
| Asymmetry pk. power (%) | 17.7 ± 10.7 | 0.05 | 0.816 | **-0.58** | **0.005** |
| **Overall** | | | | | |
| | | Peak Velocity (m.s$^{-1}$) | | Distance (m) | |
| | | 3.39 ± 0.72 | | 91.6 ±18.3 | |
| **Variable (Units)** | **Mean ± SD** | r | P | r | P |
| TTPV (sec) | 7.4 ± 2.1 | 0.26 | 0.248 | 0.25 | 0.274 |
| Push freq. (Hz) | 2.0 ± 0.4 | 0.08 | 0.729 | 0.07 | 0.776 |
| Push time (%) | 42.7 ± 8.2 | **-0.61** | **0.003** | **-0.62** | **0.003** |
| Pk. Power (W) | 432 ± 244 | **0.83** | **<0.001** | **0.78** | **<0.001** |
| Asymmetry pk. power (%) | 31.3 ± 24.4 | 0.11 | 0.621 | 0.09 | 0.700 |
| Mean Power (W) | 283 ± 153 | **0.77** | **<0.001** | **0.75** | **<0.001** |
| Min Power (W) | 131 ± 74 | **0.58** | **0.006** | **0.60** | **0.004** |
| Power drop (W) | 271 ± 167 | **0.59** | **0.005** | **0.55** | **0.010** |
| FI (%) | 67.7 ± 8.6 | **0.48** | **0.027** | 0.40 | 0.073 |

Notes: Pk = Peak, TTPV = Time to peak velocity, FI = Fatigue index. Asymmetry is calculated using the symmetry index.

## Figures

Figure 1

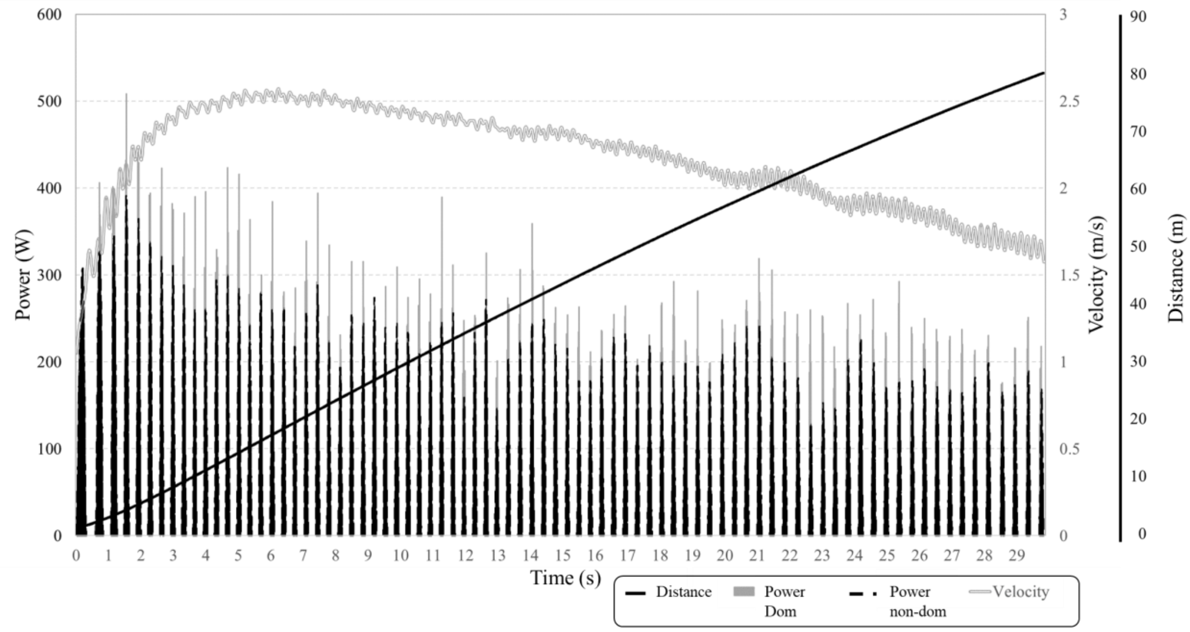
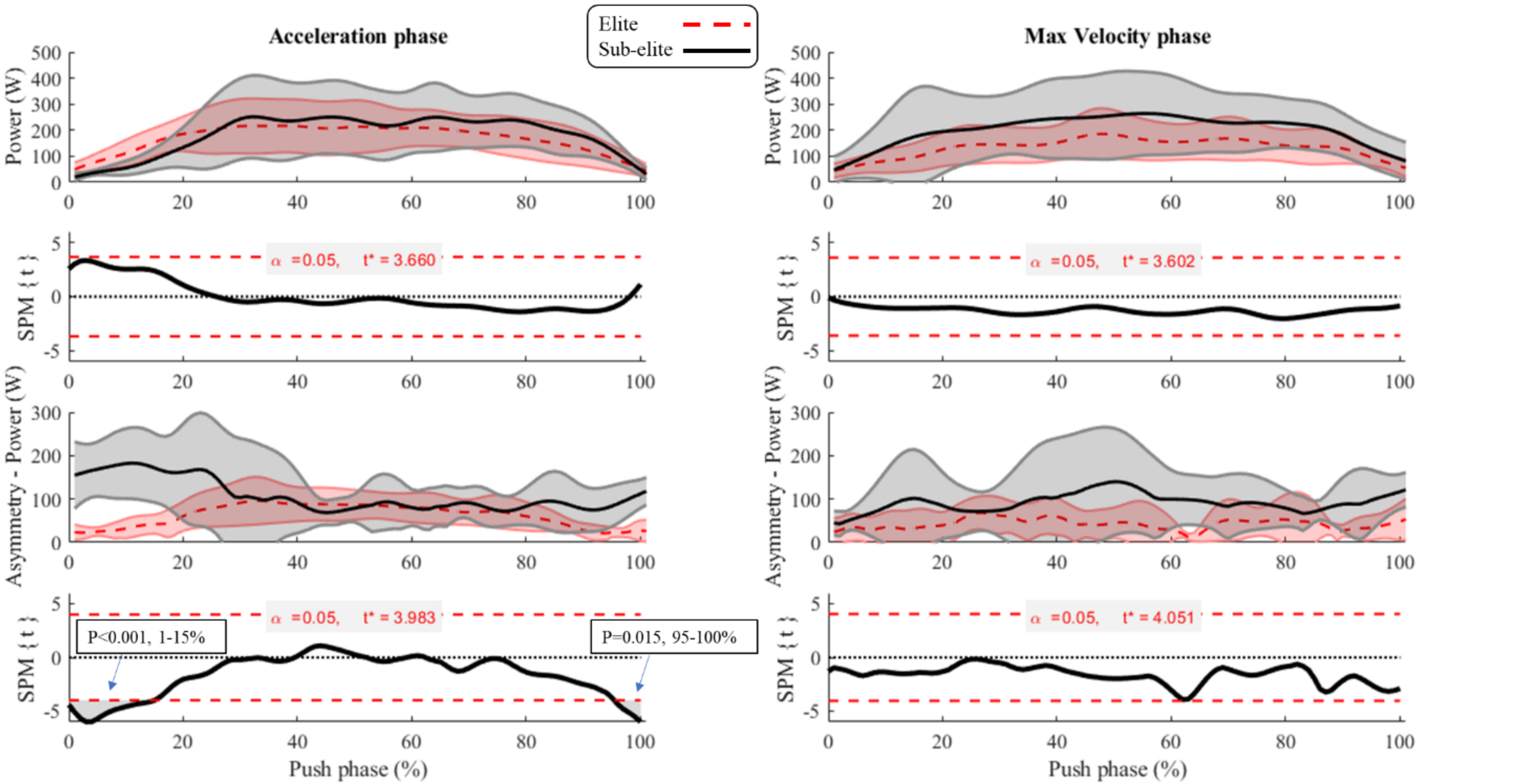



Figure 2

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## Figure Captions

Figure 1. Experimental setup of the dual-roller wheelchair ergometer.

Figure 2. Typical example of pushes across time for dominant (Dom) and non-dominant (non-dom) arms during a 30 s wingate sprint.

Figure 3. Pairwise comparisons between elite and sub-elite players during the acceleration phase of the sprint. Mean trajectory ± SD cloud for elite players (red line, red cloud) and sub-elite players (black line, dark grey cloud). SPM{t} output correspondent to each of the vector components. Grey shaded area for each suprathreshold cluster.