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# Introduction

Wheelchair rugby (WCR) is an indoor mixed-gendered contact para-sport that takes place on a rectangular court measuring 15 x 28m (Ρdes et al., 2018). The sport was designed for wheelchair basketball (WB) players who found the sport too physically demanding. It combines elements of rugby and basketball to create a unique and challenging game (Chua et al., 2010). The ball is required to be thrown, passed, bumped, or dribbled in any direction between teammates every 10 seconds. To score, the ball must be carried across the goal line, with both wheels crossing the opposition's goal line within 40 seconds of gaining possession of the ball (Goosey-Tolfrey, 2010). The sport is more commonly known for its original format and paralympic discipline WCR Fours, where four players are on the court at one time, competing in four quarters of eight minutes (Ρdes et al., 2018). The Paralympic discipline is aimed at tetraplegics, with eligibility requiring athletes to have an impairment affecting their arms and legs. Many athletes partaking in the sport have spinal cord injuries (SCI), with full or partial paralysis of the legs and partial paralysis of the arms (García-Fresneda et al. 2019). Other disabilities commonly seen in the sport involve cerebral palsy, muscular dystrophy, amputations, polio, and other neurological conditions (García-Fresneda et al. 2019). Recently a faster-paced version of the sport known as WCR Fives was developed. These games involve two x 12 min halves rather than quarters and have five players on the court at once (Wheelchair Rugby Australia, 2023). This has allowed the sport to increase its inclusivity as the version opens the sport up to paraplegics and anyone with a physical impairment (International Wheelchair Rugby Federation, 2021). The eligibility for WCR Fives requires individuals to have a permanent physical impairment that significantly impairs the function of the upper or lower limbs to the extent that they cannot run, pivot, throw, catch or jump with sufficient speed, control, stability or endurance (Great Britain Wheelchair Rugby Limited, 2019).

Both game formats have their own classification system to fairly regulate the level of influence that impairments have on games, although the reliability of the system has regularly been questioned (Tweedy and Vanlandewijck, 2009). The system allocates athletes to a classification that’s representative of functional ability rather than athletic ability. This is decided by hand, arm, shoulder, and trunk function (Goosey-Tolfrey, 2010). During a game, the WCR Fours classification total cannot exceed 8.0 points on the court at once, whilst WCR Fives cannot exceed 10.0 points. For each female on the court, an additional 0.5 points are allocated to that team. Current WCR research revolves around the paralympic discipline, and many of these studies categorise players into two groups based on their classification: high-point (HP) and low-point (LP). Those who are HP players (classification ≥ 2.0), tend to have better bodily functions and play a more offensive role in the sport resulting in higher peak velocities than LP (classification ≤ 1.5) players (Bakatchina et al., 2021). Players who are deemed LP tend to play a defensive role due to their lower functional ability, which results in limited wheelchair skills that stem from trunk instability (Goosey-Tolfrey, 2006).

An SCI can be defined as the partial or complete loss of the ability to move or sense from below an injury level (Bjerkefors et al. 2009). The physiological impact of aerobic and anaerobic capacity, aerobic power and strength is influenced by the SCI lesion level (Haisma et al. 2006). More specifically research has found significant correlations between trunk muscle strength and WCR sport-specific activities (Altmann et al., 2014). Truck function contributes to the stability and generation of momentum required for the sport, the abdominal muscle paralysis seen in SCI may result in the athlete being unable to get into the optimal position for force production (West et al. 2014). In addition, trunk function has been suggested to have the greatest impact on the first metre when accelerating from a standstill, while arm function is then a primary factor (Haydon et al., 2018). In SCI athletes it’s not uncommon to see asymmetries in the trunk and upper limbs, therefore during screening this is a considered factor due to the decrease in bilateral force production that it can cause (Haisma et al. 2006). Athletes with SCI not only lack voluntary control of their torso and upper limbs, but they also face thermoregulatory impairment caused by SCI. A study examining the thermoregulatory response of these athletes found that those with SCI covered roughly 17% less distance and pushed with approximately 10% less force than those without SCI. These athletes generated smaller amounts of heat under a greater thermal stain due reduced ability to dissipate heat (Griggs et al., 2017). Despite being classified accordingly, it has been shown that athletes without SCI can reach a heart rate (HR) that is noticeably higher than athletes with SCI (Squair et al. 2017). This reduced HR response among athletes with SCI is indicative of an impaired cardiovascular system, which is believed to be caused by injury to the spinal sympathetic pathways resulting from the SCI (Gee et al., 2017). Those without SCI (Non-SCI) may hold impairments in sensation, motor control and communication, typically this can reflect in muscle imbalance and reduced power due to increased muscle tone, spasticity and or reduced coordination. However, unlike SCI Non-SCI may still uphold a cardiovascular response similar to able-bodied (AB) athletes (Paulson and Goosey-Tolfrey 2017).

Fields tests in speed, acceleration, change of direction ability, strength and endurance have all been used to determine WB physical ability (Romarate et al. 2023). Sprint performance is a key skill in WCR, with athletes regularly required to accelerate faster than their opponents (Malone et al., 2010). Factors influencing sprint performance include wheelchair set-up, trunk function and push rim propulsion. Push rims propulsion is a necessity to maximally accelerate, the ability to complete this from fast turning and at a standstill has been deemed crucial in the sport (Haydon et al. 2018). Wheelchair sports literature has found that sprint ability is imperative to performance, with peak velocity playing a crucial role in performance outcomes during high-intensity bouts (Bakatchina et al. 2021). These bouts have been shown to occur 36 to 52 times lasting between 1.7 and 1.9 seconds during a game (Ρdes et al. 2017). These sprints are more often seen from HP players rather than LP (Goosey-Tolfrey et al. 2018). Repeated sprint (RS) ability has been recognised in wheelchair-based sports (Iturricastillo et al., 2019), and is the capacity to perform sprint efforts with incomplete rest periods (Çetin and Koçak 2022). The ability makes a player better equipped to take initiative for potential play, allowing them to gain and maintain possession of the ball (Iturricastillo et al. 2019).

Literature supporting sprint ability in AB sports is significantly larger than what can be found in wheelchair-based sports (García-Fresneda et al., 2019). The gap in research can hold back the progress of the sport, as the development of effective training and game strategies is limited due to the limited understanding of the sport. Current studies have mainly focused on an elite sample of wheelchair athletes competing at national and or international levels. This research has provided insights into the sport's physiology, functional abilities, classification system, and biomechanical analysis (Bauerfeind et al., 2015).

Many of the current studies have been completed through laboratory testing, and whilst this has provided valuable data. This method is less accessible, especially to non-elite athletes, due to the limited availability of the specialized equipment required (Goosey-Tolfrey et al., 2020). This limitation makes field-based measures a desirable method to assess performance abilities, particularly concerning acceleration, a significant quality in WCR beneficial to the sport (Malone et al., 2010; Vanlandewijck and Thompson, 2011). Gee (2018) acknowledged this gap in field-based testing and investigated the effectiveness of a 20x20m RS field test that replicated the physical demands of WCR. The results showed a positive correlation between peak heart rate (HR) and lactate ([La-]B) in the field test (r=0.470, p=0.043), as well as between peak HR and peak speed (r=0.493, p=0.031). Furthermore, significant intra-class correlations (ICCs) were found between the field test and gameplay for peak HR (ICC=0.922, p<0.001). The bland-Altman analysis also indicated good agreement between HR and [La-]B in the field test and gameplay, demonstrating excellent between-day reliability of the test. The study suggests that the 20x20m RS field test is a valuable tool for assessing and monitoring training efficiency in WCR. However, like many of the studies available, this was also based on an elite WCR sample, and a non-elite sample was a future recommendation for the study.

A further study investigating sprint performance revealed significant and large correlations between initial maximal push rim propulsion (IMPRP) mean acceleration, maximum acceleration, and 12-m sprint performance in elite WCR athletes. This was the first study to analyse the relationship between these variables, in which a 61.4–80.1% variance in sprint performance was found. This was explained to be an effect of strength-related IMPRP mechanical outputs, suggesting that by improving IMPRP, sprint performance would improve (García-Fresneda et al. 2019). The varying range and severity of impairments have been linked to the differences seen in propulsion techniques (Haydon et al. 2018). Whilst the study on the impact of impairment in activities is a challenge, it’s important to develop evidence-based classification systems and further physiologically develop the sport (Altmann et al. 2016). Due to the difficulty of classification, researchers have called for more natural groupings based on disability-specific characteristics (Altmann et al., 2017). By examining subgroups, researchers can gain insights into the impact of impairments on key performance indicators (Haydon et al., 2018). Research on WCR sprinting is limited, and this is further expanded when looking at the relationship between game format and impairment type. Therefore, further investigation is necessary to understand the relationship between these sporting variables in both non-elite and elite-level athletes before examining causation (Altmann et al., 2014). Furthermore, it must be acknowledged that no previous studies have investigated any WCR performance variables in the Fives format. Therefore, any research carried out has been on the Fours with the majority focused on elite athletes.

The first aim of this study was to investigate the differences between WCR game formats (Fours and Fives) during sprint and RS testing in a non-elite sample of athletes. A secondary aim was to investigate the differences in SCI and Non-SCI sprint and RS ability. It was hypothesized that there would be a difference between the Fours and Fives performances in the sprint and RS tests. Furthermore, when subcategorised, it was hypothesised that Non-SCI would outperform SCI, with SCI players in both the sprints and RS while having higher peak lactate values after the 10 sprints.

# Method

## Participants

A purposive sampling approach was used to recruit participants from a recreational WCR club, consisting of a diverse group of players from various game formats and classifications (Table 1). A total of 21 (17 males and 4 females) non-elite players (mean ± SD; age: 34.66 ± 12.34 years; mass: 76.23 ± 21.96 kg; stature: 1.76 ± 0.09 m) participated in the study. Before commencing testing, all participants were fully informed about the procedures, possible risks, and purpose of the study. All participants also completed a PAR-Q form and provided informed written consent. The Solent University Ethics Committee approved this study.

## Procedures

Testing took place over two sessions with a minimum of 48 hours rest between them, in the club's sports hall where they usually train. The participant's chairs were a mix of personal and club chairs set to their preferences. A standardised warm-up (Two court lengths, dynamic stretches of shoulders, trunk, and activation of the neck. Followed by 50% sprints from 90-degree turn x 2, 75% sprints from 180 degrees turn x 1, and reaction pushes in all directions) was conducted before all testing sessions.

### *Session One – Initial Sprint Testing*

Session one (Figures 1 and 2) allowed for the measurement of time (secs), average velocity (m.s-1) for each of the splits and overall average velocity (m.s-1) and acceleration (m.s-2) during three maximal 20m sprint efforts. Timing gates (SmartSpeed, Vald, Newstead, Australia) were used to record splits at 5m (CV = 2.1%, ICC = 0.82), 10m (CV = 1.8%, ICC = 0.91), 15m (CV = 1.9%, ICC = 0.92) and 20m (CV = 1.6%, ICC = 0.95). Before commencing the test, a briefing was delivered and addressed any questions. Participants were then directed to position themselves 30cm behind the first timing gate (start gate) and instructed to complete each 20m sprint maximally when ready. After each sprint, participants were given a five-minute recovery period.

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### *Session Two – Repeated Sprint Testing*

Session two measured RS ability during 10 x 20m maximal effort sprints (Figures 1 and 2). The same setup as session one was used to assess the time to complete each 20m sprint (splits as described previously). Blood lactate concentration (mmol/L) was measured before starting the test and straight after the final sprint. The sample was taken from the ear lobe using a lancet and analysed using lactate pro (Lactate Pro 2, Arkray Europe B.V., Netherlands). Before the 1st sprint, participants were instructed to complete each of the 10 sprints maximally. When ready, the participants began their 1st sprint 30cm behind the start line before turning around at the other end (20m line), allowing the start line of the previous sprint to become the finish line of the next sprint. An auditory and a visual cue from the timing gates presented like a traffic light system informing participants when to begin the next sprint after a 15-second recovery period. This procedure continued until the 10th sprint, after which lactate concentration was assessed again. Verbal encouragement was given to all participants throughout from both the team and the staff present.

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# *Statistical Analysis*

The present analysis was not pre-registered as we had no a priori hypotheses and, given the limited sample size due to resource constraints and the population, thus was considered exploratory. Inferential statistics were treated as highly unstable local descriptions of the relations between model assumptions and data in order to acknowledge the inherent uncertainty in drawing generalised inferences from single and small samples (Amrhein, Trafimow, et al., 2019). For all analyses we opted to avoid dichotomising the existence of effects and therefore did not employ traditional null hypothesis significance testing on parameter estimates (Amrhein, Greenland, et al., 2019; McShane et al., 2019). Instead, we opted to take an estimation-based approach instead (Cumming, 2014), based within a Bayesian framework (Kruschke & Liddell, 2018). For all analyses model parameter estimates and their precision, along with conclusions based upon them, were interpreted continuously and probabilistically, considering data quality, plausibility of effect, and previous literature, all within the context of each model. We focused primarily on qualitative examination of our results based on visualization of the data and models for fixed effects, and exploration of variances using random effects. All analysis was performed in R (version 4.2.3, The R Foundation for Statistical Computing, 2023) and all data and code is presented in the supplementary materials (https://osf.io/y2jdb/). Two sets of models were employed exploring the sprint trial outcomes, and the repeated sprint outcomes, for both classification (4 vs 5) and disability (other vs SCI). The brms package (Bürkner, 2017) was used to fit all models. All parameters in the models described below had values , trace plots demonstrated chain convergence, and the posterior predictive checks appeared appropriate (see https://osf.io/juex5). Given population and outcomes explored, the limited data available in past studies, and the model structures, we did not have a clear intuition or informed opinion about what priors to set and so opted to use the default weakly regularising priors and “let the data speak”. Four Monte Carlo Markov Chains with 4000 warmup and 4000 sampling iterations were used in each model. For each model results were visualised by taking draws from the expected posterior distribution (n=16000) and taking the mean of these draws along with the 95% quantile (credible) interval for the fixed effects parameters, thus providing the overall grand mean effects for the population. All data visualisations were made using ggplot2 (Wickham et al., 2022), the tidybayes package (Kay & Mastny, 2022), and the patchwork package (Pedersen, 2022).

## Sprint trial outcomes - For the sprint trials we examined both the velocities and accelerations over each of the 5m sections of the 20m sprint as dependent variables in separate models. Data was handled in long format with each row corresponding to an observation of a participants velocity or acceleration in a 5m section for a given trial. For each of velocity and acceleration we fit separate models with fixed effects for either disability or classification, and in each also included a fixed effect for the distance (i.e., section of the 20m sprint trial: 0-5m, 5-10m, 10-15m, 15-20m), in addition to their interaction. We also used included random intercepts for participant and random slopes for distance. The model equation was, where was or , and was either or , thus:

## Repeated sprint trial outcomes - For the sprint trials we examined both the time in seconds for each of the 5m sections of the 20m sprint as dependent variables in separate models. Data was handled in long format with each row corresponding to an observation of a participants time for a 5m section for a given sprint number. We fit separate models with fixed effects for either disability or classification, and in each also included a fixed effect for the distance (i.e., section of the 20m sprint trial: 0-5m, 5-10m, 10-15m, 15-20m) and also for the sprint number (from first to tenth), in addition to their interactions. We also used included random intercepts for participant and random slopes for both distance and sprint number. The model equation was, where was either or , thus:

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# Results

## Sprint trial outcomes

The overall grand means and credible intervals from the models for the fixed effects (i.e., without including the random effects) for both velocity and acceleration can be seen in [Figure 1](file:///C:\Users\james\Dropbox\Research\Dissy%20students\wheelchair_rugby_sprints\report.docx#fig-velocity-model-plot) and [Figure 2](file:///C:\Users\james\Dropbox\Research\Dissy%20students\wheelchair_rugby_sprints\report.docx#fig-acceleration-model-plot), in addition to individual data, respectively for both disability and classification models. All parameters for both outcomes and both disability and classification models are also shown in [Table 1](file:///C:\Users\james\Dropbox\Research\Dissy%20students\wheelchair_rugby_sprints\report.docx#tbl-sprint-model). As might be expected, fixed effects in both models revealed that velocity increased as distance covered increased and the reverse pattern for acceleration which decreased as distance covered increased. Random effects in both models showed that variation in velocities increased with increasing distance covered, and also the random effects correlations suggested that those who were initially faster, or faster during certain sections of the sprint, were similarly typically faster at all other distances. Variance in acceleration was more similar over increasing distance covered as compared with velocity, and also the random effects correlations suggested that those who had initially higher acceleration showed greater declines in acceleration across all distances, though between adjacent distances there were more positive relationships.

### *Disability -* SCI participants showed slower velocities across all distances. There was however little interaction effect between disability and distance upon velocity. SCI participants also had lower acceleration across all distances. However, there were interactions between disability and distance whereby although over the initial 0-5m distance SCI participants had lower accelerations, the difference between them and participants with other injuries decreased as distance covered increased. During the final 10-15 and 15-20m accelerations were similar between groups.

### *Classification*

Both 4s and 5s showed similar velocities across all distances, as well as accelerations. There was little effect of classification upon either velocity or acceleration.

Table 1: Model parameter estimates for both fixed and random effects for sprint trial outcomes (velocity and acceleration).

|  | Velocity (m·s-1) | | | Acceleration (m·s-2) | | |
| --- | --- | --- | --- | --- | --- | --- |
| Model Term | Estimate | Lower 95% CI | Upper 95% CI | Estimate | Lower 95% CI | Upper 95% CI |
| **Disability Model** | | | | | | |
| *Fixed Effects* | | | | | | |
| Intercept | 2.32 | 2.18 | 2.46 | 1.08 | 0.98 | 1.19 |
| DisabilitySCI | -0.26 | -0.46 | -0.06 | -0.22 | -0.38 | -0.07 |
| Distance5-10m | 1.00 | 0.90 | 1.10 | -0.41 | -0.48 | -0.34 |
| Distance10-15m | 1.32 | 1.19 | 1.45 | -0.84 | -0.93 | -0.76 |
| Distance15-20m | 1.57 | 1.40 | 1.75 | -0.88 | -0.97 | -0.79 |
| DisabilitySCI:Distance5-10m | -0.10 | -0.24 | 0.04 | 0.10 | 0.00 | 0.20 |
| DisabilitySCI:Distance10-15m | -0.09 | -0.29 | 0.10 | 0.21 | 0.09 | 0.32 |
| DisabilitySCI:Distance15-20m | -0.11 | -0.36 | 0.15 | 0.19 | 0.07 | 0.32 |
| *Random Effects* | | | | | | |
| σ Intercept | 0.23 | 0.17 | 0.32 | 0.17 | 0.12 | 0.23 |
| σ Distance5-10m | 0.15 | 0.11 | 0.21 | 0.10 | 0.06 | 0.15 |
| σ Distance10-15m | 0.21 | 0.16 | 0.29 | 0.12 | 0.08 | 0.17 |
| σ Distance15-20m | 0.28 | 0.21 | 0.39 | 0.13 | 0.09 | 0.18 |
| ρ Intercept:Distance5-10m | 0.69 | 0.34 | 0.90 | -0.10 | -0.53 | 0.36 |
| ρ Intercept:Distance10-15m | 0.61 | 0.26 | 0.85 | -0.85 | -0.96 | -0.63 |
| ρ Intercept:Distance15-20m | 0.54 | 0.16 | 0.80 | -0.79 | -0.93 | -0.52 |
| ρ Distance5-10m:Distance10-15m | 0.94 | 0.83 | 0.99 | 0.39 | -0.09 | 0.75 |
| ρ Distance5-10m:Distance15-20m | 0.90 | 0.74 | 0.98 | 0.47 | 0.01 | 0.79 |
| ρ Distance10-15m:Distance15-20m | 0.97 | 0.90 | 1.00 | 0.88 | 0.65 | 0.99 |
| σ Residual | 0.07 | 0.06 | 0.08 | 0.07 | 0.06 | 0.08 |
| **Classification Model** | | | | | | |
| *Fixed Effects* | | | | | | |
| Intercept | 2.17 | 2.02 | 2.32 | 0.95 | 0.84 | 1.07 |
| Classification5 | 0.04 | -0.20 | 0.27 | 0.04 | -0.14 | 0.21 |
| Distance5-10m | 0.98 | 0.89 | 1.07 | -0.32 | -0.39 | -0.26 |
| Distance10-15m | 1.33 | 1.21 | 1.45 | -0.70 | -0.80 | -0.61 |
| Distance15-20m | 1.60 | 1.45 | 1.76 | -0.74 | -0.83 | -0.65 |
| Classification5:Distance5-10m | -0.06 | -0.21 | 0.08 | -0.08 | -0.19 | 0.02 |
| Classification5:Distance10-15m | -0.13 | -0.31 | 0.06 | -0.09 | -0.23 | 0.06 |
| Classification5:Distance15-20m | -0.20 | -0.44 | 0.04 | -0.10 | -0.24 | 0.04 |
| *Random Effects* | | | | | | |
| σ Intercept | 0.26 | 0.19 | 0.36 | 0.20 | 0.15 | 0.27 |
| σ Distance5-10m | 0.16 | 0.11 | 0.21 | 0.10 | 0.06 | 0.15 |
| σ Distance10-15m | 0.20 | 0.15 | 0.28 | 0.15 | 0.11 | 0.21 |
| σ Distance15-20m | 0.27 | 0.20 | 0.36 | 0.15 | 0.11 | 0.21 |
| ρ Intercept:Distance5-10m | 0.73 | 0.41 | 0.92 | -0.29 | -0.67 | 0.16 |
| ρ Intercept:Distance10-15m | 0.65 | 0.31 | 0.86 | -0.91 | -0.98 | -0.77 |
| ρ Intercept:Distance15-20m | 0.60 | 0.24 | 0.83 | -0.87 | -0.96 | -0.69 |
| ρ Intercept:Distance15-20m | 0.60 | 0.24 | 0.83 | -0.87 | -0.96 | -0.69 |
| ρ Distance5-10m:Distance15-20m | 0.91 | 0.75 | 0.98 | 0.53 | 0.11 | 0.82 |
| ρ Distance10-15m:Distance15-20m | 0.97 | 0.90 | 1.00 | 0.91 | 0.74 | 0.99 |
| σ Residual | 0.07 | 0.06 | 0.08 | 0.07 | 0.06 | 0.08 |
| Note: |  |  |  |  |  |  |
| CI = credible interval |  |  |  |  |  |  |

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| A screenshot of a graph  Description automatically generated  Figure 1: Individual data (top row) and global grand means with distribution and 95% credible interval estimates from the expectation of the posterior predictive distribution (bottom row) for velocity by both disability, panels (A) and (B), and classification, panels (C) and (D). |

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| A group of graphs showing different types of graphs  Description automatically generated with medium confidence  Figure 2: Individual data (top row) and global grand means with distribution and 95% credible interval estimates from the expectation of the posterior predictive distribution (bottom row) for acceleration by both disability, panels (A) and (B), and classification, panels (C) and (D). |

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## Repeated sprint trial outcomes

The overall grand means and credible intervals from the models for the fixed effects (i.e., without including the random effects) for repeated sprint times can be seen in [Figure 3](file:///C:\Users\james\Dropbox\Research\Dissy%20students\wheelchair_rugby_sprints\report.docx#fig-rsa-model-plot), in addition to individual data and participant level linear smooths, respectively for both disability and classification models. All parameters for both outcomes and both disability and classification models are also shown in [Table 2](file:///C:\Users\james\Dropbox\Research\Dissy%20students\wheelchair_rugby_sprints\report.docx#tbl-rsa-model).

On average, fixed effects in both models revealed that sprint number had little impact on time, however did interact with distance revealing greater increases in time for later sprints over increasing distances. Sprint number had little impact upon the initial 0-5m. Of course, trivially, time increased as distance covered increased. Random effects in both models showed, similarly to velocity in the sprint trials, that variation in times increased with increasing distance covered. Also the random effects correlations suggested that those who were initially faster at the beginning of a sprint, faster during certain sections of the sprint, or faster during a given sprint number, were similarly typically faster at all other distances and during all other sprint numbers.

### *Disability* - Both SCI and other disabilities showed similar performances in the repeated sprints, across all distances, and all sprint numbers. There was little effect of disability upon either repeated sprint times.

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### *Classification* - Both 4s and 5s showed similar performances in the repeated sprints, across all distances, and all sprint numbers. There was little effect of classification upon either repeated sprint times.

Table 2: Model parameter estimates for both fixed and random effects for repeated sprint trial times.

|  | Time (seconds) | | |
| --- | --- | --- | --- |
| Model Term | Estimate | Lower 95% CI | Upper 95% CI |
| **Disability Model** | | | |
| *Fixed Effects* | | | |
| Intercept | 2.29 | 2.16 | 2.43 |
| DisabilitySCI | 0.10 | -0.10 | 0.31 |
| Sprint Number | 0.01 | -0.01 | 0.03 |
| Distance5-10m | 1.59 | 1.46 | 1.71 |
| Distance10-15m | 3.01 | 2.80 | 3.23 |
| Distance15-20m | 4.37 | 4.05 | 4.69 |
| DisabilitySCI:Sprint Number | 0.00 | -0.03 | 0.03 |
| DisabilitySCI:Distance5-10m | 0.02 | -0.18 | 0.21 |
| DisabilitySCI:Distance10-15m | 0.01 | -0.33 | 0.35 |
| DisabilitySCI:Distance15-20m | -0.01 | -0.51 | 0.49 |
| Sprint Number:Distance5-10m | 0.02 | 0.01 | 0.03 |
| Sprint Number:Distance10-15m | 0.04 | 0.03 | 0.05 |
| Sprint Number:Distance15-20m | 0.07 | 0.05 | 0.08 |
| DisabilitySCI:Sprint Number:Distance5-10m | -0.01 | -0.02 | 0.01 |
| DisabilitySCI:Sprint Number:Distance10-15m | -0.01 | -0.03 | 0.01 |
| DisabilitySCI:Sprint Number:Distance15-20m | -0.02 | -0.04 | 0.00 |
| *Random Effects* | | | |
| σ Intercept | 0.18 | 0.12 | 0.28 |
| σ Sprint Number | 0.02 | 0.02 | 0.04 |
| σ distance5-10m | 0.15 | 0.11 | 0.22 |
| σ distance10-15m | 0.31 | 0.23 | 0.43 |
| σ distance15-20m | 0.48 | 0.36 | 0.66 |
| ρ Intercept:Sprint Number | -0.24 | -0.64 | 0.23 |
| ρ Intercept:Distance5-10m | 0.41 | -0.02 | 0.75 |
| ρ Intercept:Distance10-15m | 0.38 | -0.03 | 0.69 |
| ρ Intercept:Distance15-20m | 0.35 | -0.06 | 0.67 |
| ρ Sprint Number:Distance5-10m | 0.55 | 0.14 | 0.84 |
| ρ Sprint Number:Distance10-15m | 0.62 | 0.28 | 0.85 |
| ρ Sprint Number:Distance15-20m | 0.65 | 0.34 | 0.86 |
| ρ Distance5-10m:Distance10-15m | 0.95 | 0.83 | 0.99 |
| ρ Distance5-10m:Distance15-20m | 0.94 | 0.81 | 0.99 |
| ρ Distance10-15m:Distance15-20m | 0.99 | 0.94 | 1.00 |
| σ Residual | 0.12 | 0.11 | 0.13 |
| **Classification Model** | | | |
| *Fixed Effects* | | | |
| Intercept | 2.39 | 2.25 | 2.53 |
| Classification5 | -0.12 | -0.34 | 0.09 |
| Sprint Number | 0.00 | -0.01 | 0.02 |
| Distance5-10m | 1.60 | 1.47 | 1.72 |
| Distance10-15m | 3.01 | 2.79 | 3.23 |
| Distance15-20m | 4.34 | 4.01 | 4.66 |
| Classification5:Sprint Number | 0.01 | -0.02 | 0.04 |
| Classification5:Distance5-10m | -0.01 | -0.20 | 0.19 |
| Classification5:Distance10-15m | 0.02 | -0.31 | 0.35 |
| Classification5:Distance15-20m | 0.07 | -0.43 | 0.57 |
| Sprint Number:Distance5-10m | 0.01 | 0.00 | 0.03 |
| Sprint Number:Distance10-15m | 0.03 | 0.02 | 0.05 |
| Sprint Number:Distance15-20m | 0.06 | 0.04 | 0.07 |
| Classification5:Sprint Number:Distance5-10m | 0.00 | -0.01 | 0.02 |
| Classification5:Sprint Number:Distance10-15m | 0.00 | -0.01 | 0.02 |
| Classification5:Sprint Number:Distance15-20m | 0.00 | -0.01 | 0.02 |
| *Random Effects* | | | |
| σ Intercept | 0.19 | 0.12 | 0.30 |
| σ Sprint Number | 0.02 | 0.02 | 0.03 |
| σ Distance5-10m | 0.15 | 0.11 | 0.21 |
| σ Distance10-15m | 0.31 | 0.23 | 0.42 |
| σ Distance15-20m | 0.48 | 0.36 | 0.65 |
| ρ Intercept:Sprint Number | -0.16 | -0.60 | 0.31 |
| ρ Intercept:Distance5-10m | 0.40 | -0.04 | 0.74 |
| ρ Intercept:Distance10-15m | 0.35 | -0.06 | 0.68 |
| ρ Intercept:Distance15-20m | 0.33 | -0.08 | 0.66 |
| ρ Sprint Number:Distance5-10m | 0.57 | 0.14 | 0.84 |
| ρ Sprint Number:Distance10-15m | 0.63 | 0.26 | 0.86 |
| ρ Sprint Number:Distance15-20m | 0.65 | 0.31 | 0.87 |
| ρ Distance5-10m:Distance10-15m | 0.95 | 0.83 | 0.99 |
| ρ Distance5-10m:Distance15-20m | 0.94 | 0.80 | 0.99 |
| ρ Distance10-15m:Distance15-20m | 0.99 | 0.94 | 1.00 |
| σ Residual | 0.12 | 0.11 | 0.13 |
| Note: |  |  |  |
| CI = credible interval |  |  |  |

|  |
| --- |
| A screenshot of a graph  Description automatically generated  Figure 3: Individual data with linear smooths by participant (top row) and global grand means with distribution and 95% credible interval estimates from the expectation of the posterior predictive distribution (bottom row) for repeated sprint times by both disability, panels (A) and (B), and classification, panels (C) and (D). |

# Discussion

The current study aimed to investigate the differences between WCR game formats during sprint and RS field-based testing in a non-elite sample of athletes. A secondary aim was to investigate the differences in impairment type of SCI and Non-SCI sprint and RS ability. The main findings of this study were that there were no significant differences (*p* > 0.05) in initial sprints between the Fours and Fives. However, significant differences (*p* < 0.05) were seen between SCI and Non-SCI during the sprints. The largest effect sizes were seen in the Mann-Whitney U test results for the 5m times (rB = -0.69), followed by the 10m times (rB = -0.64), 15m times (rB = -0.60), 20m times (rB = -0.55), and the fastest 20m times (rB = -0.52). The rank biserial correlations showed moderate to large effect sizes between SCI status and sprint times, with larger effect sizes indicating a greater difference in sprint times between Non-SCI and SCI groups. Within the Student t-test results, the largest effect size was seen for 5m acceleration (*d* = 1.24), 5m velocity (*d* = 1.17), 10m velocity (*d* = 0.97), and overall velocity (*d* = 0.97). These effect sizes also indicate a moderate to large difference between Non-SCI and SCI groups, with larger effect sizes indicating a greater difference in acceleration and velocity measures between the two groups.

During the RS no significant differences were observed between the conditions for either the Fours or Fives or SCI and Non-SCI and no significant interactions were observed (*p* > 0.05) over any of the split times. The RS results for game format (figure 3) indicate that there was a significant effect (*p* < 0.05) of sprint number across all split times (5m, 10m, 15m, and 20m). In addition, the RS effects on disability (figure 4) indicate that there also was a significant effect (*p* < 0.05) of sprint number across all split times (5m, 10m, 15m, and 20m). This indicates that for both the Fours and Fives and SCI and Non-SCI as the number of sprints completed increased the time the participants took to cover each of the splits also increased (figures 3 and 4).

The mean times and velocities for the Fives were slightly faster than the Fours across all measured distances, however this was of no significant difference. This is surprising given that Fours have a higher level of impairment for eligibility compared to the Fives, contradicting previous studies that suggest more severe impairments lead to lower levels of physical fitness and functional capacity (Martin and Whalen 2014). Whilst this is the first study to investigate the Fives, influences such as the small sample size used and the variance in the athlete's ability from the non-elite group may contribute to these findings. As the study introduces the Fives game format into research, this comes with an additional classification system. Whilst it opens the sport up to a more diverse group of individuals it has also produced an overlap between game formats. As a result, some players who are classified as Fours can also play for Fives, and vice versa. Players who are currently classified as 0.5-1.5 IWRF (fours) are eligible to compete as 0.5 classified Fives, those classified as 2.0-3.5 IWRF (fours) can compete as 1.0 classified Fives, and those classified as 4.0 IWRF (fours) can compete as 1.5 classified Fives (Great Britain Wheelchair Rugby 2021). These factors contribute to the ongoing debate about the dependability of the classification system (Altmann et al. 2013). Whilst coaches can improve RS in players across both formats with specific training programmes, those looking to advance to a higher level in the sport can only do so in the Fours format. Those who compete in the Fives will not be able to progress outside of their personal goals in the sport and team ranking due to its paralympic exclusion. Even though in this study there was no significant difference seen between the two formats sprint and RS ability. Additionally, the results showed a significant difference in sprint performance between SCI and Non-SCI, with Non-SCI players demonstrating faster sprint times and velocities across all measured distances. The significant differences at 5m times, 10m times, 15m times, 20m times, fastest 20m times and 5m acceleration indicate that SCI is a significant factor affecting sprint performance in WCR. This is consistent with previous literature that showed SCI athletes covered 17% less distance with an average of 10% slower pushing rate. These athletes presented with thermoregulatory strain due to impaired sudomotor and vasomotor control as a consequence of the injury, contributing to their slower performance (Griggs et al. 2017). The larger thermal strain and thermally induced fatigue that is seen in SCI can negatively affect performance and health if not monitored appropriately (O'Brien et al. 2022). The difference seen in this study's 5m acceleration may be due to the trunk's ability to function effectively during the initial push, with active trunk flexion only occurring during the initial push. After this the trunk remains relatively stable after gathering momentum, allowing for arm function to take the lead. The importance of arm function is highlighted by its association with greater peak speeds, which is evident in sprinting performance beyond the first two meters (Mason et al. 2019).

A study found differences in propulsion techniques between HP and LP WCR players, HP players produced a higher push frequency and a lower percentage push time. The HP players achieved faster sprint times over 28 meters, with higher peak power output leading to higher acceleration and total speeds. However, the high standard deviations show there was considerable heterogeneity within the two groups, with some LP players being faster than some HP players. The study suggests that training status, technical experience, wheelchair configuration, and total mass of the wheelchair-user may contribute to these differences in sprint performance (Goosey-Tolfrey et al. 2018). Whilst the success of sprint performance requires the ability to apply force to the hand rim, previous research has additionally established that trunk function plays a crucial role in determining the amount of force generated in this skill. Therefore, better trunk function reflects the force applied to the hand rim resulting in greater peak speeds across sprints (Ρdes et al. 2015). Wheelchair configuration and strapping can play have a significant effect on performance, helping to maximise trunk contribution for performance through seat angle manipulations. For example, LP players with a lower trunk functionality typically prefer a more posterior seat position aiding in support (Goosey-Tolfrey et al. 2018). Whilst fitted chairs are necessary for optimal sports performance, it is expensive and not always achievable for those of a non-elite calibre. The athletes involved in the study had a variation of personal and club chairs which could potentially have influenced their sprint times (Cooper and De Luigi 2014).

The linear mixed model analysis showed a significant effect of sprint number on all sprint distances. This suggests that RS performance has a significant effect on sprint performance in WCR. However, there were no significant effects of game format or impairment type or the interaction between sprint number and game format or impairment type. This suggests during this study sprint performance in WCR is affected by natural fatigue as you would see in AB RS rather than by game format or impairment. According to research conducted in AB RS, fatigue is characterized as a decrease in the maximum power output, leading to a progressive decrease in both physical and cognitive abilities (Collins et al. 2018). Typically, fatigue sets in shortly after the initial sprint (Mendez-Villanueva et al. 2008), due to limitations from energy supply and accumulation of metabolic by-products (Girard et al. 2011). The accumulation of lactate throughout the study showed significant progressive increases in blood lactate levels. The increase in blood lactate levels post-exercise was similar between athletes with SCI and without SCI, indicating that SCI status does not affect anaerobic metabolism during WCR. Similarly, there were no differences in blood lactate levels between the Fours and Fives groups, indicating that the level of functional impairment does not affect anaerobic metabolism during WCR.

A study was conducted by West (2014) on the effects of abdominal binding on ten Paralympians with cervical SCIs during field-based exercises. The study involved a 10 x 20m RS test with 20s rest intervals, the results showed that although there was only a slight difference between the mean fastest 20 times for unbounded (6.39s) and bounded (6.38s) conditions, the use of binding indicated an improvement in trunk stability. The study concluded that abdominal binding can significantly enhance certain field-based tests, but did not within the agility test, which suggested that improvements in trunk stability are limited to the sagittal plane (West et al., 2014). Gee found similar results in a 20 x 20m sprint test with a mean fastest 20m at 6.66s, the fastest average 5m peak speed reported at 3.71 m/s similar to West’s report of 3.70 m/s and Mason et al. reported a speed of 3.69 m/s during a 15m sprint test in ten elite WCR athletes. Gee also found higher levels of lactate (8.0 ± 3.3 mmol/L) compared to previous studies involving a 4 and 40-minute push (6.5 ± 1.2 mmol/L). However, since the study was treated as a whole and not sub-categorised, any heterogeneity responses in athletes with SCI were unknown. However, the current study showed no significant difference (*p* > 0.05) in lactate values between SCI and Non-SCI pre or post-exercise (SCI Pre 2.12 ± 0.82, post 7.30 ± 2.41, Non-SCI, Pre 2.58 ± 1.15, post 8.16 ± 3.21). Further examination of subgroups can help achieve a better understanding of the specific physiological impact caused by each impairment in relation to WCR key performance indicators (Haydon et al., 2018).

## Limitations

The study had several limitations that have been acknowledged, firstly the sample size was relatively small and covered a broad age range of predominantly males. Additionally, there were more Fives than Fours players in the study, with an overall larger representation of the SCI impairment type. All of those ranged from novice to experienced WCR players using their own wheelchair configurations which were not standardized. Furthermore, not all participants who completed session one participated in the second session for the RS. Future research should investigate research on a larger sample size to investigate game formats of non-elite players, as well as the further specification of the subcategories of impairments.

## Conclusion

In conclusion, this study provides valuable information on the impact of impairment type on sprint and RS ability in WCR players. As the study aimed to investigate the differences between WCR game formats (Fours and Fives) during sprint and RS testing in a non-elite sample of athletes. As well as to investigate the differences in SCI and Non-SCI sprint and RS ability in non-elite WCR players. The study found no significant differences in initial sprints between the Fours and Fives. However, significant differences were seen between SCI and Non-SCI during the sprints. During the RS the study found no significant differences between either the Fours or Fives or between SCI and Non-SCI, however significant differences were seen within participants. The results therefore rejected the study’s first hypothesis as no differences were seen between the Fours and Fives performances in the sprint and RS tests. In addition, whilst Non-SCI outperformed SCI in the initial sprints, no significant difference was seen in RS ability or lactate values. The results highlight the importance of trunk function for the sport and its possible relationship between SCI and Non-SCI sprint performance. Clubs working with athletes with SCI should be aware of the decreased sprint performance and adjust their training accordingly. In addition, this study suggests that players with spinal cord injuries may need to be further sub-classified to ensure a fairer classification system.

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