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Criterion Validity of a Field-Based Assessment of Aerobic Capacity in Wheelchair Rugby Athletes

Vicky L. Goosey-Tolfrey, Sonja de Groot, Keith Tolfrey, and Tom A.W. Paulson

Purpose: To confirm whether peak aerobic capacity determined during laboratory testing could be replicated during an on-court field-based test in wheelchair rugby players. ***Methods:*** Sixteen wheelchair rugby players performed an incremental speed-based peak oxygen uptake ($\dot{V}O_2$peak) test on a motorized treadmill (TM) and completed a multistage fitness test (MFT) on a basketball court in a counterbalanced order, while spirometric data were recorded. A paired *t* test was performed to check for systematic error between tests. A Bland–Altman plot for $\dot{V}O_2$peak illustrated the agreement between the TM and MFT results and how this related to the boundaries of practical equivalence. ***Results:*** No significant differences between mean $\dot{V}O_2$peak were reported (TM: 1.85 [0.63] vs MFT: 1.81 [0.63] $L \cdot min^{-1}$; $P = .33$). Bland–Altman plot for $\dot{V}O_2$peak suggests that the mean values are in good agreement at the group level; that is, the exact 95% confidence limits for the ratio systematic error (0.95–1.02) are within the boundaries of practical equivalence (0.88–1.13) showing that the group average TM and MFT values are interchangeable. However, consideration of the data at the level of the individual athlete suggests that the TM and MFT results were not interchangeable because the 95% ratio limits of agreement either coincide with the boundaries of practical equivalence (upper limit) or fall outside (lower limit). ***Conclusions:*** Results suggest that the MFT provides a suitable test at a group level with this cohort of wheelchair rugby players for the assessment of $\dot{V}O_2$peak (range 0.97–3.64 $L \cdot min^{-1}$), yet caution is noted for interchangeable use of values between tests for individual players.

Keywords: fitness testing, Paralympic, profiling, endurance

Wheelchair rugby (WR) is a sport that requires great wheelchair mobility,[1] with varying periods of accelerations and decelerations.[2–4] About 75% of the active portion of the game is spent performing low-intensity activities,[2–4] with players covering distances ranging between 3500 and 4600 m during matches.[3,4] Thus, both anaerobic and aerobic proficiencies require attention for physical preparation.[5,6] Benchmarking and profiling of WR players requires reliable performance tests that provide a valid representation of the physical competencies specific to on-court performance. That said, there is often conflict between maintaining high reliability while compromising the ecological validity when laboratory compared with field-based protocols are chosen.[5,7,8]

While technological advances in wheelchair ergometry[9] and treadmill (TM) design have permitted well-established protocols for anaerobic[10] and aerobic[8,11] wheelchair testing during standardized conditions, on-court sport-specific testing still remains the coach's preferred method.[5,12] Yet, the validity of continuous tests of aerobic capacity adapted from able-bodied field-based protocols remains inconclusive.[5] For example, direct measurements of peak oxygen uptake ($\dot{V}O_2$peak) during an adapted Leger Bouchard test on a 400-m track and during wheelchair ergometry reported a moderate Spearman correlation ($r = .65$), and Bland–Altman plots showed poor agreement between tests for some individuals.[13]

However, undeniably, turning and chair proficiency have a large influence on results in the field,[12,14] and the suitability is greatly influenced by the format of the multistage fitness test (MFT), speed, and duration of stages and impairment type. For example, a low correlation ($r = .39$) was noted using an MFT that involved frequent and acute turns when compared with other less severe MFT formats.[15,16] This octagon format reducing the sharp turns has resulted in higher physiological responses in wheelchair basketball players of mixed physical impairments.[16] It is quite possible that this format of MFT may be more suited to WR players, who have less chair maneuverability skills due to impaired postural control.

Eligibility for WR involves players with tetraplegia (ie, a cervical spinal cord injury not paraplegia) and with neuromuscular conditions (such as cerebral palsy), multiple amputations and congenital limb defects. It is likely that these players would propel the wheelchair very differently as demonstrated with a comparison between persons with different levels of spinal cord injury.[17] To date, no study has designed an MFT specially for the sport of WR to assess aerobic capacity in athletes with lower functional and $\dot{V}O_2$peak capabilities.[11] That said, with emerging data advocating the benefits of field-based testing for WR players,[18,19] the purpose of this study was to confirm whether peak aerobic capacity of laboratory-based TM testing could be replicated during an MFT in WR players.

Methods

Participants

Sixteen male WR players (age = 28 [6] y; body mass = 70.3 [12.2] kg; time in wheelchair = 12 [9] y; training hours = 5 [1] with a minute of 3 $h \cdot wk^{-1}$) volunteered to participate in the current

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study. Prior to participation, all players provided their written informed consent and completed separate health, training, and disability questionnaires. It was noted, participants were involved in national-level WR but not competing internationally, the relevant participant characteristics and functional ability were reported according to the International WR Federation (IWRF) criteria. Participants comprised of 4 low-point players (IWRF 0.5–1.0), 6 mid-point players (IWRF 1.5–2.0), and 6 high-point players (IWRF 2.5–3.5). In general, the 0.5 class includes those athletes with least functional capacity and the 3.5 class includes those with a minimal disability eligible for the sport of WR. As a group there were 8 players with a cervical spinal cord injury and 8 without (eg, had cerebral palsy, an amputation or Charcot-Marie-Tooth disease), all players used a wheelchair for daily ambulation. Ethical approval for the study was obtained through Loughborough University's local ethical committee for human participants.

Design and Physiological Procedures

This study was performed at 2 sites (United Kingdom and The Netherlands) with specialized TMs that accommodated wheelchair propulsion (HP Cosmos, Traunstein, Germany and Motekforce link, Amsterdam, The Netherlands). Both sites had indoor wooden basketball courts with similar playing surfaces. Body mass was obtained to the nearest 0.1 kg with 2 different seated balance scales (seca Ltd, Birmingham, United Kingdom or AllScales Europe, Veen, The Netherlands). Spirometric data were recorded continuously during the TM and MFT using an online portable gas analysis system in breath-by-breath mode with participants wearing a facemask and the system operated in telemetry mode (either via a MetaLyzer 3B; Cortex Biophysik GmbH, Leipzig, Germany at the UK site or a K4b[2]; COSMED, Rome, Italy at the Dutch testing location). Before each test, gases were calibrated using a 2-point calibration ($O_2 = 17.0\%$, $CO_2 = 5.0\%$ against room air), volumes with a 3-L syringe at flow rates of 0.5 to 3.0 $L{\cdot}s^{-1}$, according to the manufacturer's recommendations for both devices. Breath-by-breath data allowed the highest 30-second rolling average $\dot{V}O_2$ value recorded and was taken as the $\dot{V}O_2$peak, using customized excel spreadsheets. Heart rate was continuously recorded at 5-second intervals using a heart rate monitor belt (Polar; Polar Electro Inc, Woodbury, NY), and rating of perceived exertion (RPE) using the Borg scale ranging from 6 to 20[20] was recalled at the end of all tests at both testing venues. All participants were accustomed to the described methods by being involved previously in some TM testing and on-court field-based testing. The laboratory speed-based TM exercise test for the determination of peak heart rate and $\dot{V}O_2$peak and modified MFT (Figure 1) on a wooden sprung floor. Both tests were performed on separate days (minimum of 48 h and maximum 7 d) in a counterbalanced order. While the authors accept that protocol choice (eg, increasing TM grade at a constant speed; speed increments at a constant grade or a combination of increments in speed and grade) can influence $\dot{V}O_2$peak,[21] a speed-based TM exercise test was chosen to mimic the speed increments of the on-court MFT. The outcome measures for both the lab and field tests were $\dot{V}O_2$peak, peak heart rate, respiratory exchange ratio, and peak RPE.

Graded Exercise Test to Exhaustion on the TM

All participants' performed an incremental speed-based test in their competition, WR sports wheelchair, on the motorized TM at a constant 1.0% gradient to account for differences between TM and overground propulsion.[22] Tyer pressure was set at levels participants normally competed with and was controlled between trials. In brief, following a low-intensity 5-minute warm-up and 10-minute passive rest for stretching (to relieve any spasticity) the laboratory testing commenced. The starting speed of the TM test varied between 1.4 and 2.9 $m{\cdot}s^{-1}$ accounting for participants' IWRF classification. The speed was then continually increased by 0.2 to 0.4 $m{\cdot}s^{-1}$ every minute, the increase again individually chosen for the above reason. The test was terminated when participants were unable to maintain the speed of the TM, and verbal encouragement was given throughout the test.

Multistage Fitness Test

The protocol for the MFT was in a similar format to that described by Weissland et al[16] as the "8 form", and the "figure of 8 course" used by Mason et al.[22] However, a modified able-bodied test[23] was used with a starting speed of 1.8 $m{\cdot}s^{-1}$, which involved increments of 0.1 $m{\cdot}s^{-1}$ every minute prompted by an audio "bleep." The test was completed on an indoor wooden basketball court and involved participants pushing over 80 m in a "figure of 8" (Figure 1). The test was terminated if the participant could not reach the target line on 2 consecutive occasions, despite strong verbal encouragement. The total distance traveled during the test was recorded in meters (MFT-m).

Statistical Analyses

Descriptives (mean and SD) were calculated for all personal characteristics and for the outcomes of the TM and the MFT to exhaustion. The following analyses were performed for the main outcome, which is $\dot{V}O_2$peak, only. Correlations between the mean of TM and MFT outcome measure and the residuals (MFT minus TM) were used to determine whether proportional bias was evident. This was repeated with the absolute residuals and the mean to check for heteroscedasticity.

A paired *t* test was performed to determine whether there was a significant systematic error between the $\dot{V}O_2$peak, measured during the TM test and MFT, and the effect size (Cohen *d*) was calculated. $\dot{V}O_2$peak data were transformed using a natural logarithm to create ratio 95% limits of agreement (LoA), and exact 95% confidence intervals for the ratio systematic error and ratio 95% LoA were constructed.[24] The threshold for statistical significance for all above-mentioned analyses was $P \le .05$.

Finally, based on the day-to-day variation of $\dot{V}O_2$peak determined in a reliability study,[8,25] consisting of a TM exercise test in wheelchair athletes, a 13.2% change is required to document an improvement or a reduction of $\dot{V}O_2$peak in athletes with a tetraplegia. The 13.2% was used to calculate the ratio boundaries ($1/1.132$ to $1 \times 1.132 \Rightarrow 0.88$ to 1.13) within which the $\dot{V}O_2$peak can be declared practically equivalent (ie, interchangeable) between the TM and MFT (Figure 2).

Results

Table 1 shows the descriptive statistics of all outcomes of the TM test and MFT. No significant differences between mean $\dot{V}O_2$peak were reported (1.85 [0.63] vs 1.81 [0.63] $L{\cdot}min^{-1}$, $P = .33$ for TM and MFT, respectively; Cohen $d = 0.252$), indicating that the systematic error was not statistically significant and also not meaningful.

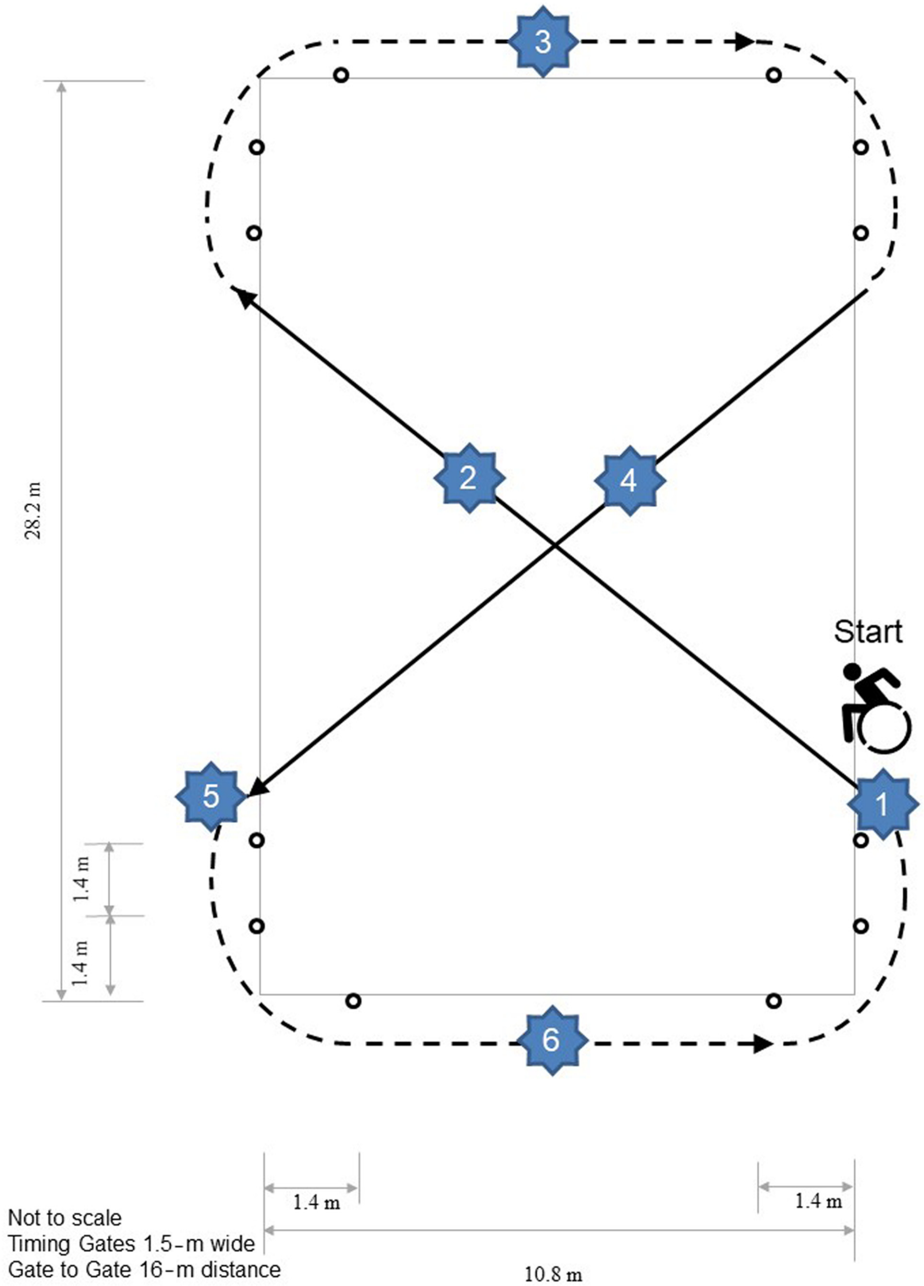

Figure 1 — The MFT: 80 m in a figure of 8 separated into 5-×16-m sections. MFT indicates multistage fitness test.

A Bland–Altman plot for $\dot{V}O_2$peak was constructed to illustrate the agreement between the TM and MFT results and how this related to the boundaries of practical equivalence (Figure 2). The systematic error for $\dot{V}O_2$peak suggests that the mean values are in good agreement at the group level; that is, the exact 95% confidence limits for the ratio systematic error (0.95–1.02) are within the boundaries of practical equivalence (0.88–1.13) showing the group average TM and MFT values are interchangeable. However, consideration of the data at the level of the individual athlete suggests that the TM and MFT results were not interchangeable because the 95% ratio LoA either coincide with the boundaries of practical equivalence (upper limit) or fall outside (lower limit). Ideally, the entire exact 95% confidence intervals for the upper and lower LoA would fall within the boundaries of practical equivalence to declare the TM and MFT protocols interchangeable at the level of the individual athlete, which they clearly do not (Figure 2).

Discussion

This study is the first to examine whether peak aerobic capacity of laboratory-based TM testing could be replicated during an MFT in WR players. It extended previous research that was limited to groups of wheelchair athletes with paraplegia, cerebral palsy, postpolio, or an amputation[13,14] to include WR players with tetraplegia. The mean $\dot{V}O_2$peak obtained during the TM testing compares well to previous work of a similar sample,[26] and we are

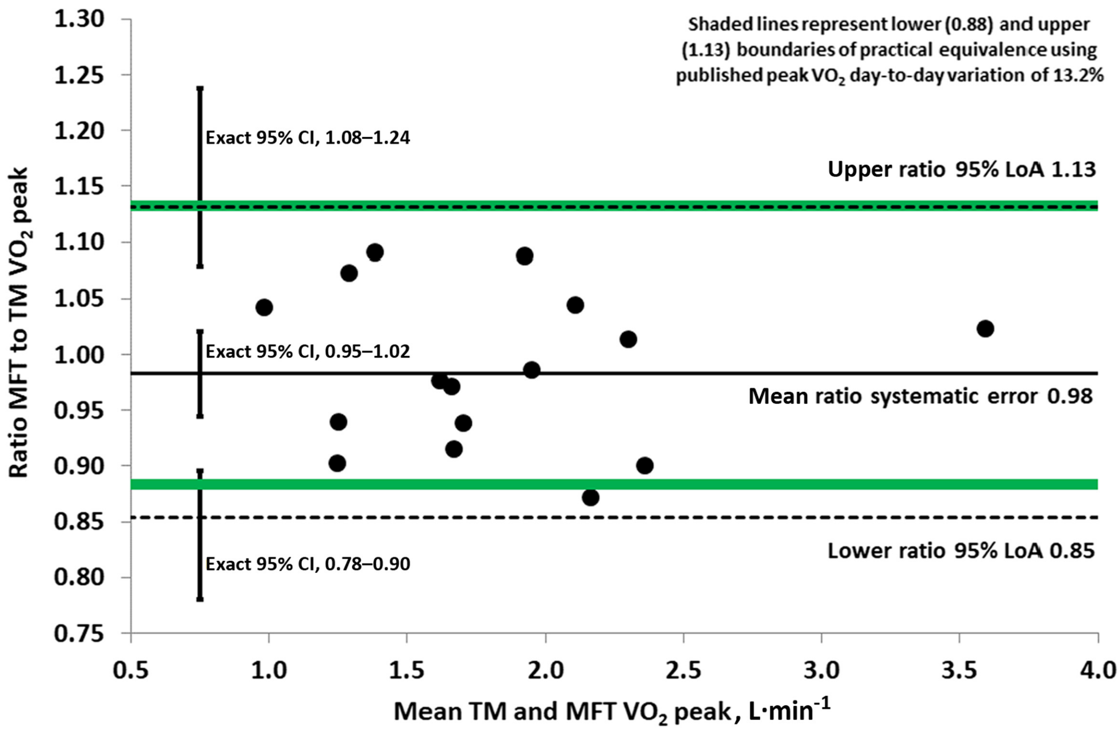

Figure 2 — Ratio LoA for TM versus MFT protocols for deriving $\dot{V}O_2$peak. The region of practical equivalence (thick, shaded lines) was calculated using the $\dot{V}O_2$peak 13.2% day-to-day variation value reported in the literature[8,25]; it is bounded by ratios of 0.88 (1 ÷ 1.132) and 1.13 (1 × 1.132). The mean ratio systematic error (0.98) with lower (0.85) and upper (1.13) ratio 95% LoA are shown with exact 95% CIs.[24] CI, confidence interval; LoA, limits of agreement; MFT, multistage fitness test; TM, treadmill; $\dot{V}O_2$peak, peak oxygen uptake.

Table 1 Descriptives of the Outcomes of the TM Test and MFT

Variable	N	TM, Mean (SD)	MFT, Mean (SD)
$\dot{V}O_2$peak, L·min^{-1}	16	1.85 (0.63)	1.81 (0.63)
HR_{peak}, bpm	14[a]	163 (34)	161 (28)
RER_{peak}	16	1.17 (0.10)	1.21 (0.08)
RPE_{peak}	16	Median: 18 IQR = 17–19	Median: 16 IQR = 15–19
End speed, m·s^{-1}	16	2.9 (0.6)	3.1 (0.4)
Distance, m	16	—	1848 (720)

Abbreviations: $\dot{V}O_2$peak, peak oxygen uptake; bpm, beats per minute; HR_{peak}, peak heart rate; IQR, interquartile range; MFT, multistage fitness test; RER_{peak}, peak respiratory exchange ratio; RPE_{peak}, peak rating of perceived exertion; TM, treadmill.

[a] Technical issues resulted in missing data (n = 2).

confident that the secondary parameters like respiratory exchange ratio (above defined values 1.10) were as expected to verify this attainment of $\dot{V}O_2$peak. The main findings indicated that there was not a systematic error in $\dot{V}O_2$peak between the TM and MFT. However, the absolute agreement was low as shown by the wide 95% LoA, suggesting that at the individual level the TM and MFT outcomes are not interchangeable.

It is well known that WR players enjoy on-court testing and although several studies have investigated field tests to evaluate, among others, $\dot{V}O_2$peak and peak heart rate in wheelchair users and wheelchair athletes,[12,13,15,16,27,28] only 2 studies have examined the validity of these field test outcomes.[13,14] When comparing our results to those of older studies, as far as known, only Vinet et al[13] compared the $\dot{V}O_2$peak during an outdoor wheelchair 400-m field test with a TM test. In this small group of wheelchair athletes (n = 9) only a moderate Spearman intraclass correlation coefficient of .65 was found, and Bland–Altman plots showed that most of the participants had a higher $\dot{V}O_2$peak during the TM test. Our finding differs from this, with close group-level agreement between tests as our MFT was performed indoors with a format requiring fewer turns. Interestingly, the current study suggested that a higher peak RPE was achieved following the TM test when compared with the MFT, which is partly explained by test duration being on average ~2 minutes longer during the TM test when compared with the MFT ($P = .024$). That said, we believe that the pushing technique adopted during MFTs involve an intermittent style (eg, 3 short pushes followed by a short break for inhalation) as noted by West et al.[19] However, on the TM, this technique is not possible as the wheelchair would roll back to the end of the TM if pushing were to cease, resulting in termination of the test.[19] Consequently, it is quite possible that push rates are higher at a given speed on the TM compared with overground, which has been shown to influence RPE greatly.[29] Future work is warranted to examine whether push rate differs between the TM and MFT test conditions to provide further insight into these perceptual differences, which did not feature in the work of Mason et al.[22]

We chose speed increments instead of increases in rolling resistance during the laboratory test on the TM to mimic propulsion on the court. However, a speed incremental TM test leads to high hand velocities and subsequently upper-body coordination problems, which might have an impact on effective power transfer on the hand rim[30] and subsequently on the $\dot{V}O_2$peak. For a good indication of peak power output, combined with peak aerobic capacity, a test protocol with an increase in resistance (via a slope, pulley system, or ergometer motor) instead of velocity increments might be a consideration for future work.[12,21]

Practical Applications

Importantly, our results provide an alternative method to test groups of WR players on court, who may have no regular access to TM testing due to lack of funding and resources. However, the coach of less experienced WR players will need to be mindful that the MFT requires wheelchair skills (like maneuvering), which are important as well as optimal wheelchair configuration, for example, position of the center of gravity to be able to turn quickly.[31] Furthermore, MFTs have also been shown to be sensitive to environmental (floor surface) and equipment changes (eg, in the wheelchair-user interface).[28]

The limitations of this study naturally pertain to adopting 2 different locations which might have introduced some variability, which was considered minimal given one key researcher was involved in all testing sessions. Yet, it could be argued that by adopting a multicenter approach, we were able to have a sample, reasonable in size and representative of a group of developmental WR players. Future research should further develop and confirm these initial findings and it will be good to investigate the other clinimetric properties of the MFT including reliability and responsiveness.

Conclusions

Overall, the results suggest that the MFT provides a suitable test at a group level with this cohort of WR players for the assessment of $\dot{V}O_2$peak (~1.85 [0.63] $L \cdot min^{-1}$; range 0.97–3.64 $L \cdot min^{-1}$), yet caution is noted for interchangeable use of individual player values between tests. That said, although the MFT may not consistently provide the same results for an individual as the TM test, it does provide a good indication of aerobic capacity on a group level and can be used for monitoring the (individual) WR athletes over time.

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