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Correlation and Group Differences Between the 30-Second Parallel Bar Dip Test and the 30-Second Wheelchair Roller Test Among Wheelchair Athletes

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ABSTRACT

To our knowledge, few studies have examined the muscle power and performance of wheelchair athletes in para-athletics, and thus, neither the muscle power required for wheelchair racing nor the associated assessment criteria have been established. This study aimed to examine whether parallel bar dips are associated with performance in wheelchair racing by having wheelchair athletes perform a 30-s parallel bar dip test (PBD-TEST) and a 30-s wheelchair roller test (WR-TEST). The participants in the present study were 13 male Japanese wheelchair athletes. The numbers of athletes by class were one in the T52, five in the T53, and seven in the T54 class. The participants were classified into amputation/motor disability classes, including spinal cord injury, in para-athletics, with a smaller last digit indicating more severe disability. No significant correlation was found between the number of dips in the PBD-TEST and the peak wheelchair speed in the WR-TEST. Next, to examine differences by competitive performance, the participants were divided into an international-level group (ILG) and a national-level group (NLG). A significant positive correlation was found between the number of dips in the PBD-TEST and the peak wheelchair speed in the WR-TEST for the ILG (r = 0.892, p = 0.007), whereas a significant negative correlation was found for the NLG (r = –0.919, p = 0.010). In the ILG, the athletes with more dips in the PBD-TEST achieved a greater peak wheelchair speed in the WR-TEST, suggesting that they had the skills necessary to convert upper limb muscle power into wheelchair speed. These results suggest that the PBD-TEST is an effective performance-related measure for high-performance wheelchair athletes.

Keywords: Wheelchair speed, Blood lactate, Heart rate, Weight training.

INTRODUCTION

The parallel bar dip (PBD) requires the body to be lowered eccentrically between two parallel bars and pushed up to the starting position by extending the arms (21). This exercise is primarily used to train the pectoralis major and triceps brachii (15,21,27,28). The PBD is often carried out using body weight as a load, but advanced trainers suspend weights from the waist to increase the load (15). Due to its high load (15) and the need for sufficient muscle power to control the speed and range of motion of the movement, this exercise is not recommended for beginners with little or no training experience (21). Other exercises that similarly work the pectoralis major and triceps brachii include back dips (or bench dips) (1,15,26,27), wider grip PBDs (1), and ring dips (26,27). However, the PBD has been reported to excite and produce recruitment of the triceps brachii more than back dips (or bench dips) and wider grip PBDs (1,27). In addition, greater electromyography activity of the triceps brachii in the PBD has been reported to be similar to that of advanced exercises such as ring dips (27).

Triceps brachii contraction in the PBD involves an eccentric contraction in the descending phase (elbow flexion), an isometric contraction at the lowest point, and a concentric contraction in the ascending phase (elbow extension). A previous study (9) reported that the mean percentage maximal voluntary isometric contraction was significantly higher in isometric contractions at 75° elbow flexion (maximum elbow extension angle: 0°) than at 85° and 95° elbow flexion (no significant difference between angles in eccentric and concentric contractions), so there is no need to sink further to increase electromyography activity. In addition, sinking deeply into the body results in hyperextension of the glenohumeral joint, which increases the possibility of anterior instability of the glenohumeral joint (26) and pectoralis major strain (26) or rupture (5). The reason for this is that glenohumeral extension in the end-range with abduction, combined with high loads during eccentric contraction, may place the pectoralis major at higher risk of injury (26). In other words, to reduce the risk of injury from the PBD, it is important not to extend the glenohumeral joint to its full range. Exercises that mimic sport-specific movements have been reported to help improve performance (18). Because the PBD resembles the hand-rim push of a wheelchair, this exercise can be described as a sport-specific movement. In the propulsive movement of wheelchair athletics, it has been reported that the pectoralis major is active immediately before hand–rim contact and the triceps brachii is active during the push phase (8). Especially in wheelchair sprint events in para-athletics, upper limb muscle power is required to overcome inertia (2,7) and accelerate the wheelchair from a stationary position (2,23). Wheelchair athletes must also have the ability to exert high muscle power continuously from the start, as maximum wheelchair speed is significantly negatively correlated with 100-m goal time (6,23). Wheelchair athletes in para-athletics were seated in their wheelchair in a heel-sitting or end-sitting position, leaning forward with their trunk to push on the hand rims. The elbow joint flexion angle during hand–rim contact in the T54 class (wheelchair class defined by World Para Athletics) (36) is reported to be approximately 80° (7), similar to the elbow joint angle at the lowest point in the PBD.

Although substantial physiological data have been collected on wheelchair athletes in para-athletics, to our knowledge, few studies have investigated muscle power or the relationship between muscle power and performance (12,20,35). Establishing the level of muscle power required in wheelchair racing and methods for evaluating it could be useful information for athletes and coaches. Therefore, we wondered whether the PBD could be used in a fitness test to measure the sprinting ability of wheelchair racing athletes. The advantages of conducting measurements using the PBD are as follows: 1) simplicity, 2) requires only a few support personnel, 3) inexpensive equipment, 4) few preparations, and 5) measurements that take into account the characteristics of the competition. The PBD satisfies all the conditions necessary to be widely used as a measurement, and by devising a method of implementation, could be used to measure all wheelchair athletes, not only those in para-athletics.

Fitness tests are generally evaluated using the one-repetition maximum (1RM), maximum, time, and number of repetitions. Previous studies using the PBD have used the 1RM test (13,14) and the maximal repetition test (11,17,25,32). Both the 1RM and maximal repetition tests are important measures because to accelerate the wheelchair, the upper limb must continuously exert maximum muscle power. However, if the goal is to create a test that can be employed by recreational as well as elite athletes, a test using maximal repetitions would be more appropriate than a 1RM test, which carries a higher risk of injury. As of May 2024, the world records for the men's 100-m and 200-m wheelchair sprints in the T52, T53, and T54 classes are 16.41 s, 14.10 s, and 13.63 s, and 29.88 s, 25.04 s, and 24.18 s, respectively (37). Therefore, it is sufficient to measure the maximum repetitions in 30 s. Although demonstrating anaerobic power is important in sprint events, the Wingate anaerobic test (4), a typical anaerobic power measurement, is also performed in 30 s, and this measurement time is considered appropriate.

Given this background, the present study aimed to examine whether PBD measurement is associated with performance in wheelchair racing by having wheelchair athletes perform a 30-s PBD test and a 30-s wheelchair roller test. We hypothesized that there would be a significant positive correlation between the number of dips and the peak wheelchair speed.

METHODS

Participants

The participants in the present study were 13 Japanese wheelchair athletes (Table 1). The inclusion criteria were: male adult athlete, in the T52, T53, or T54 class, and participation in at least one national competition. Because certain wheelchair propulsion skills are required to perform the 30-second wheelchair roller test accurately, participation in a national competition was set as a condition for participation in this study. The exclusion criteria were: unable to bend the elbow joint to 90° during the descending phase of the PBD, unable to repeat the PBD without resting at the starting position, difficulty with wheelchair propulsion movements at maximum effort, and pain in the shoulder or elbow. Participants were recruited through two approaches: direct outreach at national competitions, and referrals provided by officials of Japan Para Athletics. Participants were contacted by email, provided with an explanation of the study's objectives and measurement procedures, and subsequently screened for eligibility based on the inclusion and exclusion criteria. All participants met the inclusion criteria and agreed to participate in the present study. The numbers of athletes by class were as follows: one in the T52, five in the T53, and seven in the T54 class. The conditions for the T52, T53, and T54 classes as defined by World Para Athletics (36) are as follows: T52 class athletes usually have normal shoulder, elbow, and wrist muscle power and poor to normal muscle power in the finger flexors and extensors, with wasting of the intrinsic muscles of the hands. These athletes usually have no muscle power in the trunk (complete spinal cord injury at neurological level C7–8). T53 class athletes typically have normal arm muscle power with no abdominal or lower spinal muscle activity (complete spinal cord injury at neurological level T1–7). T54 class athletes usually have normal arm muscle power with a range of trunk muscle power extending from partial to normal trunk control (complete spinal cord injury at neurological level T8–S4). Athletes who compete in this group may have significant leg muscle power. To examine differences by competitive performance, the participants were divided into an international-level group (ILG) and a national-level group (NLG). Athletes who had competed in international competitions were assigned to the ILG, whereas those who had only competed in national competitions were assigned to the NLG. All testing protocols were approved by the research ethics committee of Takarazuka University of Medical and

Table 1. Participant characteristics.

Group	Subject	Sex	Age (years)	Height (m)	Body Mass (kg)	Race class category
ILG (n = 7)	ILG-1	M	40	1.672	55.4	T52
	ILG-2	M	39	1.636	55.0	T53
	ILG-3	M	49	1.752	57.0	T53
	ILG-4	M	53	1.694	52.6	T53
	ILG-5	M	29	1.327	46.9	T54
	ILG-6	M	25	1.699	57.5	T54
	ILG-7	M	43	1.672	60.8	T54
NLG (n = 6)	NLG-1	M	57	1.705	60.6	T53
	NLG-2	M	45	1.760	60.1	T53
	NLG-3	M	36	1.754	71.7	T54
	NLG-4	M	46	1.624	68.5	T54
	NLG-5	M	54	1.678	58.6	T54
	NLG-6	M	40	1.410	39.3	T54

ILG: international-level group, NLG: national-level group.

Health Care (approval No.: 2107271). Before the experiment began, the aims and risks of the study were explained in full, and written informed consent was obtained from all athletes.

Experimental Procedure

The experimental procedure is shown in Figure 1. Prior to the experiment, resting blood lactate and heart rate were measured, followed by body measurements (height, body mass, and circumference). After the body measurements, the participants were allowed to warm up sufficiently and then asked to perform a 30-s PBD test (PBD-TEST) and a 30-s wheelchair roller test (WR-TEST) at maximum effort. The test time was set at 30 s because the Wingate anaerobic test, a typical test of anaerobic power, is performed in 30 s, and because the world record for the 200-m wheelchair race in the T52–54 class is around 25 s. The exercises, amount, and intensity of the warm-up were left up to the participants, as was the preparation of the equipment used in the warm-up. The warm-up consisted mainly of static and dynamic stretching of the upper extremities and light-load exercises using tubing and dumbbells. The intensity and volume were left to each athlete to prepare for the best performance in both tests. The order of the PBD-TEST and WR-TEST was randomized to avoid order-dependent effects. For the randomization, the first test was assigned alternately from the athletes who completed the warm-up, regardless of age, class, or competition level. Each test was conducted once, with a rest period of at least 30 min between each test.

Body Measurement

To investigate the morphological characteristics of the participants, height, body mass, upper limb length (left and right), chest circumference, upper arm circumference (left and right), and forearm circumference (left and right) were measured. Height was measured in the supine position, and when there were no contractures in the lower limbs, the horizontal distance from the top of the head to the sole of the foot was measured with the knee in extension. When the knees were bent due to contractures, height was calculated using the height estimation formula by Miyazawa et al. (29):

Men's height (cm) = 64.02 + (knee height x 2.12) – (age x 0.07)

Knee height was defined as the distance from the superior border of the patella to the heel (cm).

The mass of the participant in the wheelchair was measured using a wheelchair scale (PW-630; TANITA, Tokyo, Japan), and the body mass was calculated by subtracting the mass of the wheelchair. Upper limb length was measured from the acromion to the radial styloid process with the upper limb in a posture with the upper limb in a drooping position. Chest circumference was measured by placing the measuring tape directly under the inferior angle of the shoulder blades, with the tape circling horizontally at that height. Upper arm circumference was defined as the maximum circumference of the upper arm, not including the deltoid, and was measured as the circumference

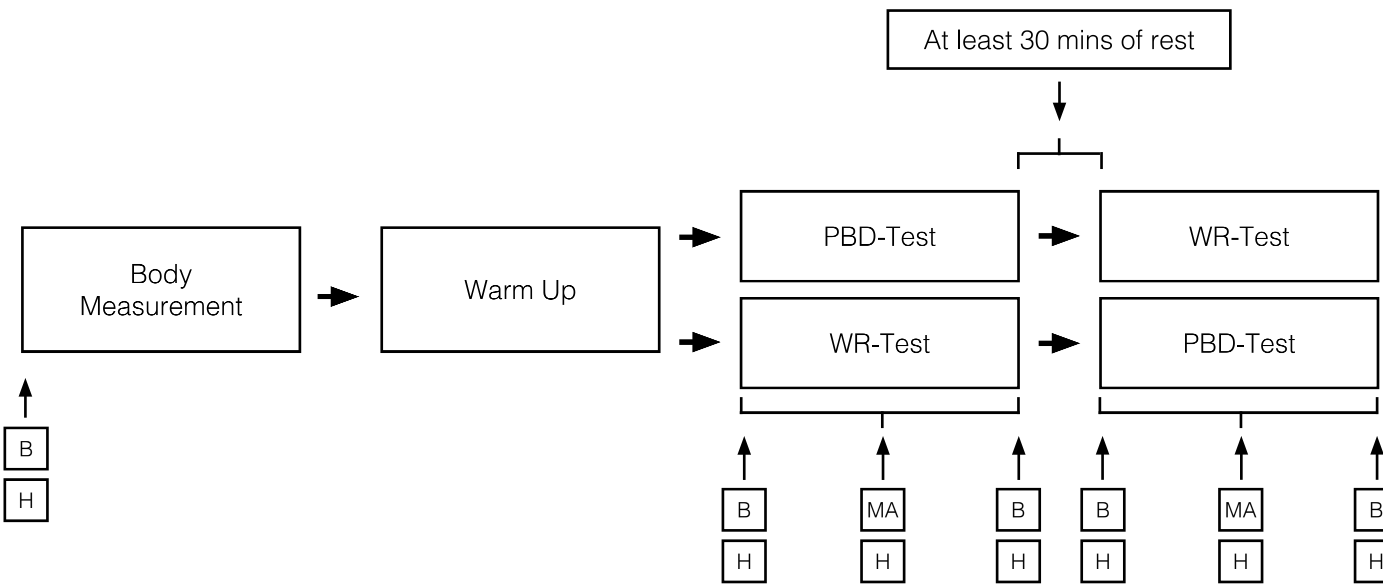

Figure 1. Measurement procedure. PBD-TEST: 30-s parallel bar dip test, WR-TEST: 30-s wheelchair roller test, B: collection of blood sample for lactate analysis, H: heart rate measurement, MA: video recording for motion analysis.

orthogonal to the long axis of the upper arm in a posture with the palms facing upward and the upper limbs raised to the horizontal. Forearm circumference was measured as the circumference of the most distended area slightly below the elbow joint, orthogonal to the long axis of the forearm, in a posture with the upper limb in a drooping position.

30-s PBD Test (PBD-TEST)

The dip bars (Dip Stand; Alpen, Nagoya, Japan) were set up as shown in Figure 2A. The dip bars were positioned in parallel 0.1 m away from the right and left hips. The starting posture was set with the elbow joint in full extension and the angle between the trunk and thighs at 90°. The measurement movement consisted of dipping the body from the starting posture until the elbow joint angle reached 90°, and then lifting the body while pushing the dip bar with both arms until the elbow joint was in full extension. The participant's legs were lifted anteriorly upward in the knee extension position, and the measurer secured the feet to prevent the participant's legs from moving during the test. To ensure safety, a bench was placed directly under the body at a height that would not interfere with the test. After measuring blood lactate, the initiation of the test was indicated by a sync signal light, and the athlete was instructed to repeat this movement at maximum effort for 30 s. The correct descent and ascent movements were counted as one time, and the number of times during 30 s was counted. Trials that deviated significantly from the correct movement were considered failed movements and excluded from the count.

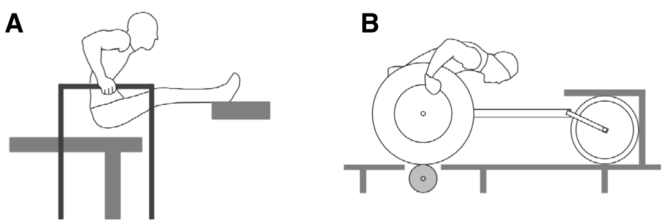

Figure 2. An athlete performing (A) a PBD-TEST and (B) a WR-TEST. PBD-TEST: 30-s parallel bar dip test, WR-TEST: 30-s wheelchair roller test.

30-s Wheelchair Roller Test (WR-TEST)

A training roller for wheelchair athletes (Ishinuki, Koshi, Japan) was used for the WR-TEST (Figure 2B). The wheelchair was placed on a training roller and secured so that the rear axle was directly above the center of the roller. All athletes used their own wheelchair. The load on the roller was set to the lowest of five levels. This load was close to the running load on the track. After measuring blood lactate, the test was initiated by the lighting of the sync signal, and the athlete was instructed to run at maximum effort for 30 s. No instructions were given regarding pushing movements or frequency, and gloves were worn as used in daily training. Standardized verbal encouragement was provided to all athletes during the WR-TEST.

Video Recording for Motion Analysis

Three high-speed cameras (DMC FZ-300; Panasonic, Osaka, Japan) were used to capture the movements. One of the cameras was placed at the side of the athlete, while the other two were placed at the right-front and right-rear of the athlete so that the optical axes of the two cameras were at 90°. The three cameras were synchronized using a sync signal (PTS-167; Q'sfix, Tokyo, Japan). Because of the different motion speeds of each test, the PBD-TEST was captured at 60 Hz and the WR-TEST at 240 Hz. Prior to the experiment, reflective markers were affixed to the greater trochanter (PBD-TEST only), acromion, lateral humeral epicondyles, and midpoints of the radial and ulnar styloid processes on the right side of the athlete to assist in the analysis. Motion analysis software (Frame-DIAS V; Q'sfix, Tokyo, Japan) was used to analyze the PBD-TEST and WR-TEST data. In the PBD-TEST, the number of dips (counting from full extension of the right elbow to the next full extension of the right elbow as one dip) and push time (time from the lowest point of the right greater trochanter to full extension of the right elbow joint) were calculated at 60 Hz. In the WR-TEST, the numbers of strokes for 30 s (counting from glove hand–rim contact to the next hand–rim contact as one stroke) and stroke time (time from glove hand–rim contact to the next hand–rim contact) were calculated using video data down-sampled to 60 Hz. The numbers of dips and strokes were measured entirely from video data and not counted in real time. Wheelchair speed was calculated using the following procedure with 240 Hz video data. First, the average angular velocity was calculated from the time required for one rotation with reference to the reflective marker affixed to the rear wheel, and the average speed per rotation was calculated by multiplying the average angular velocity by the radius of the rear wheel. This speed was defined as the wheelchair speed.

Measurement of Blood Lactate and Heart Rate

Blood samples were taken using a portable lactate analyzer (Lactate Pro2 LT-1730; ARKRAY, Kyoto, Japan) from the earlobe, at rest (before the body measurement and each test), immediately after the test, and at 3, 5, and every 2 min thereafter until lactate values decreased (Figure 1). Prick blood samples were obtained twice at each point, and the average of the two lactate values was used for analysis. As an indication of recovery after the test, blood lactate was measured after 30 min of rest, and if the level was < 2 mmol·L^{-1}, the next test was performed. If blood lactate was ≥ 2 mmol·L^{-1}, a rest period was added and continued until the level was < 2 mmol·L^{-1}. In addition, blood lactate measurements were taken after warming up, with the first test initiated when the blood lactate was < 2 mmol·L^{-1}. The blood samples were drawn by a doctor who was a co-investigator in the present study. Heart rate was measured using a heart rate sensor fixed to the chest with a belt (Polar H10; Polar Electro Oy, Kempele, Finland). Heart rate was monitored constantly during the test, and also measured at blood sampling before and after the test (Figure 1). The heart rate sensor was disconnected in one athlete in the ILG and one in the NLG, so heart rate could not be measured immediately after the WR-TEST in these participants.

Statistical Analysis

Data were analyzed using SPSS statistical analysis software (version 23.0 for Windows; SPSS, Chicago, IL, USA). All parameters in each group were tested for normality using the Shapiro–Wilk test. The results indicated that all variables were normally distributed ($p > 0.05$), justifying the use of parametric analyses. Differences in mean values between the PBD-TEST and WR-TEST were determined using a paired-sample *t*-test. The difference between the mean values of the ILG and NLG was evaluated using Levene's test for equal variances, with Student's *t*-tests used when equal variances were confirmed and Welch's *t*-test when they were not. Cohen's *d* was used to calculate the effect size (ES) for each *t*-test. The ES magnitudes were interpreted based on Cohen's *d* (small = 0.2, moderate = 0.5 and large = 0.8) (10). The level of statistical significance for t-test was set at $\alpha = 0.05$. The relationships between parameters were examined using Pearson's correlation coefficient. To control for multiple comparisons in the correlation analyses, the alpha level was adjusted using the Bonferroni correction ($\alpha = 0.05/2$; adjusted $\alpha = 0.025$).

RESULTS

Table 2 shows the results of the PBD-TEST and WR-TEST for all participants. The mean number of dips in the PBD-TEST was 37 ± 7. The mean number of strokes in the WR-TEST was 62 ± 3. The mean peak blood lactate concentration after the test was 7.8 ± 2.1 mmol·L^{-1} for the PBD-TEST and 11.7 ± 2.7 mmol·L^{-1} for the WR-TEST. The mean peak blood lactate concentrations were significantly higher after the WR-TEST than after the PBD-TEST ($t = 4.835$, $p < 0.001$, $ES = 1.600$, 95% confidence interval [CI] = 2.130 to 5.624). The mean peak heart rate after the test was 157.1 ± 14.6 beats·min^{-1} for the PBD-TEST and 151.5 ± 17.7 beats·min^{-1} for the WR-TEST. No significant difference in mean peak heart rate was found after the PBD-TEST and WR-TEST ($t = -0.639$, $p = 0.537$, $ES = 0.197$, 95% CI = –13.875 to 7.693).

The top panel of Figure 3 shows the relationships between the number of dips in the PBD-TEST and the peak wheelchair speed in the WR-TEST. No significant relationship was found for all participants,

Table 2. Comparison of PBD-TEST and WR-TEST parameters.

Parameter	PBD-TEST (n=13) Mean ± SD	WR-TEST (n=13) Mean ± SD	PBD-TEST vs. WR-TEST				
			t-value	*p*-value	ES (*d*)	95% CI	
						Lower bound	Upper bound
Number of dips	37 ± 7	-	-	-	-	-	-
Number of strokes	-	62 ± 3	-	-	-	-	-
Peak BLa (mmol·L^{-1})	7.8 ± 2.1	11.7 ± 2.7	4.835	<0.001*	1.600	2.130	5.624
Peak HR (beats·min^{-1})	157.1 ± 14.6	151.5 ± 17.7[a]	–0.639	0.537	0.197	–13.875	7.693

[a]: Data for 11 athletes.
**: Significant difference in the t-test (p < 0.05) between the PBD-TEST and WR-TEST.*
PBD-TEST: 30-s parallel bar dip test, WR-TEST: 30-s wheelchair roller test.
ES: effect size, BLa: blood lactate, HR: heart rate, SD: standard deviation, CI: confidence interval.

but a significant relationship was found for both the ILG (r = 0.892, p = 0.007) and NLG (r = –0.919, p = 0.010). In other words, the ILG and NLG showed contrasting results. The bottom panel of Figure 3 also shows the relationships between body mass and the number of dips in the PBD-TEST. No significant relationships were found across all groups.

Table 3 shows the physical characteristics and the kinematic and physiological data for the PBD-TEST and WR-TEST for each group. Comparing the ILG and NLG, significant differences were found only in peak wheelchair speed (t = 3.254, p = 0.008, ES = 1.810, 95% CI = 1.032 to 5.349) and time to reach peak wheelchair speed (t = 4.135, p = 0.002, ES = 2.301, 95% CI = 2.044 to 6.695) in the WR-TEST.

DISCUSSION

In this study, 13 wheelchair athletes were asked to perform a PBD-TEST and a WR-TEST. The primary muscles in the PBD-TEST are the pectoralis major, anterior deltoid, and triceps brachii (27,28). These muscles are in eccentric contraction during the downward phase and concentric contraction during the upward phase (28), so greater muscle activity is required at all times throughout one stroke. By contrast, it has been reported that during the push phase of the WR-TEST, the triceps brachii is primarily active as the agonist muscle (concentric contraction), and is not observed to have noticeable muscle activity during the recovery phase (7,8). Therefore, the triceps brachii is required to have greater muscle activity during the push phase only. In addition, because the WR-TEST starts from a stationary posture, substantial muscular effort is required for the first few strokes (2,23,31), but thereafter, the resistance load becomes smaller with each stroke by inertia. As fewer dips were recorded in the PBD-TEST than in the WR-TEST, the PBD-TEST is considered to be a high-load, low-rotation exercise, while the WR-TEST is considered to be a low-load, high-rotation exercise. In this study, the test time was set to 30 s with reference to the Wingate test, which is primarily

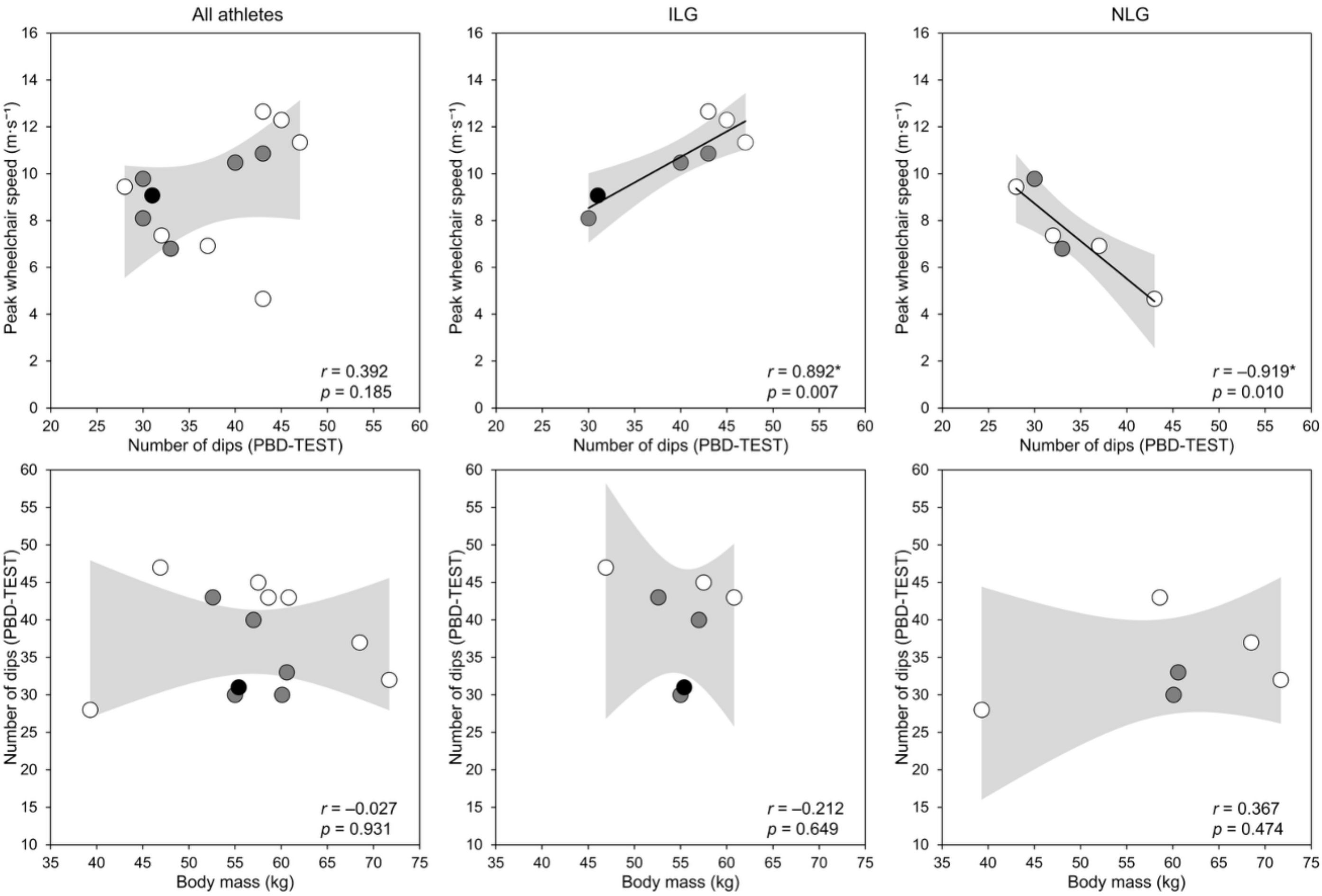

Figure 3. Relationships between number of dips and peak wheelchair speed (top panel), and between body mass and number of dips (bottom panel), shown for all athletes, the ILG, and the NLG. The solid line indicates the fitted linear regression, and the shaded area represents the 95% confidence interval. *p < 0.025. ILG: international-level group, NLG: national-level group. PBD-TEST: 30-s parallel bar dip test. White dots: class T54, Gray dots: class T53, Black dots: class T52.

Table 3. Comparison of parameters between the ILG and NLG.

Parameter	All athletes (n = 13) Mean ± SD	ILG (n = 7) Mean ± SD	NLG (n = 6) Mean ± SD	ILG vs. NLG				
				t-value	*p*-value	ES (*d*)	95% CI	
							Lower bound	Upper bound
Height (m)	1.645 ± 0.131	1.636 ± 0.141	1.655 ± 0.130	–0.253	0.805	0.141	–0.186	0.147
Body mass (kg)	57.2 ± 8.3	55.0 ± 4.4	59.8 ± 11.3	–1.035	0.323	0.576	–14.917	5.374
Chest circumference (m)	0.933 ± 0.079	0.917 ± 0.051	0.953 ± 0.104	–0.805	0.438	0.448	–0.134	0.062
R. UL length (m)	0.553 ± 0.027	0.552 ± 0.023	0.555 ± 0.033	–0.211	0.837	0.117	–0.038	0.031
L. UL length (m)	0.549 ± 0.028	0.550 ± 0.021	0.549 ± 0.036	0.044	0.965	0.025	–0.035	0.036
R. UA circumference (m)	0.316 ± 0.028	0.325 ± 0.014	0.306 ± 0.037	1.201	0.273	0.668	–0.020	0.058
L. UA circumference (m)	0.313 ± 0.028	0.324 ± 0.019	0.301 ± 0.034	1.594	0.139	0.887	–0.009	0.056
R. FA circumference (m)	0.274 ± 0.018	0.278 ± 0.015	0.270 ± 0.020	0.798	0.441	0.444	–0.014	0.030
L. FA circumference (m)	0.276 ± 0.021	0.282 ± 0.024	0.269 ± 0.017	1.097	0.296	0.610	–0.013	0.039
PBD-TEST								
Number of dips	37 ± 7	40 ±7	34 ± 5	1.753	0.107	0.975	–1.540	13.587
Average push time (s)	0.413 ± 0.082	0.388 ± 0.093	0.443 ± 0.060	–1.242	0.240	0.691	–0.153	0.043
Peak BLa (mmol·L^{-1})	7.8 ± 2.1	8.4 ± 2.4	7.2 ± 1.6	1.080	0.303	0.601	–1.298	3.798
Peak HR (beats·min^{-1})	157.1 ± 14.6	154.0 ± 6.1	160.7 ± 20.9	–0.754	0.481	0.419	–28.548	15.215
WR-TEST								
Number of strokes	62 ± 3	62 ± 2	62 ± 4	0.110	0.914	0.061	–3.614	3.995
Peak wheelchair speed (m·s^{-1})	9.2 ± 2.4	10.7 ± 1.6	7.5 ± 1.9	3.254	0.008*	1.810	1.032	5.349
Time to reach peak wheelchair speed (s)	9.307 ± 2.906	11.324 ± 2.399	6.954 ± 1.014	4.135	0.002*	2.301	2.044	6.695
Peak BLa (mmol·L^{-1})	11.7 ± 2.7	11.8 ± 2.1	11.6 ± 3.5	0.076	0.942	0.042	–3.666	3.914
Peak HR (beats·min^{-1})	151.5 ± 17.7[a]	161.0 ± 7.9[b]	140.0 ± 20.1[c]	2.200	0.079	1.332	–3.474	45.474

[a]: Data for 11 athletes; [b]: Data for 6 athletes; [c]: Data for 5 athletes.
**: Significant difference in the t-test (p < 0.05) between the ILG and NLG.*
PBD-TEST: 30-s parallel bar dip test, WR-TEST: 30-s wheelchair roller test.
ILG: international-level group, NLG: national-level group, ES: effect size, BLa: blood lactate, HR: heart rate, UL: upper limb, UA: upper arm, FA: forearm, SD: standard deviation, CI: confidence interval.

used to assess anaerobic energy supply because wheelchair racing is a short-duration, high-intensity exercise (3,16). This is evidenced by the significant correlation observed between peak blood lactate concentration after the Wingate test and output power (19,33). It has also been reported that the higher the output power, the higher the blood lactate concentration at a higher cadence (pedaling speed) compared with at a lower cadence (30). The peak blood lactate concentration in this study was significantly higher in the WR-TEST than in the PBD-TEST. The results and the loading characteristics of both tests suggest that the PBD-TEST requires more energy supply from the phosphagen system (anaerobic power) than from the glycolytic system (anaerobic endurance), suggesting that the energy supply system required may be different from that for the WR-TEST. In this study, a rest period of at least 30 min was ensured between both tests. In addition, because blood lactate was used as a recovery indicator, the exact rest time for each athlete was not recorded. Generally, different types of training use time for rest intervals, so it was necessary to confirm the actual rest time required. Considering the spread of the PBD-TEST, a simplified method rather than blood lactate is required, so it will also be necessary to examine rest periods.

As stated in the introduction, the purpose of this study was to examine whether PBD is associated with performance in wheelchair racing. The results revealed no significant correlation between the number of dips in the PBD-TEST and the peak wheelchair speed in the WR-TEST. The reasons for this include a mix of different classes of participants (differences in residual function) and physical characteristics (e.g., spinal cord injury, spina bifida), but may also be influenced by training and performance levels. Therefore, we decided to examine the relationship between the two tests by dividing the participants into an ILG and a NLG, using their athletic history as a reference. The results showed a significant positive correlation between the number of dips in the PBD-TEST and the peak wheelchair speed in the WR-TEST for the ILG, but a significant negative correlation for the NLG. In the ILG, the wheelchair athletes with more dips in the PBD-TEST had greater peak wheelchair speed in the WR-TEST, suggesting that they had the skills needed to convert upper limb muscle power into wheelchair speed. In the ILG, higher dip performance likely reflects both muscle power and technical efficiency in propulsion. On the other hand, in the NLG, the wheelchair athletes with more dips in the PBD-TEST had lower peak wheelchair speed in the WR-TEST, suggesting that wheelchair athletes with greater upper limb muscle power may have pushed the hand rim with brute force, but were unskilled in the technique of transferring upper limb muscle power to the hand rim. In the NLG, strength may not translate into propulsion efficiency without refined technique, leading to a negative association. To achieve high acceleration, the athletes must overcome the inertia at the start, so they need to increase the muscle power of their upper limbs through weight training and other means (2,21). Furthermore, to exert such muscle power efficiently, a high level of skill is also required to synchronize the movements of the trunk and upper limbs (2). Athletes also reported that during the starting phase, they tend to push the hand rim out of the way, whereas during the steady state, they adopt a more striking motion to the hand rim, and that as speed increases, more skill is required to transfer force to the hand rim in a shorter amount of time (24). From these reports, it can be said that the ILG was superior to the NLG in not only the magnitude of muscle power, but also upper limb and trunk synchronization and the timing of muscle power exertion. Because a previous study has also shown that upper body muscle power is not a valid predictor of wheelchair sprint speed, and that racing technique is a related additional factor (20), the acquisition of a high propulsion technique may be necessary to improve wheelchair speed. In this study, the degrees of disability and physical fitness varied for each athlete, so the exercise, volume, and intensity of the warm-up were left to the athletes themselves. Therefore, while the warm-up in this study was not standardized, all athletes were in a state where they could approach the test with maximum effort. However, because differences in warm-up routines may lead to varying test results, future experiments will require adjusting warm-up routines according to physical fitness and impairment levels.

No significant difference in the number of strokes in the WR-TEST was found between the two groups, but the ILG had greater peak wheelchair speed in the WR-TEST and a shorter time to reach peak wheelchair speed than the NLG. In other words, it is thought that the ILG had the ability to reach peak wheelchair speed in a shorter period of time. It has been reported that under heavy loading conditions, such as the starting phase of wheelchair racing, push times are longer (7) and decrease with increased speed (22). Because wheelchair athletes start from a stationary position, a powerful push of the hand rim is required to accelerate the wheelchair. Although 1RM of the PBD-TEST was not measured in this study, it was inferred that international-level wheelchair athletes with a higher number of dips in the PBD-TEST have greater elbow extensor strength, and thus, it was assumed that this effect was responsible for their superior performance in peak wheelchair speed and time to reach peak wheelchair speed in the WR-TEST compared with the NLG. Improving muscle power in the upper limb is considered essential to increase acceleration in the starting phase of wheelchair racing (2). As previous studies have reported that high-impact resistance training significantly increases muscle power in wheelchair athletes (34), push training, including dip training, should be undertaken to improve performance during the starting phase of wheelchair racing. In the present study, we did not verify whether the roller load used was identical to the load on the synthetic track surface. The reason for this is that synthetic track surfaces vary in terms of load magnitude depending on the type of surface and the degree of surface degradation. Therefore, in this study, the load was set based on subjective feedback from the athletes, meaning that their perception of the load could vary depending on their physical condition. The difference in load between the roller and synthetic track surface should be verified if the goal is to set a load close to that of an actual race.

In the present study, the PBD-TEST was performed in the knee extension position with the foot fixed anteriorly upward. The reasons for adopting this posture were to eliminate the instability caused by swaying of the lower limbs and to approximate the posture during wheelchair propulsion. PBDs for able-bodied subjects are often performed with the torso slightly tilted forward and knees bent (5,13,15,21,26,28), and the reason for this is thought to be to maintain the center of gravity of the body near the fulcrum (hand holding the bar) in the sagittal plane. However, because wheelchair athletes cannot use their lower limbs, it is impossible for them to assume the same posture as able-bodied people. The posture in this study did not support the entire body weight with the upper limbs as in the case of able-bodied athletes, which may have reduced the body weight load somewhat. Thus, the optimal movement posture for wheelchair athletes requires further study.

This study included 13 wheelchair athletes (seven in the ILG and six in the NLG). The sample size was small, and the number of participants by sport class was even smaller, so it is difficult to say that the results reflect the characteristics of each class. Originally, we would have liked to analyze a larger sample size, but in Japan, it is difficult to collect a large number of international-level wheelchair athletes in each class, so we had to conduct the analysis with a small sample size. Small and heterogeneous sample sizes carry statistical and interpretive risks, including limitations on generalizability, unstable estimates, and increased sampling bias. However, because the relationship between the PBD-TEST and the WR-TEST could be generally understood, there is a strong possibility that the PBD-TEST could become a performance indicator in wheelchair racing in the future. To ensure the effectiveness of the PBD-TEST, additional experiments should be conducted with more participants in each sport class. If additional experiments can help ensure the generalizability of the present results and establish the PBD-TEST as an evaluation standard that reflects peak wheelchair speed, this would contribute not only to athletes seeking to enhance their athletic performance, but also to talent identification and athlete development. In addition to the PBD-TEST conducted in this study, other physical assessment measures (e.g., muscle power, muscle mass, flexibility) may be related to wheelchair racing performance. If these physical assessments could be integrated with the present results, a clearer assessment would be possible. Therefore, other physical assessments should be considered in conjunction with additional PBD-TEST studies. The results of this study clarified the relationship between the PBD-TEST and WR-TEST and obtained foundational insights for establishing causal hypotheses. However, as this was a cross-sectional study, it could not definitively establish a causal relationship between the PBD-TEST and WR-TEST. To clarify causal relationships, it is necessary to intervene in daily training and conduct longitudinal studies. To achieve more accurate testing, verification through longitudinal studies will also be necessary.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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ETHICAL APPROVAL

The study protocol and recruitment procedures were approved by the research ethics committee of Takarazuka University of Medical and Health Care (approval number: 2107271).

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