USE OF WHEELMILL SYSTEM FOR PEAK VO_2 MEASUREMENT FOR MANUAL WHEELCHAIR USERS

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Abstract

The purpose of this research was to develop and validate an endurance exercise assessment (peak oxygen consumption (VO_{2Peak})) protocol using an innovative wheelchair dynamometer, the Wheelmill System (WMS). The WMS exercise protocol was validated against the standard arm crank ergometer (ACE) exercise protocol. Ten participants were recruited from the community. VO_{2Peak} was measured three times using the WMS twice, and an arm ergometer once. VO_{2peak} was highly correlated between the two testing modes, indicating the WMS protocol to be reliable and valid compared to the gold-standard ACE protocol for MWUs with spinal cord injuries (SCI).

Introduction

Approximately 282,000 people in the United States are living with SCI (NSCISC, 2016) with a majority using a manual wheelchair for everyday mobility. Physical activity is very important for this population to maintain a healthy and independent lifestyle (Centers for Disease Control and Prevention (2007). Manual wheelchair users (MWU) are at increased risk of a sedentary lifestyle, possibly leading to an increase in susceptibility to cardiovascular disease (Haisma, 2006; Whiteneck, 1992).

The gold standard for assessing cardiovascular fitness is measuring peak volume of oxygen consumption (VO_{2peak}) during a graded exercise test (Vanhees et al., 2005; Hoffman, 1986; Knechtle & Köpfli, 2001). The graded exercise for non-wheechair users is typically a treadmill or stationary bike, which is not feasible for MWU. For MWU, the most common method of graded exercise is an arm ergometer, which is an uncommon upper extremity motion for this population in their daily lives (Ilias, 2009). We have developed the WMS (Figure 1), which is a wheelchair dynamometer for MWU (Klaesner, 2013). The purpose of this study was to develop and validate an exercise testing protocol that will evaluate cardiorespiratory endurance in MWUs with SCI using the WMS that allows for use of personal wheelchairs during testing.

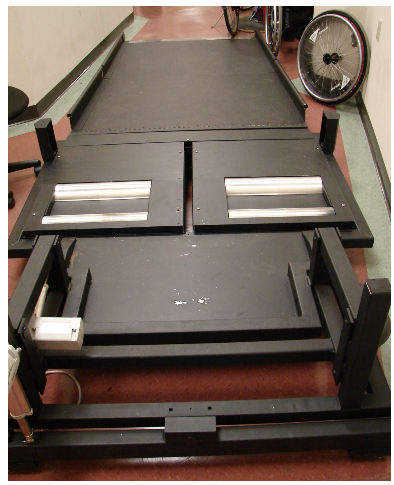

Figure 1: The Wheelmil System.

Methods

We had an approved IRB protocol that was followed. Ten participants that had a spinal cord injury (level C5/6 or below) and used a manual wheelchair for everyday mobility were recruited. Prior to the exercise tests, all participants obtained approval and signed release from a medical physician.

All participants performed three incremental maximal exercise tests, two on a wheelchair dynamometer and one on an arm crank ergometer. Testing sessions were performed on three separate days; tests were conducted at least 48 hours apart. The order of the three exercise tests was randomized for each participant to minimize order and carry-over effects.

After participants were securely positioned in their everyday manual wheelchair on the testing device (dynamometer or ergometer), a 3-min standardized warm-up commenced, followed by a maximal exercise test using a continuous stepwise protocol with workload increases in 1-minute intervals until exhaustion. All maximal exercise tests were immediately followed by an active cool down period lasting at least three minutes. Standard indications for exercise test termination were used (ACSM 2014).

During the exercise tests, VO_2 ($L \bullet min^{-1}$ and $ml \bullet kg^{-1} \bullet min^{-1}$), respiratory exchange ratio (RER), carbon dioxide production (VCO_2; $L \bullet min^{-1}$), pulmonary ventilation ($L \bullet min^{-1}$), and energy expenditure (EE; $Kcal \bullet min^{-1}$ and AcKcal) were measured using a metabolic measurement system (TrueOne 2400, ParvoMedics, Sandy, UT, USA). Ratings of perceived exertion (RPE) was measured during the warm-up period, the last 30 seconds of each incremental stage, immediately following completion of the maximal test, and every minute of cool down. The Borg Scale (6-20; Flaherty, 2008) was used to measure RPE.

Results

Ten participants (Table 1) completed all exercise tests without any adverse events including no reports of severe pain, fatigue, or experiences of autonomic dysreflexia. Due to inability to maintain 60 rpm beyond 52 watts, one participant's ACE test was terminated prior to volitional exhaustion (RER < 1.1; RPE < 17), therefore his ACE_{peak} data was excluded from statistical analysis.

There were no significant differences in VO_{2peak}, peak HR, peak RER, peak RPE, peak AcKcal, peak rate of energy expenditure, or peak power output among WMS and ACE trials (Table 2). Between WMS_{peak} and ACE_{peak} tests, there were significant moderate-to-strong correlations for VO_2 ($P<0.05$, $r=0.79$), HR ($P<0.01$, $r=0.80$), AcKal ($P<0.01$, $r=0.81$), rate of energy expenditure ($P<0.01$, $r=0.90$), and RPE ($P<0.01$, $r=0.85$; Table 3). Peak pulmonary ventilation had a strong correlation ($P<0.01$, $r=0.87$) between testing modes, however approached a significant difference ($P=.088$). Between WMS trials, significant moderate-to-strong correlations existed for VO_2 ($P<0.01$, $r=0.82$), AcKal ($P<0.01$, $r=0.91$), rate of energy expenditure ($P<0.01$, $r=0.94$), and peak power output ($P<0.01$, $r=0.98$; Table 3).

Table 1: Subject Data

Participant	Testing Order	Age-predicted Max HR	Gender	Age	Injury Level	ASIA Level
1	WM, AE, WM	183	M	37	C7	A
2	AE, WM, WM	193	M	27	C7	B
3	AE, WM, WM	197	M	23	C7	B
4	AE, WM, WM	197	M	23	C6-7	B
5	WM, AE, WM	189	M	31	C6-7	C
6	WM, WM, AE	192	M	28	T-11	A
7	WM, AE, WM	156	M	64	T8-9	B
8	AE, WM, WM	184	M	36	C5-6	B
9	WM, WM, AE	192	M	28	C6-7	B
10	WM, WM, AE	189	M	31	T4-6	C

Table 2: Peak and submaximal metabolic values (mean ± SD) during WMS and ACE trials

Variables	WMS_1 peak ($n=10$)	WMS_2 peak ($n=10$)	ACE peak ($n=9$)	WMS_1 30 W ($n=10$)	ACE 30 W ($n=10$)
VO_2 ($ml \bullet kg^{-1} \bullet min^{-1}$)	17.3 ± 3.3	18.1 ± 2.3	15.9 ± 2.0	9.0 ± 2.2	9.6 ± 1.4
VO_2 ($L \bullet min^{-1}$)	1.3 ± 0.42	1.4 ± 0.31	1.2 ± 0.25	0.7 ± 0.12	0.73 ± 0.08
RER	1.1 ± 0.03	1.1 ± 0.02	1.2 ± 0.08	1.1 ± 0.13	0.91 ± 0.04
HR	140 ± 27.2	148.5 ± 27.0	131.2 ± 28.2	116.7 ± 28.76	94.3 ± 21.5*
Vemax ($L \bullet min^{-1}$)	55.5 ± 13.8	56.0 ± 10.0	47.3 ± 11.0	-	-
AcKcal	38.3 ± 18.8	42.9 ± 14.9	36.1 ± 12.1	6.2 ± 4.5	10.54 ± 1.1
EE ($kcal\ min^{-1}$)	8 ± 2.1	7.9 ± 1.6	7.5 ± 1.5	3.4 ± 0.6	3.5 ± 0.3
RPE	18.9 ± 0.94	19.4 ± 0.72	19.2 ± 0.69	9.8 ± 2.4	11.5 ± 1.8
Workload (W)	62 ± 20.93	62 ± 17.37	61.3 ± 13.48	30	30
WE (%)	-	-	-	30.0 ± 7.4	31.9 ± 4.6
ME (%)	-	-	-	23.5 ± 7.5	20 ± 2.9

* Significant difference ($P<0.05$)
WMS_1 peak: WMS trial 1 at maximal effort
WMS_2 peak: WMS trial 2 at maximal effort
ACE peak: ACE at maximal effort
WMS_1 30 W: WMS trial 1 at submaximal effort ($VO_{2\text{-}30W}$)
ACE 30 W: ACE at submaximal effort ($VO_{2\text{-}30W}$)
VO_2 ($ml \bullet kg^{-1} \bullet min^{-1}$): Oxygen uptake
VO_2 ($L \bullet min^{-1}$): Oxygen uptake
RER: Respiratory exchange ratio
HR: Heart rate
Vemax: Pulmonary ventilation at VO_{2peak}
AcKcal: Accumulated Kcal
EE ($kcal \bullet min^{-1}$): energy expenditure during exercise
RPE: Ratings of perceived exertion
Workload (W): Power output in watts
WE (%): Work economy ($VO_{2\text{-}30W}$)
ME (%): Mechanical efficiency ($VO_{2\text{-}30W}$)

Table 3: Correlations of peak metabolic and submaximal ($VO_{2\text{-}30W}$) energetic values (*r*-values) during WMS and ACE trials

Variables	WMS_1 vs. ACE (*n* = 9)	WMS_1 vs. WMS_2 (*n* = 10)
VO_2 (ml·kg^{-1}·min^{-1})	0.792†	.824*
RER	0.252	0.316
HR	0.801*	0.537
Vemax (L•min^{-1})	.869*	.834*
AcKcal	.811*	0.91*
EE (kcal min^{-1})	.899*	.954*
RPE	0.845*	0.125
Workload	0.775	.983*
WE[a]	0.584	0.001*
ME[a]	0.133	.680†

† Correlation is significant at $P < 0.05$
* Correlation is significant at $P < 0.01$
[a] $N = 10$
WMS_1: WMS trial 1
WMS_2: WMS trial 2
VO_2 (ml•kg^{-1}•min^{-1}): Oxygen uptake
RER: Respiratory exchange ratio
HR: Heart rate
Vemax: Pulmonary ventilation at VO_{2peak}
AcKcal: Accumulated Kcal
EE (kcal•min^{-1}): energy expenditure during exercise
RPE: Ratings of perceived exertion
Workload (W): Power output in watts
WE (%): Work economy ($VO_{2\text{-}30W}$)
ME (%): Mechanical efficiency ($VO_{2\text{-}30W}$)

Discussion

Participants exhibited moderate-to-strong correlations of cardiorespiratory responses between WMS and ACE with no significant differences between the two testing modes in regards to testing VO_{2peak}. No significant difference was found between WMS trials. Overall, we feel that we demonstrated the validity of the WMS for a graded exercise challenge for the VO_{2Peak} test. The time to exhaustion generally occurred within the 8-12 minute range. The WMS testing met the criteria for peak RER for VO_{2Peak} testing, which is greater than or equal to 1.1. The participants almost all met the criteria for 80% of predicted peak heart rate (HR). The only statistically significant result that existed was HR however RPE approached significance between testing modes at submaximal workloads.

The test durations and RERs were similar between the three groups, indicating that the WMS was repeatable, and comparable to the arm ergometer. At submaximal workloads, mechanical efficiency was slightly higher in WMS compared to ACE however these esults were not statistically significant. ifferences in perceived exertion and efficiency t submaximal workloads and maximal ulmonary ventilation at peak workloads ndicated potential advantages of the WMS rotocol. Anecdotally, all but one of the articipants preferred using the WMS for O_{2Peak} testing.

Conclusion

This study found VO_{2peak} to be highly correlated between the two testing modes, indicating the WMS protocol to be reliable and valid compared to the gold-standard ACE protocol. The findings of this study has clinical implications by validating a newly developed exercise testing protocol that promotes task specificity and testing individualization.

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