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Effect of variable loading in the determination of upper-limb anaerobic power in persons with tetraplegia

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Abstract—This article examines the effects of levels of resistance loading during arm Wingate Anaerobic Testing (WAnT) in persons with differing levels of cervical spinal cord injury (SCI). Thirty-nine persons with motor-complete SCI tetraplegia (13 each at C5, C6, and C7) performed six bouts of arm-crank WAnT with relative loads equivalent to 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 percent of body mass (BM). Power output was determined with the use of the SMI OptoSensor 2000 (Sports Medicine Industries, Inc., St. Cloud, MN, USA) hardware and software package. Values of peak power (P_{peak}) and mean power (P_{mean}) were examined statistically between groups (C5, C6, and C7) and across levels of resistance loading. Resistance loads that provided the greatest values of P_{mean} for the three groups were as follows: C5 = 1.0 or 1.5 percent of BM; C6 = 1.5 or 2.0 percent of BM; and C7 = 2.5, 3.0, or 3.5 percent of BM. Appropriate loading for arm WAnT is specific to the level of tetraplegia and may provide a useful assessment of upper limb power production.

Key words: anaerobic, power, spinal cord injury, tetraplegia, Wingate.

INTRODUCTION

Individuals with motor/sensory-complete cervical-level spinal cord injury (SCI) display a state of tetraplegia defined as a “lack of volitional control of movement and sensation within the lower limbs and torso musculature with varying degrees of neuromuscular impairment within the upper extremities” [1]. Persons with tetraplegia must rely solely on efforts of the upper body musculature to complete activities of daily living (ADLs), which can often lead to the development of overuse injuries [2]. The daily life of survivors of SCI tetraplegia can be characterized as long intervals of relative inactivity with brief periods of high-intensity effort that require muscular strength and power of the upper limbs, such as wheelchair propulsion up an incline and bodyweight transfers [3].

A prerequisite for the development of truly evidence-based medical and fitness practices is the availability of clinical outcome measures that provide precise, reliable, and valid assessments. Unfortunately, the measurement tools of the production of muscular force in persons with lower-limb disability are limited. Generally, the clinical measurement tools such as the American Spinal Injury

Abbreviations: ADL = activity of daily living, ASIA = American Spinal Injury Association, SCI = spinal cord injury, WAnT = Wingate Anaerobic Testing.

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Association (ASIA) classification and other means based on manual muscle testing are crude classifications, at best, and are definitely not precise enough to allow application as a precise measurement tool [1]. Laboratory measurement tools (such as graded arm exercise testing with metabolic assessment and isokinetic muscle testing) may provide valuable information in this population, but are rarely found in clinical SCI settings. The assessment of upper-body strength and power is of vital importance for individuals with SCI tetraplegia, as mobility and exercise capacity are severely limited by muscular weakness.

One of the most commonly used tools to assess muscular power output is the Wingate Anaerobic Test (WAnT). The WAnT requires pedaling or arm cranking at maximum speed against a constant resistance for 30 s [4–6]. Values of power output are generally calculated as a product of the resistance applied to the ergometer and the velocity of the flywheel. Accurate assessment of anaerobic power with the WAnT requires the application of the optimal resistance load for the specific population.

The majority of research efforts into the assessment of muscular power output have been performed in the able-bodied population, with particular emphasis on athletic groups. Unlike able-bodied individuals, persons with neurologically complete tetraplegia are unable to stabilize their sitting position by using the lower limbs, therefore they would perform arm WAnT as an open kinetic chain exercise. Persons with tetraplegia also have varying levels of motor function, related to the level of injury, which would directly affect performance of WAnT and ADLs. Thus, this population has unique characteristics warranting specific protocols for rehabilitation testing and training. The purpose of this investigation was to determine the optimal loading levels for arm WAnT in individuals with differing levels of cervical SCI. Level of SCI and resistance-loading level of WAnT served as the independent variables and anaerobic power production (W) served as the dependent variable in this study.

METHODS

Subjects

Thirty-nine individuals (33 males, 6 females) with neurologically complete cervical level SCI (C5–C7) participated in this investigation. The total subject pool was obtained from a convenience sample and included three groups of subjects differing in injury level, with 13 subjects each at the C5, C6, and C7 levels. Injury level and degree of completeness were determined from a motor and sensory physical examination that used the International Standards for Neurological Classification of Spinal Injury [1]. Subject characteristics of the three study groups are provided in **Table 1**. All subjects were at least one year post-injury. Subjects were apparently healthy and were not taking any medications that would affect test results. All testing procedures were verbally explained in detail, and subjects provided written, informed consent before they participated, in accordance with the guidelines established by the Institutional Medical Sciences Subcommittee for the Protection of Human Subjects at the University of Miami.

Wingate Testing Procedures

The WAnT sessions were performed on a Monark 834E leg cycle ergometer (Monark, Varberg, Sweden) that was modified for arm cranking, which was securely mounted to a height-adjustable table [7]. Values of anaerobic power were determined with the SMI Optosensor 2000 (Sports Medicine Industries, Inc., St. Cloud, MN, USA) system. The SMI Power software calculates power output for each second of the test as a function of the resistance load applied to the flywheel and the velocity of the flywheel as measured with an optical sensor attached to the ergometer frame. The power parameters computed and used in this study included peak power output (P_{peak}), taken as the highest power output measured during any 5 s period, and mean power output (P_{mean}), which is the average power output sustained throughout the 30 s test.

Each subject attended a preliminary session to become familiar with the WAnT procedure and to have their body mass determined. Subjects were weighed in their wheelchairs on a floor scale, and the wheelchairs were also weighed. Body mass was operationally defined

Table 1.
Subject demographics.

Characteristics	C5	C6	C7
n	13	13	13
Gender	M = 10, F = 3	M = 11, F = 2	M = 12, F = 1
Age (yr)	31.0 ± 11.7	35.2 ± 9.2	41.3 ± 16.1
Body Mass (kg)	77.5 ± 18.3	75.6 ± 17.9	73.6 ± 13.3

M = male
F = female

as the difference of those two measurements. Within 14 days of the preliminary session, six assessment trials of WAnT were performed. Two test bouts were completed on each of three different test days, with at least 72 h between test days and at least 20 min between test bouts. The six WAnT trials applied resistance loads equivalent to 1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 percent of each subject's body mass, in randomized order. Previous investigations have determined that 3.5 percent of body mass is appropriate for arm WAnT when testing persons with paraplegia [7]. We reasoned that the proper resistance loading for WAnT in persons with tetraplegia would likely be less than (or possibly equal to) that used with persons with paraplegia, because they have less active muscle mass under volitional control.

Subjects performed the WAnT seated in their own wheelchairs, wearing leather gloves to secure their hands to the ergometer handgrips. The height of the table was adjusted such that the arm crank axis was horizontal to the subjects' shoulder joints. Wheelchairs were positioned to allow for a slight bend in the elbows at the point of maximal arm extension.

As a warm-up activity, subjects performed 3 to 5 min of unloaded arm cranking before the WAnT session began. Subjects were then directed to progressively increase their pedaling cadence (without resistance applied) to their own maximal velocity. The resistance load was applied, and the subjects were verbally encouraged to crank as rapidly as possible for 30 s. Following each bout, the ergometer freewheel was unloaded to allow for a 1 to 3 min cooldown. Each of the three test sessions of WAnT included two cranking bouts, with a recovery period of approximately 20 min between bouts.

STATISTICS

Values of power output were generated in 1 s increments across each of the six 30 s arm WAnTs for each subject. The 1 s data were then averaged into six periods, with each period encompassing 5 s. As the study data did not fulfill the requirements for parametric analyses, the primary outcome measures of this investigation, P_{peak} and P_{mean}, were examined with Friedman's two-way analysis of variance, by ranks in each of the three subject groups. When appropriate, post hoc examination between loading levels was performed with the use of tables of critical values. Statistical significance was accepted at the $p < 0.05$ level.

RESULTS

All subjects completed a total of seven arm WAnTs (one familiarization and six testing) without complications. All 13 subjects in the C7 group were able to produce cranking movements for 30 s across all loading levels. In contrast, only one subject in the C6 group was able to complete the test with 3 percent of body mass, and none of those C6 subjects finished at the 3.5 percent loading level. None of the subjects in the C5 group were able to complete 30 s of WAnT at the 3.0 or 3.5 percent workloads, and only one subject was able to do so at the resistance level of 2.5 percent of body mass, and three at 2.0 percent of body mass.

Figure 1 displays the mean P_{peak} values across the six levels of resistance loading for the three subject groups. Visual inspection reveals dramatic differences between groups, with significantly greater values of mean P_{peak} with descending levels of injury. Statistical analyses indicated that each of the three subject groups displayed similar relationships between the P_{peak} measurements across the six loading levels. Subjects demonstrated significantly greater peak values of power when performing the WAnT assessments with resistance loads equivalent to 3.0 and 3.5 percent of body mass than when using loads of 1.0, 1.5, or 2.0 percent ($p < 0.05$).

The values of P_{mean} for each of the three subject groups are shown in **Figure 2**. Similar to P_{peak}, these values differed between groups with C7 > C6 > C5 across all loading levels. However, each of the three groups displayed different optimal loading levels for P_{mean}. Subjects in the C7 group displayed significantly greater values at the 2.5, 3.0, and 3.5 percent of body mass resistance loads than at 1.0 or 1.5 percent loads. In the C6 group, subjects produced significantly greater values of P_{mean} at resistance loads of 1.5 or 2.0 percent body mass than at the 1.0, 3.0, or 3.5 percent levels. Subjects with the highest level of SCI, the C5 group, established significantly greater P_{mean} at the 1.0 and 1.5 percent resistance load levels compared with values from the loads of 2.5, 3.0, and 3.5 percent. (All $p < 0.05$.)

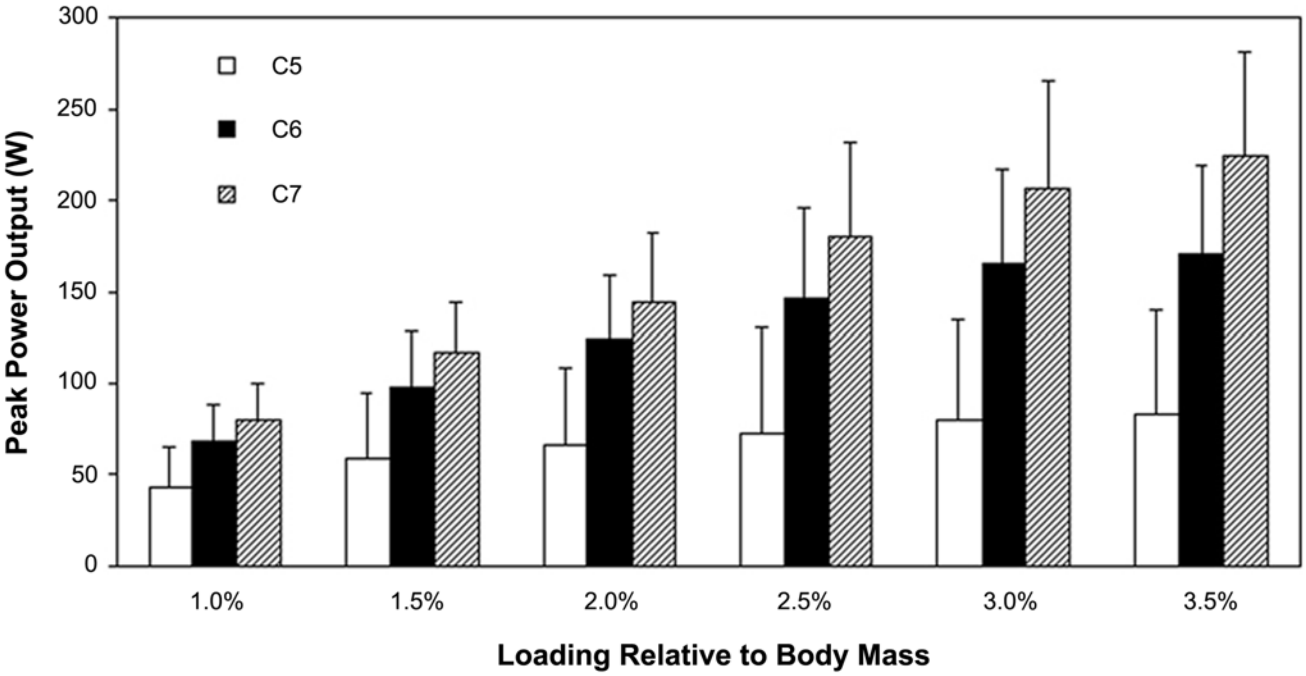

Figure 1.
Peak anaerobic power (W) during variable loading of arm WAnT testing in persons with SCI tetraplegia.

DISCUSSION

The performance of ADLs by individuals with motor-complete, cervical-level SCI is limited by the magnitude of muscular forces that can be established within the upper limbs. Previous exercise studies in this population have generally focused on the effects of endurance training with wheelchair propulsion or arm cranking [8,9]. The performance of ADLs, such as weight transfers and wheelchair propulsion up an incline, require high-intensity muscular efforts of limited duration [7,10,11]. The clinical assessment of the ability to perform such ADLs has traditionally focused on the performance of the tasks themselves, as there are limited laboratory protocols available for the appraisal of upper-limb power in this population. While WAnT has been successfully applied in various groups and has proven a valid and reliable clinical measure, its application in persons with tetraplegia has been hampered by the lack of fundamental research studies with this group.

The results of our investigation indicate that the resistance loading for the greatest values of P_{peak} in persons with SCI at C5–C7 levels, is 3.0 or 3.5 percent of body mass, regardless of the level of injury. However, the loading for the greatest values of P_{mean} varied between levels of tetraplegia, and subjects in the C5 and C6 groups were unable to complete 30 s of cranking at the 3.0 and 3.5 percent loads. Therefore, we suggest that the future application of WAnT in this population include applying the resistance loads that produce the greatest values of P_{mean}. Our investigation finds that WAnT will produce the greatest values of P_{mean} in persons with SCI at the C5, C6, and C7 levels when applying resistance loading of 1.0 or 1.5 percent, 1.5 or 2.0 percent, and 2.5, 3.0, or 3.5 percent of body mass, respectively. The values of P_{peak} and P_{mean} for each of the three groups in our investigation are presented in **Table 2**. We examined WAnT by level of SCI, as determined using the ASIA motor/sensory scales [1]. We note that this approach may allow a degree of variation in triceps strength, a vital component involved in arm ergometry, between subjects with the same level of SCI. However, this approach was selected to provide a simple strategy that might be more readily accepted in clinical and sporting settings.

The appropriate loading levels for arm and leg WAnT have been determined in various populations. Leg anaerobic cycle testing is generally performed with 7.5 to 10 percent resistance loading, with greater loads applied in

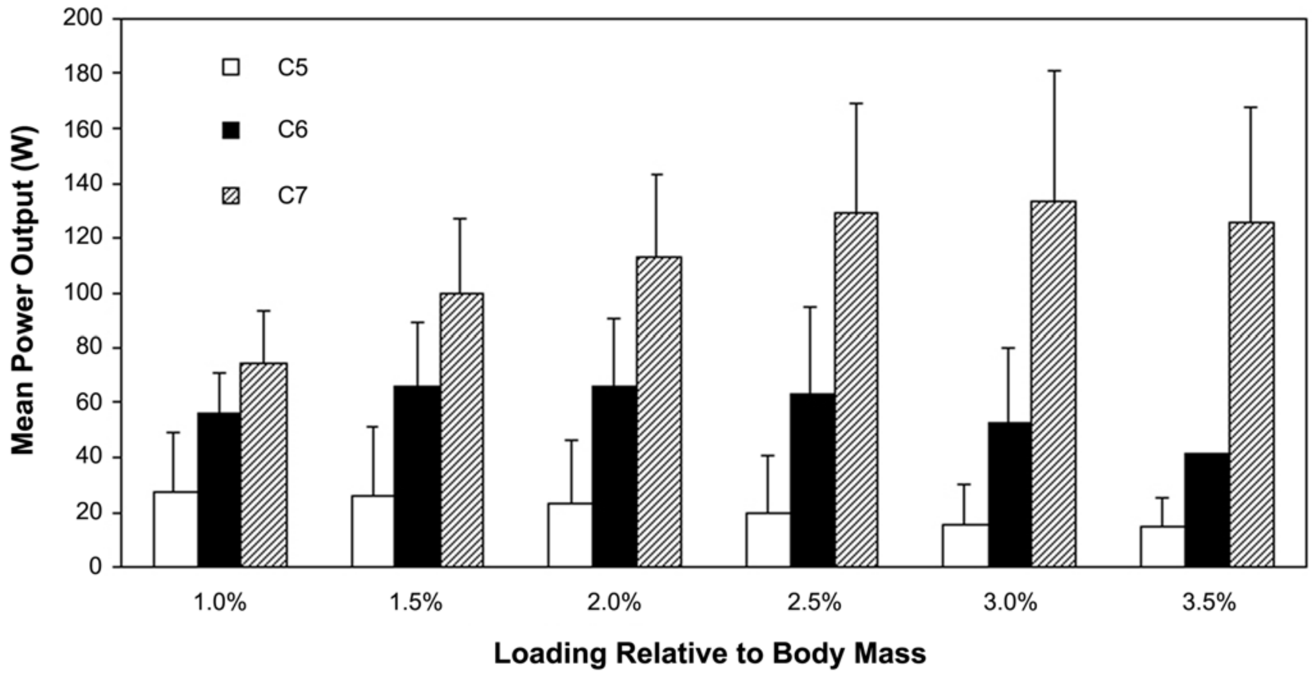

Figure 2.
Mean anaerobic power (W) during variable loading of arm WAnT testing in persons with SCI tetraplegia.

more fit and athletic groups [12–14]. Research has indicated upper-limb WAnT should generally be performed with resistance loads ranging from 3.5 to 7.0 percent of body mass, again depending on the population [5,15,16]. Previous studies in persons with paraplegia have indicated that optimal power output is produced when external loads of 3.5 percent are applied [7]. Thus, the optimal level of loading for WAnT is directly related to the amount of muscular force that can be generated and therefore associated, to some degree, with the amount of muscle mass than can be utilized in the generation of those forces. Persons with tetraplegia have dramatically less active muscle mass available for volitional control, produce much less force than other groups, so they require quite low amounts of resistance loading compared with other groups.

Table 2.
Power output values of persons with tetraplegia.

Power Output (W)	C5	C6	C7
P_{peak}	83.2 ± 57.2	171.3 ± 47.5	224.5 ± 56.8
P_{mean}	27.5 ± 21.4	66.4 ± 24.0	133.1 ± 47.9

Objective outcome measures are necessary for the evaluation of both program and individual progress. Effective rehabilitation outcome measures are specifically necessary for the advancement of evidence-based rehabilitation medicine. Outcome measures that are relatively inexpensive and easy to use, and that have actual clinical application, are most likely to be retained and utilized. Our study addresses a relatively short and simple means of assessing anaerobic power capacity. However, we used an ergometer fashioned from a standard WAnT leg-testing cycle that was slightly modified to allow arm testing. We recommend that future efforts develop an ergometer specific to arm WAnT testing for the assessment of upper-limb anaerobic power in wheelchair users and the nondisabled. We also recommend that future research investigations establish the reliability of WAnT in persons with tetraplegia.

CONCLUSION

The clinical assessment of upper-limb strength and power is essential for the rehabilitation process of individuals with SCI tetraplegia. The WAnT was originally developed for the nondisabled and athletic populations and has since been found to be feasible, reproducible, and highly reliable for individuals with lower-limb neurological disorders such as SCI. However, the optimal resistance loads had not been previously determined for individuals with SCI tetraplegia. Our investigation was performed to determine the appropriate resistance loads for WAnT in individuals with differing levels of cervical-level (C5, C6, C7) SCI. The results revealed that the greatest resistance loads for the three groups were 1.0 or 1.5 percent, 1.5 or 2.0 percent, and 2.5, 3.0, or 3.5 percent of body mass for the C5, C6, and C7 levels of SCI, respectively.

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