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Original Article

HEART RATE AND PERCEIVED EXERTION RESPONSES TO PROTOCOL INCREMENTAL SPEED DYNAMOMETRY FOR WHEELCHAIRS

RESPOSTAS DA FREQUÊNCIA CARDÍACA E DA PERCEPÇÃO SUBJETIVA DE ESFORÇO A UM PROTOCOLO DE VELOCIDADE INCREMENTAL EM DINAMOMETRIA PARA CADEIRAS DE RODAS

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RESUMO
Para verificar as respostas cardíacas e perceptivas a um protocolo de incremental no dinamômetro para cadeiras de rodas, oito voluntários foram selecionados intencionalmente, e avaliados numa sessão experimental usando um dinamômetro compacto para cadeiras de rodas. Uma cadeira de rodas padronizada foi utilizada por todos os participantes. Após período de familiarização, realizou-se um protocolo progressivo, com incremento de velocidade de 5% por minuto. A frequência cardíaca (FC) e a percepção subjetiva de esforço (PSE, 6-20) foram medidas ao final de cada minuto. A FC no estágio 8 foi maior em comparação aos estágios 1 e 2. A PSE diferenciou-se nos primeiros 5 estágios. Verificou-se alta correlação entre a FP e a FC (r=0,93; p=0.0006), e entre a FC e a PSE (r=0,98; p<0.0001). Concluiu-se que o equipamento possui especificidade para avaliações de variáveis cinéticas e cinemáticas do movimento em cadeiras de rodas, em detrimento das variáveis cardíacas.
Palavras-chave: Locomoção. Pessoas com deficiência. Sistema cardiovascular.

ABSTRACT
To check the cardiac and perceptual responses an incremental protocol on the wheelchair dynamometer, eight volunteers were intentionally selected and evaluated in an experimental session using a compact dynamometer for wheelchairs. A standard wheelchair was used by all participants. After familiarization period, there was a progressive protocol, increasing rate of 5% per minute. Heart rate (HR) and rating of perceived exertion (RPE, 6-20) were measured at the end of every minute. HR on stage 8 was higher compared to the stages 1 and 2. The RPE differed in the first 5 stages. There was a high correlation between FP and FC (r = 0.93; p = 0.0006), and between HR and RPE (r = 0.98; p <0.0001). It was concluded that the equipment has specificity for evaluation of kinetic and kinematic variables of the movement in wheelchairs at the expense of cardiac variables.
Keywords: Locomotion. People with disabilities. Cardiovascular system.

Introduction

For wheelchair users (WUs), daily movement and overcoming barriers require high levels of power and muscle strength[1]. Quantifying the determinants of physical capacity in WUs is important for them as well as many health care professionals such as kinesiologists, physicians, and physiotherapists. Evaluation of the kinetic aspects in hand-rim propulsion in manual wheelchairs is fundamental for diagnosis of injury, overuse, disability, and functional capacity for daily living and athletic performance.

Ergometric equipment was developed to measure or estimate the maximum capacity of muscle exertion in WUs. However, most equipment disregards the movement ergonomics[2], have oversized[3,4] and complex calibrations[5], and are restricted to therapeutic analysis laboratories. Recently, Oliveira et al[6] developed and validated a compact roller dynamometer to evaluate wheelchair propulsion using a simple, small device. In the context of sports and exercise science, ergometers measure the amount of work required during physical effort[7] and dynamometers measure strength[8]. In contrast, the literature on exercise for WUs uses the terms interchangeably, reflecting a theoretical mistake that translates to clinical practice. Therefore, verifying the scientific purpose of new equipment is needed to better understand the tools that evaluate physical performance in WUs. It will also contribute to the development of a guideline for ergometer and dynamometer protocols that can be used in real world settings.

When utilizing ergometers or dynamometers for training evaluation in exercise and sports, it is necessary to consider the physiologic parameters that indicate response to physical effort[9]. Therefore, for accurate estimation of heart rate (HR) and oxygen consumption, tests and ergometric training are usually controlled and evaluated by chronotropic response, which provides evidence of increase/decrease in the level of oxygen sent to active muscles[10]. Because of this, the increase in HR as a result of incremental exercise becomes indicative of energy expenditure and, consequently, aerobic capacity.

In contrast, equipment with dynamometric characteristics such as handgrip and isokinetic dynamometers, can evaluate and predict muscle strength and power during training protocols[11]. For dynamometers that measure effort, a smaller cardiovascular response is expected, because a majority of cases have shown that a smaller number of muscles are involved in these movements[12]. Though the responses of heart rate and perceived exertion are well consecrated at the literature, these phenomena have yet to be clarified with a view to the development of new equipment for the physical evaluation and athletic performance.

For practical applications, knowledge of the specificity of the responses measured by the roller dynamometer designed for WUs has fundamental importance for health care professionals who work with this patient group, and can help develop protocols that match the physical capacities evaluated. The aim of this study was to verify the specificity responses (cardiovascular and perceptual) of mean roller dynamometer results by using an incremental speed test protocol at variable propulsion frequency (PF). Due to specificity of the equipment, we hypothesized there is no relation between speed increment with the Dynacom and the chronotropic response of the subjects. Additionally, we hypothesized that there is no significant difference between HR at different stages of the protocol and response to speed increment.

Methods

Research and volunteer selection

This study is descriptive, correlational,[13] and cross-sectional in design. The study protocol was approved by the Ethics Committee on Human Research of the University of Pernambuco. The study sample was selected intentionally. Eight healthy subjects without experience with using manual wheelchairs were enrolled based on the results of the Physical Activity Readiness Questionnaire (2002 version). This instrument is compost of seven questions with dichotomous answers, "yes" or "not". If any volunteers answered "yes" to a question, I would not be able to realizer physical effort and could not be included in the search. No subject sample answered "yes", all being included in the following phases of the study. The descriptive data of the subjects involved are presented in Table 1. All experimental sessions took place at the Assessment Laboratory of Human Performance under conditions controlled for temperature (24°C) and relative humidity (44%H_2O).

We chose non-WUs for our study because the natural locomotor adaptations due to daily use of wheelchairs can result in chronotropic responses and lower perceptive responses[14,15], and in WUs with spinal cord injury, the use of drugs that interact with the autonomic nervous system can, in the same way, modify the chronotropic responses from the individuals, especially for those with autonomic dysreflexia episodes[14].

Equipment description

The Compact Wheelchair Dynamometer (DYNACOM; Figure 1) is constructed to accommodate the weight of system subject-wheelchair. It has a system of 2 cylinders (Easy Scroll, Ribeirão Preto, Brazil) arranged in parallel and connected to a supporting system by their axes. The system comprises 3 cylinders separated by 2 different distances (0.10 to 0.20 m), so that higher effects and lower rolling resistance can be produced when in use. The instrumented cylinder also has 2 inductive rotational sensors (SensorBrás, Campinas, Brazil) on its central point of junction. Each cylinder has a length of 0.45 m, a perimeter of 0.24 m, and mass of 1.6 kg.

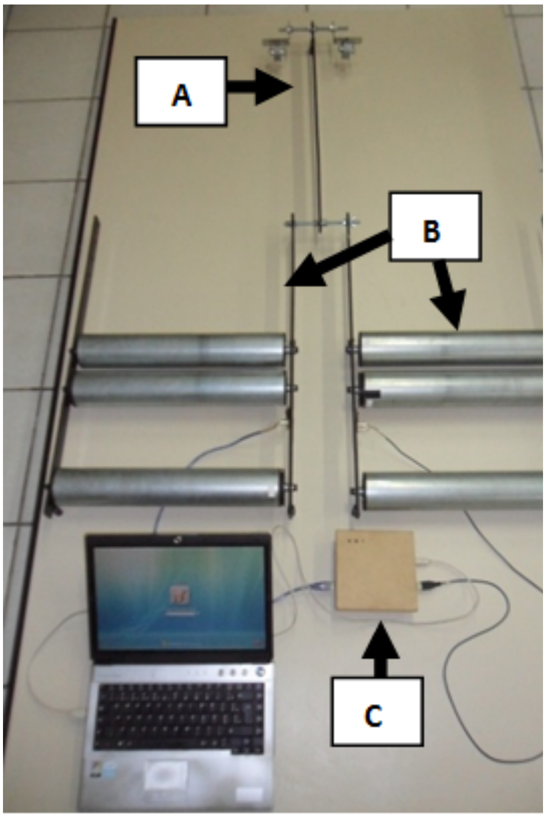

Figure 1. Top view of DYNACOM and its components parts. (A) Inertial dynamic calibration system; (B) Parallel rollers for mobility; (C) Digital-analog converter board
Source: The authors

For acquisition of the electronic signals, we used Arduino and open software, an open-source computer based on a simple microcontroller board, and a development environment for writing software for the board (Arduino®, Italy). For this communication, we used inductive sensors to count the rotations per minute (rpm) developed by the cylinders. The board was properly programmed to read interval signals less than a second, and at the same time, their signals were transmitted to the Software Microsoft Excel 2007 via the serial communication protocol PLX-DAQ (Parallax, Califórnia, United States), with possible construction of graphics, and accumulation and recording data. It is worth mentioning that we only used the mechanical part of the equipment (cylinders and security strips) for all the procedures.

General procedures

Initially, upon arrival in the laboratory, a single trained evaluator assessed the subjects' anthropometric measurements using internationally standardized procedures from the International Society of Advancement of Kinanthropometry[16]. The anthropometric measurements of the volunteers were collected using the skinfold adipometer model Lange (Santa Rosa, United States), a mechanical balance with an accuracy of ± 0.1 kg (Filizzola, São Paulo, Brazil), and a stadiometer with an accuracy of ± 0.1 cm. Body composition was evaluated according to the Jackson and Pollock protocol[17]. The evaluator was certified by the International Society for the Advancement of Kinanthropometry level 1. The volunteers were positioned on a wheelchair placed on a Dynacom. The wheelchair used was a specialized basketball wheelchair. The tires were calibrated at full inflation before each test with 0°icamber axes to reduce the rolling resistance effect[18]. All subjects were properly acquainted with the equipment before the test start. The adjustments of the wheelchair on the Dynacom are shown in Figure 2.

Figure 2. Tires of the wheelchair fixed by a roller dynamometer. Red arrows show the belts for lateral movement of the wheelchair.

Fonte: The authors

Incremental speed protocol

All volunteers went through a period of familiarization to the equipment. During this period the volunteers had the opportunity to handle the wheelchair between synchronous and asynchronous propulsion strategies, and with different frequencies and drive speeds. In this period, some guidelines were passed by the researchers, so that there remained any questions about the study protocol. After being positioned on DYNACOM and familiarized with the equipment, the volunteers were instructed to move the propulsive hand rims at a comfortable speed in a synchronous manner for 2 minutes. In the last minute of the warm-up, 2 independent evaluators visually analyzed the level of propulsion and considered it the freely chosen frequency propulsion (FCF), according to procedures already performed[19]. If there was no agreement on the values, another attempt would be made. The subjects followed a pace set by metronome (M & M Systems, Braugasse, Germany), with a rate of propulsion per minute (PPM) increased by 10% of the FCF at the end of each minute. The test was stopped if the subject did not follow a metronome pace, reported pain or excessive discomfort in the upper limbs, or voluntarily stopped. HR was continuously monitored by an electronic monitor (Polar, model FT1, Kempele, Finland), and the rate of perceived effort (RPE) was assessed with the Borg RPE scale, from 6 to 20[20]. The Borg scale was presented to each volunteer in a clipboard, so everyone could see the response options clearly.

Statistical Analysis

The normality (Shapiro-Wilk) and homoscedasticity (Levene) tests were performed to determine the central tendency and variability. Considering the time needed to analyze the cardiovascular responses and perceived exertion in ergometric tests, we considered only the data from subjects who completed a minimum of 8 stages of the incremental protocol, in 8 minutes of aerobic physical effort[21]. To determine the effectiveness of loading increments at each stage of the protocol, as well as the cumulative effect of physiologic strain parameters of the subjects (HR and Borg RPE scale) variance analysis for repeated measures (1-way analysis of variance) was used. The assumptions of sphericity in repeated measurements were tested by Mauchly test. For variables with violation of this assumption, we decided to make the correction Geisser-Greenhouse's epsilon, according to the recommendations of Field (2009).

To analyze the specificity of the equipment, we verified the Pearson product-moment correlation coefficient (r) between the frequency in PPM, HR (bpm), and RPE. All the analyses were performed with a bicaudal model using the software SPSS 20.0 (IBM, USA), and Graphpad Prism 5.0, and a $P \leq .05$ (5% of significance) was considered significant.

Results

The anthropometric characteristics of the volunteers are described in Table 1. All volunteers completed a minimum of 8 stages or 8 minutes of aerobic exercise.

Table 1. Descriptive data from anthropometry, heart rate, and propulsive frequency of the volunteers.

Variables	Average	SD	Minimum	Maximum
Age (y)	19.71	2.25	18.00	25.00
Weight (kg)	69.60	13.68	56.80	96.80
Height (cm)	174.15	6.42	165.40	186.50
BMI (kg/m^2)	23.06	5.06	17.65	33.49
Body fat (%)	9.73	4.49	3.11	17.93
Fat mass (kg)	7.05	3.98	1.84	13.15
Lean mass (kg)	62.55	10.95	52.96	84.52
HR (bpm)	71.63	12.21	52.00	96.00
PF (ppm)	71.14	12.14	52.00	96.00

Legends: body mass index (BMI); heart rate (HR); propulsion frequency (PF)
Source: The authors

The selected volunteers had reasonable body mass index (23.06 ±h5.06) and body fat (9.73 ±.4.49), constituting a sample of euthrofic subjects. The results of the 3 variables in accordance with the stages completed by all subjects are presented in Figure 3. All eight volunteers completed the eight stages of the proposed incremental protocol.

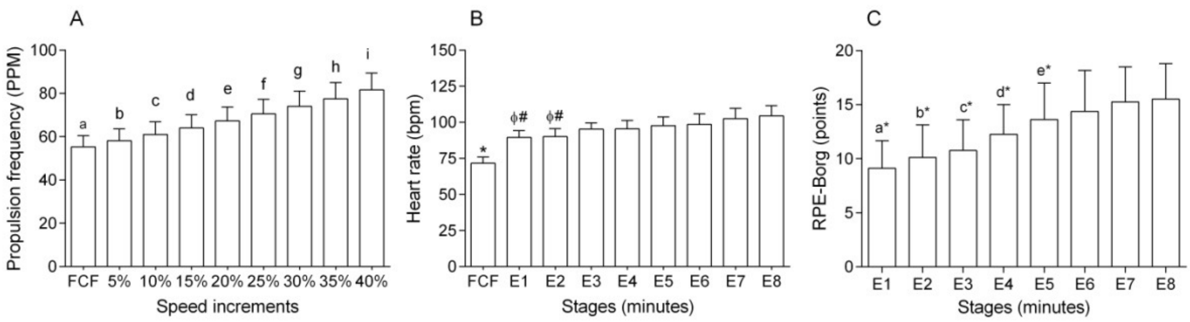

Figure 3. Analysis of propulsive frequency, heart rate, and perceived exertion in response to the incremental speed protocol from the freely chosen propulsion frequency; Panel (A) comparison of the PF (PPM) among the 8 stages analyzed (ANOVA). (i) Statistically significant differences ($P < .05$) among all FPF values; Panel (B) Comparison of the HR between the stages of the incremental exercise protocol (ANOVA).

Statistically significant difference ($P<.05$) in the HR at stages 1 and 2. φ.# Statistically significant difference between stages 1 and 2 and the stage 8; Panel (C) Comparison of the RPE between the stages of incremental exercise protocol. a (difference between E1 to E4, E5, E6, E7 and E8), b* (difference between E2 to E5, E6, E7 and E8), c*(difference between E3 to E5, E6, E7 and E8), d*(difference between E4 to E5, E6, E7 and E8); e*(difference between E5 to E7 and E8). N=8

Source: The authors

The increase in speed in each subject was significantly high in all stages of the protocol (Figure 3, panel A, *P* < .05). HR (Figure 3, panel B) showed an increase at all stages of the incremental protocol. However, differences (*P* < .05) were only observed between 1 and 2 minutes compared with the last minute of the protocol.

RPE also increased at all stages of the protocol (Figure 3, panel C). In contrast, RPE only significantly differed until the fifth stage of the incremental protocol compared with that in the later stages (*P* < .05). The RPE responses to the proposed incremental protocol were statistically significant when comparing the stages 1, 2, 3 and 4 on stages 5, 6, 7 and 8, respectively (p <0.05). Additionally, in stage 5 volunteers exhibit lower RPE in relation to the stages 7 and 8 (p <0.05). The RPE responses stabilized from the sixth minute of the protocol.

Figure 4 shows the results of an incremental protocol, with the FCF resulting in an increase in HR (panel A) in a similar manner to RPE (panel B), for all eight subjects tested.

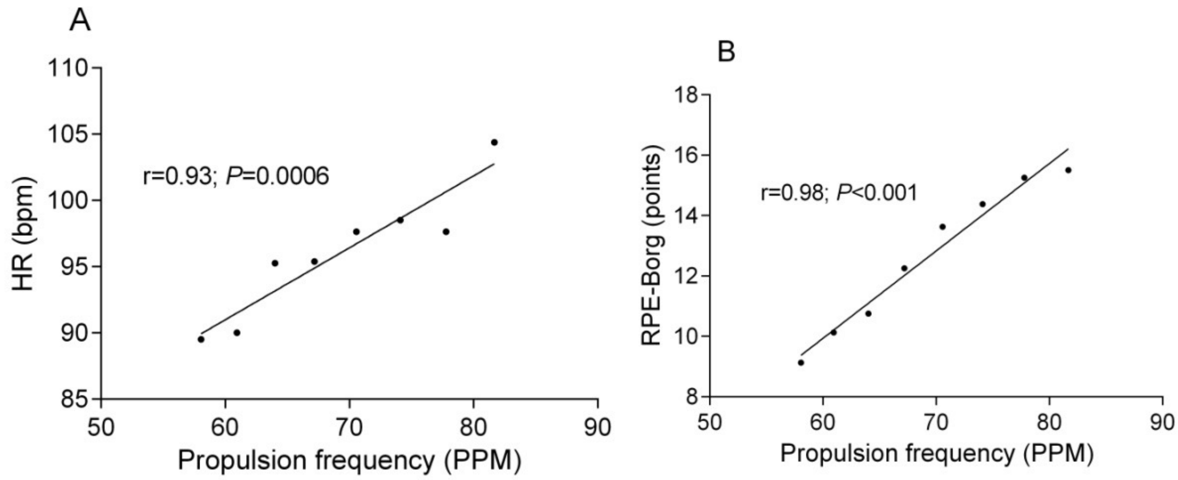

Figure 4. Correlation between the increase in propulsive frequency and the responses of heart rate and perceived exertion every minute of the exercise protocol; (A) Pearson correlation between HR (bpm) and the PF (PPM); (B) Pearson correlation between Borg scale points (points) and the PF (PPM). N=8

Source: The authors

Discussion

The main purpose of this study was to verify the HR and RPE responses from healthy volunteers without experience in wheelchair use, obtained by a dynamometer designed for this purpose. Our initial hypotheses were partially confirmed. HR showed a significant relationship with speed increment (*r* = .93; *P* = .0006). In addition, HR also showed a relationship with RPE (*r* = .98; *P* < .0001).

Previous studies have shown a strict relationship between speed (or quantity) increment and body movements, HR, and oxygen consumption. Increased muscle activity in addition to resistance to movement increased the requirement for oxygen by these muscles[22]. In the case of the specific use of manual wheelchairs for locomotion, specific values of propulsive frequency are related to increased movement and energy expenditure economy[23]. This behavior would be related to the protecting effects of the upper limb muscles[24].

We did not use specific PFs for the test protocol. It was designed to include the ergometric characteristics of the chosen effort. However, the HR increments were significant only from the first to the second and third minutes. In general, considering the analyzed group average, a 40 bpm increase in HR was noted (Table 1) from the rest moment to the end of the activity. Although this increase has been linear with FCF, it is according to what has been found in other studies[23,25].

This increase can be explained by some aspects. The locomotion movement in wheelchairs is considerably less efficient than that with other locomotion modes[26]. In this case, even experienced WUs showed inadequate oxygen consumption and energy expenditure, which also reflects the linear increase in HR in response to the speed increments. Another aspect that should be considered is the relative contribution of other body segments to the speed increment. An increased contribution of the thorax is observed at higher locomotion speeds in a wheelchair[27,28].

The participants were not familiarized with the Borg RPE scale (6-20), the unusual low amplitude movement, constant repetition, and high speed. This may have affected the effort perception in sedentary subjects, since they were not accustomed to use their shoulder so repeatedly, creating an increased sense of effort, which could have resulted in a global inadequate perception.

The results of this study provide relevant information on the specificity of tools to evaluate sports performance or training in Wus. Although a correlation between HR and PF was seen, the Dynacom may not provide sufficient overload to the wheelchair, and required a mechanical brake system to increase the physical effort of the active muscles, which will increase muscle contraction[29].

This seems to be a crucial aspect distinguishing DYNACOM from the other ergometric equipment. The brake's additional load, which is seen in cycle ergometers and manual ergometers, requires greater strength and power production from the muscles, and is not recommended in individuals with severe conditions such as muscle dystrophy and sclerosis[30].

The speed increment was added from the FCF obtained at the beginning of the protocol. FCF was determined according to the comfortable speed maintained by each subject during the warm up session. There was a 5% increment in speed from the initial stage and throughout the test, prompted by a sound stimulus from a metronome, to control the rhythm of the subject.

Our results show that the HR and analyzed stages did not differ statistically, except between the first 2 stages and the later stages. We found that the analyzed equipment does not have adequate ability to prompt important adjustments in cardiovascular parameters, which proves its specific utilization only for evaluating and training for developing propulsive strength and enhancing strength, which are essential in the daily routine of WUs.

Future studies should focus on developing normative standards for the utilization of DYNACOM; differentiating between responses of propulsive strength and power in individuals with severe disabilities; and comparing this tool with other equipments for manual propulsion in terms of strength and power. Additionally, we showed a high and linear correlation between HR, RPE, and PF, which indicates the need for specific scales to determine the effort permissible during exercise in the upper limbs, especially in WUs.

For practical implications, we can interpret those stationary dynamometers such as the equipment used in this study, should be part of the training and assessment of manual propulsion capability for individuals who use manual wheelchairs, only for muscular power of physical fitness and sports training purposes. However, if the goal is the physical conditioning or the assessment of cardiovascular function, wheelchair ergometers with electromechanical brake system should be chosen. Other studies can be conducted to quantify the effort of persons with disabilities in manual wheelchairs with analogue scales or kinetic propulsion protocols.

Conclusion

We conclude that effort protocols performed through increased speeds or frequencies carried out in a DYNACOM promote insufficient increases in heart rate and are not recommended for evaluation of cardiovascular components of the wheelchair effort. Therefore, the DYNACOM is a valid and specific device for assessments of kinetic variables of mobility in wheelchairs, and not for cardiovascular or metabolic variables in this form of locomotion.

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