Original Article

Acta FISIÁTRICA
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Handgrip fatigue test using dynamic contractions in typical children

Teste de fadiga de preensão manual usando contrações dinâmicas em crianças típicas

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Conflict of Interests
Nothing to declare

Submitted: February 14, 2023
Accepted: April 28, 2023

How to cite
Martins EJ, Franco CSB, Zaparoli L, Ravanelli LS, Camargo MV, Mattiello-Sverzut AC. Handgrip fatigue test using dynamic contractions in typical children. Acta Fisiátr. 2023;30(2):105-110.

DOI: 10.11606/issn.23170190.v30i2a208192

Funding
Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), Processos nº 2017/17596-4 e 2019/19553-6
Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Processo nº 2020-00/88887.586702
Fundação de Apoio ao Ensino, Pesquisa e Assistência do Hospital das Clínicas da Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo (FAEPA)

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Instituto de Medicina Física e Reabilitação – HCFMUSP

ABSTRACT

Objective: To verify the development of fatigue and sex-influence on the handgrip during dynamic contractions in typical children. **Methods:** Cross-section study. Fifty-eight children, distributed into two groups according to sex (30 boys), aged 8 to 12 years, of both sexes, performed successive dynamic contractions with a bulb dynamometer until they reached maximum perceived effort. The values from the first, the last contractions of the fatigue test, and the measure after 30-s of the last contraction (recovery contraction) were recorded and compared using the linear regression model with mixed effects. T-Student test was used to compare the perceived effort scores and time-to-fatigue between groups. **Results:** The handgrip values significantly decreased, and perceived effort scores significantly increased in the final measure in relation to the initial measure of the fatigue test. After the fatigue handgrip test, 30-sec of recovery was insufficient to restore the baseline handgrip values. There were no differences between the female and male groups for all variables. **Conclusion:** The handgrip fatigue test using dynamic contractions showed it efficiently induces motor and perceived fatigue in children, without differences between sexes.

Keywords: Hand Strength, Muscle Strength Dynamometer, Fatigue, Child

RESUMO

Objetivo: Verificar o desenvolvimento da fadiga e a influência do sexo na preensão manual durante contrações dinâmicas em crianças típicas. **Métodos:** Estudo transversal. Cinquenta e oito crianças, distribuídas em dois grupos de acordo com o sexo (30 meninos), com idades entre 8 e 12 anos, de ambos os sexos, realizaram sucessivas contrações dinâmicas com um dinamômetro de bulbo até atingirem o esforço máximo percebido. Os valores da primeira, da última contração do teste de fadiga e da medida após 30 segundos da última contração (contração de recuperação) foram registrados e comparados usando o modelo de regressão linear com efeitos mistos. O teste T-Student foi usado para comparar os escores de esforço percebido e o tempo até a fadiga entre os grupos. **Resultados:** Os valores de preensão palmar e os escores de esforço percebido diminuíram significativamente durante o teste de fadiga. Não houve diferenças entre os grupos para todas as variáveis. **Conclusão:** O teste de fadiga de preensão palmar utilizando contrações dinâmicas mostrou-se eficaz na indução da fadiga motora e percebida em crianças, sem diferenças entre os sexos.

Palavras-chaves: Força da Mão, Dinamômetro de Força Muscular, Fadiga, Criança

INTRODUCTION

Children and teenagers have been spending increasingly more hours using electronic devices, such as smartphones, video games, tablets, and computers, either for school activities or for leisure. The excessive use of these devices has been associated with several health problems, such as headache, obesity, anxiety, stress, sleep disorders, and musculoskeletal pain and fatigue.[1,2]

Recent studies have shown that both healthy children and adolescents, aged 9 to 15 years,[2] and adults, aged 18 to 24 years,[3] of both sexes, with high levels of daily smartphone use, showed decreased handgrip strength and the functional capacity of their hands during daily activities, such as opening a tight or new bottle, washing their backs, and using a knife to cut food. A possible reason for muscle pain and fatigue may be the reduced blood supply due to repetitive hand movements, compromising nutrient and oxygen absorption and metabolic exchange.[2]

Confident instruments and protocols are available in the literature for the assessment of pain[4] and strength[5] related to the upper limbs. An equipment that has been widely used to assess handgrip pressure (HGP) is the bulb dynamometer.[6] The bulb dynamometer is more easy-to-use and affordable instrument compared to Jamar dynamometer,[7] although the first measure grip pressure and the second is used to assess grip strength. Furthermore, normative data on handgrip isometric from Brazilian children (aged 6 to 13 years, using the bulb dynamometer North Coast - NC70154)[8] and Serbian children (aged 4 to 10 years, using the bulb dynamometer Baseline, USA) are available in the literature.[9] Contrarily, for children and adolescents, there is no gold standard protocol for assessing upper limb muscle fatigue.

Motor fatigue-assessment protocols monitored the decrease in force, or torque, during or after the development of successive isometric, concentric, or eccentric contractions.[10] Central mechanisms (such as the decreased recruitment rate of motor units) or peripheral mechanisms (such as an increased lactate concentration), decreased muscle contractile force resulting from disuse, and/or changes in mechanisms related to action potential transmission at the neuromuscular junction are responsible for the progressive reduction in strength/torque during physical efforts.[10] Variables related to the fatigue process should be monitored in order to confirm tissue and local neurophysiological and/or metabolic changes. For this purpose, instruments such as dynamometry, electromyography,[11] perceived exertion scales, and biological markers, such as lactate concentration in the blood test,[12] can be used. Some studies have assessed strength and fatigue during handgrip[13,14] in isometric contractions sustained for 10 seconds[15] and 30 seconds[16] in typical children and adolescents; however, no study has evaluated the development of handgrip fatigue using dynamic contractions. As the functional tasks performed daily mainly involve dynamic contractions, this study aimed to analyze the development of handgrip fatigue using dynamic contractions in typical children. We also investigated the sex influence and total duration of the handgrip fatigue test.

OBJECTIVE

To verify the development of fatigue and sex influence on the handgrip during dynamic contractions in typical children.

METHOD

This observational cross-sectional study was performed at the Ribeirão Preto Medical School of University of São Paulo and in public and private elementary schools in the city of Ribeirão Preto (SP, Brazil). The participants spontaneously accepted to participate in the research through an invitation made to them in the schools. This research was approved by the Human Research Ethics Committee of Ribeirão Preto Medical School of University of São Paulo, reference number CAAE: 63579916.2.0000.5440. All participants and their guardians signed a permission and consent form.

Typically developing participants were recruited from public and/or private schools in Ribeirão Preto and surrounding towns. Participants of the study involved 62 typical children (convenience sample), aged 8 to 12 years of both sexes. The exclusion criteria included cardiopulmonary and neurological diseases, recent upper limb fracture (less than one year), and the inability to understand and perform the handgrip test. From the total sample of 62 children, 4 were excluded due to the inability to understand the test. Thus, 58 children were evaluated, of which 30 were males.

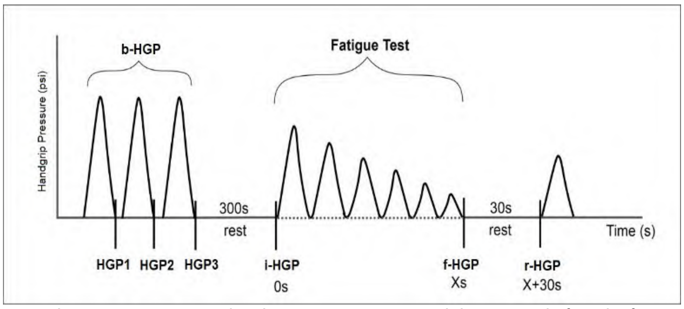
All participants were initially submitted to a physical assessment to obtain anthropometric data (weight and height) and assess the level of physical activity by the Physical Activity Questionnaire for Older Children (PAQ-C). The PAQ-C was designed to assess children aged 8 to 13 years and comprises nine questions that measure different aspects of physical activity performed in the last seven days. The first question collects information about the frequency of weekly physical activity during free time. The next six questions are related to moderate and vigorous physical activity during specific periods of the day. The last two questions identify the level of physical activity during the week and the frequency on each specific day. The questionnaire has an extra question that identifies whether the participants were ill or unable to normally perform physical activities. Children under 10 years of age answered the questionnaire assisted by their guardians.[17]

The handgrip fatigue test was developed using a bulb dynamometer (North Coast®). The children remained in the seated posture with backrest, feet flat on the floor, upper limb with shoulder adduction and neutral rotation, elbow flexion at 90º, neutral forearm and wrist between 0 and 30º of extension, and between 0 and 15º of ulnar deviation, as recommended by The American Society of Hand Therapists.[18] Evaluation was done only for the hand of the non-preferred upper limb since, during the pilot tests, less measure variability was observed between the dynamic repetitions of handgrip in this upper limb compared to the contralateral side.

Before the handgrip fatigue test, all the participants performed three maximal voluntary isometric contractions (MVCs) for 5-s with 20-s rest time between each one. To represent the HGP before the fatigue test, the mean value of these three measurements of HGP (corresponding to HGP 1, HGP 2, and HGP 3) was calculated, and we called it baseline HGP (b-HGP) (Figure 1).[8,19]

Afterward, the participants rested for 300-s. Subsequently, the handgrip fatigue test was performed using successive MVCs, with one-second intervals, standardized by a metronome. The first MVC of the fatigue test was called initial fatigue HGP (i-HGP), and the last MVC of the fatigue test was called final fatigue HGP (f-HGP) (Figure 1). The fatigue test was finished when the participant reported maximum score perceived effort using the visual analogue scale (VAS) and/or inability to synchronize the contractions with the metronome.

Therefore, the time-to-fatigue was different for each participant. Finally, after 30-s of rest, one more MVC was recorded, called recovery HGP (r-HGP) (Figure 1). The participants were verbally encouraged to develop maximum contractions during the test. For analysis, the HGP values at b-HGP, i-HGP, f-HGP, and r-HGP were recorded (in psi), as well as time-to-fatigue (in seconds) and perceived effort scores before and after the fatigue test. The participants were familiarized with the bulb dynamometer previously, using five maximum isometric contractions.



Legend: HGP1, HGP2, HGP3: handgrip pressure measured three times before the fatigue test; b-HGP: baseline handgrip pressure; i-HGP: initial fatigue handgrip pressure; f-HGP: final fatigue handgrip pressure; r-HGP: recovery handgrip pressure; s: seconds; X: unlimited fatigue test time

Figure 1. Schematic representation of the test protocol

The sample's size and power were calculated using the data from a pilot test with 15 children of both sexes. We considered the difference between the means of the HGP recorded at the beginning and the end of the dynamometric test and the largest standard deviation for both female and male groups. Therefore, the estimated minimum sample size was 60 participants, comprising ten individuals in each age group (aged from 8 to 12 years), five of each sex. The statistical analysis was performed using SAS 9.2 software.

Initially, we described the data using absolute and percentage frequencies (qualitative variables) and measures such as mean, standard deviation, median, minimum, and maximum (quantitative variables). The linear regression model with mixed effects (random and fixed effects) was proposed to compare steps with more than one measure per individual. Linear mixed-effects models are used in data analysis in which responses are grouped (more than one measure for the same individual) and where the assumption of independence between observations in the same group is not adequate.[20] We also evaluated the effect of interaction between the experimental protocol steps and sexes. These models assumed that their residues have a normal distribution with a mean of 0 and a constant variance of σ^2. For comparisons, the post-test by orthogonal contrasts was used. Therefore, we assessed whether there was a significant decrease in HGP induced by the fatigue test (i-HGP vs. f-HGP) and if 30 seconds of recovery is enough to restore the

HGP obtained in baseline conditions (b-HGP vs. r-HGP). For the comparison between the perceived effort scores in the initial and final steps of the fatigue test (i-HGP vs. f-HGP) and the comparison between sexes on the total time of the fatigue test, we used the t-Student test (parametric test). All analysis were performed using SAS 9.2 software. For all comparisons, we adopted a significance level of 5%.

RESULTS

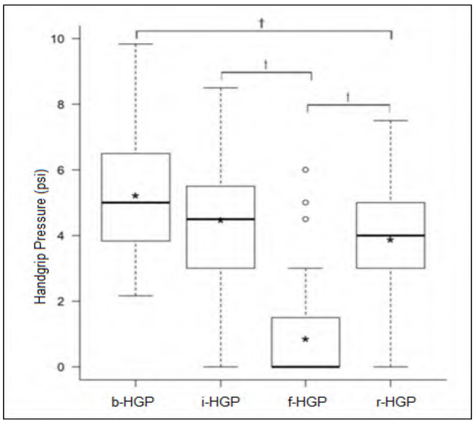
All participants performed the protocol test. Table 1 presents data regarding the mean values (and standard deviation) for age, weight, and height. The preferred limb was the right in 92.8% and 90% of the girls and boys, respectively. The level of physical activity was sedentary to the majority for both girls and boys (Table 1). The mean value (standard deviation) of the time-to-fatigue was 107.7 (43.2) seconds for girls and 122.0 (65.0) seconds for boys, and a statistical analysis of the comparison between the sexes regarding the duration of the fatigue test showed no significant difference (p=0.33) (Table 1). The mean total time of the handgrip fatigue protocol proposed in the present study was 441.7 seconds (6.8 minutes) for girls and 456 seconds (7.6 minutes) for boys.

Table 1. Physical characterization, physical activity level, and mean duration of fatigue test

Variables		Sexes	
		Female	Male
Number of participants		28	30
Age (years)		10.0 (1.4)	9.8 (1.5)
Body weight (kg)		37.2 (11.1)	32.5 (9.5)
Height (cm)		142.8 (10.7)	138.6 (9.0)
BMI (kg/m-2)		18.0 (4.3)	16.7 (3.2)
Preference	R	26	27
	L	2	3
Physical activity level	S	24	23
	A	4	5
Time-to-fatigue (s)		107.7 (43.2)	122.0 (65.0)

Legend: Mean (standard deviation); BMI: body mass index; Preference (R: right; L: left); Physical activity level (S: sedentary; A: active)

The initial statistical analysis showed no significant difference between the sexes for the variables analyzed, and, therefore, we will present the results considering all the participants (n=58). The mean values (standard deviation) obtained in each phase of the test protocol were at b-HGP: 5.22 (1.97); i-HGP: 4.47 (1.88); f-HGP: 0.85 (1.44); and r-HGP: 3.88 (1.57). Figure 2 shows the comparison between the HGP in different steps of the research protocol using a box plot. b-HGP was significantly higher than r-HGP (estimate difference: 1.34; 95% CI: 0.95/1.74; p<0.01). Also of note is that i-HGP was significantly higher than f-HGP (estimate difference: 3.62; 95% CI: 3.23/4.02; p<0.01), and f-HGP was significantly lower than r-HGP (estimate difference: -3.02; 95% CI: -3.41/-2.63; p<0.01) (Figure 2).



Legend: b-HGP: baseline handgrip pressure (before the fatigue test); i-HGP: initial fatigue handgrip pressure; f-HGP: final fatigue handgrip pressure; r-HGP: recovery handgrip pressure; Asterisk (*): Mean; Cross (ł): when p<0.01 in the comparison between the different steps of the test protocol

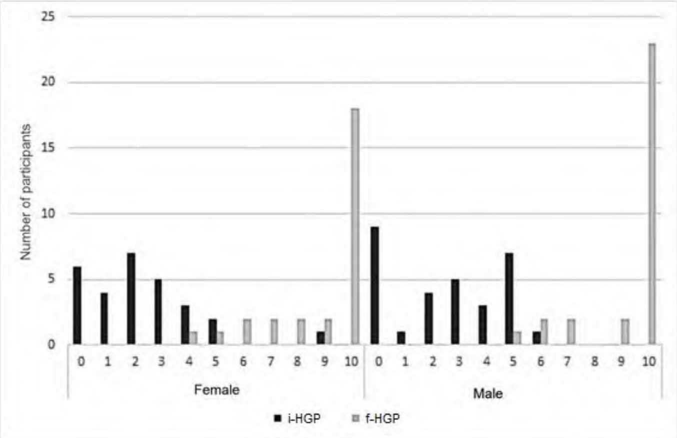
Figure 2. Caption: Handgrip pressure (in psi) for each step of the fatigue test

The analysis of the perceived effort, evaluated by VAS, indicated median values corresponding to score= 2 in the i-HGP and score= 10 in f-HGP. A comparative analysis between the test steps showed significantly higher values at the end of the test (p<0.01) (Table 2). Figure 3 illustrates the frequency of the scores of the perceived effort assigned in the i-HGP and f-HGP steps for males and females.

Table 2. Comparison between the perceived effort scores obtained at initial and final steps of the fatigue test

Steps	Median	Minimum	Maximum	p-value
i-HGP	2	0	9	<0.01*
f-HGP	10	4	10	

Legend: i-HGP: initial fatigue handgrip pressure; f-HGP: final fatigue handgrip pressure. Asterisk (*): when p<0.01 in the comparison of the perceived effort scores obtained at the initial and final steps of the fatigue test



Legend: i-HGP: initial fatigue handgrip pressure; f-HGP: final fatigue handgrip pressure

Figure 3. Caption: Frequency of the scores of perceived effort in the initial and final fatigue test for both sexes

DISCUSSION

The handgrip dynamometric test proposed in the present study respected an individualized performance with unlimited contractions until the participant reported maximum perceived effort. It was able to evoke motor fatigue in typical children since it was observed a significant decline in the final HGP (f-HGP) in relation to the initial HGP (i-HGP). There was no significant difference in HGP between girls and boys, so sex was not an important covariate for motor fatigue development during dynamic handgrip activity in this population. We also observed that the r-HGP values were not completely restored, indicating that 30 seconds of recovery are not enough to restore the HGP to baseline conditions.

The handgrip fatigue test induced by the bulb dynamometer showed to be feasible for clinical application because the total duration of the test was satisfactory (about 7 minutes). Additionally, it also showed to be feasible for health professionals since they prefer to use portable, practical, inexpensive, and easy-to-use equipment in their clinical rehabilitation practice. These aspects favor the measurement of handgrip clinical responses in different situations of therapeutic care. The use of the visual analogue scale corroborated the test's completion until maximum perceived effort in parallel to the monitoring of the contraction frequency by the metronome during the fatigue test. Studies that assessed handgrip fatigue using dynamic protocols with a limited number of contractions, used test protocols that consisted of 12 consecutive maximum isometric contractions of 3 seconds and a 5-second rest between repetitions.[21] Thus, the handgrip fatigue test proposed here, in addition to being able to induce fatigue, respects the individuality of the response of its participants since the number of contractions is unlimited, that is, each participant has reached fatigue in the maximum time.

De Ste Croix et al.[22] evaluated the effect of sex and age on the development of knee flexors and extensors fatigue using an isokinetic dynamometer in children and adults. The effect of sex on fatigue was not observed, but rather of age, as it was noted that adults had more significant fatigue than children. In 2002, Schneider et al.[23] carried out a study with healthy children of both sexes and at different stages of sexual maturation. They assessed muscle strength using an isokinetic dynamometer and observed that differences between sexes arise from puberty.[23] In 2004, Schneider et al.[24] evaluated muscle strength through the isokinetic dynamometer of child athletes and verified that the differences between the sexes appear with the beginning of puberty.[24] However, the authors still concluded that sexual maturation influences muscle strength more than sex. Thus, our results are in line with literature data.

Muscle fatigue, in addition to being objectively assessed, can also be monitored through scales or questionnaires of subjective perception of physical exertion (self-report measures), which are considered valid and reliable indicators. These scales are widely applied in the pediatric population,[25] especially the Children's OMNI Scale of Perceived Exertion (OMNI).[26] However, OMNI was not used in this study, as it is still in the process of being validated for Brazilian Portuguese. Therefore, we chose to use the VAS to assess perceived exertion after the fatigue test. The VAS is formatted as a numerical response range in ascending order of effort intensity (0–2: mild; 3–7: moderate; 8–10: intense) with pictorial descriptors that illustrate the face of a person experiencing various effort levels, which can help a child to adequately indicate the status of their effort/tiredness. A study that evaluated fatigue in children and adolescents with juvenile idiopathic arthritis using the VAS to measure tiredness/effort showed that the volunteers were able to safely indicate the level of fatigue.[27]

The level of physical activity of most participants was classified as sedentary. We believe that the PAQ-C cannot adequately categorize the level of physical activity of children who have good cardiorespiratory fitness. For example, a child who does physical activity regularly, that is, five days a week, rarely reports tiredness when asked about routine day-to-day activities. However, this child will be classified as sedentary or extremely sedentary by the PAQ-C. Due to this limitation, we did not relate the physical activity level classification to the fatigue data. In future studies, an alternative would be to measure the level of physical activity of children through more reliable devices, such as the accelerometer.[28]

The proposition of a new clinical assessment protocol must go through the validation process so that the degree of effectiveness of the new test in predicting the subject's performance can be tested. The process would involve the application, simultaneously, of two instruments that confirm the same measure, with one of these instruments already established (gold standard), and also by the process of reproducibility, to verify if the test maintains stability at different times (intra and inter-examiner analyses).[29] However, no test/protocol exists that is considered the gold standard for the assessment of motor fatigue in the upper limbs and could be compared to the protocol presented in this study.

One possibility would be to carry out the dynamometric assessment combined with the electromyographic analysis, since both, in a complementary way, would indicate the failure of the neuromuscular system during the fatigue process.

Activities involving handgrip are also part of a relevant clinical context in this population, involving fine and gross motor activities. Despite scientific literature presenting some studies that relate handgrip strength to muscle fatigue,[30,31] there are no strategies to evaluate the pediatric population. Therefore, future researches may investigate the interference of factors such as age, sex, sexual maturation, and body composition in resistance to fatigue in both typical participants and those with chronic diseases. In particular, in pediatric chronic diseases, this fatigue test may guide the choice of the therapy adopted for patients who report weakness and fatigue of the upper limbs, such as cerebral palsy and neuromuscular disorders. In the future, neurophysiological studies of muscle function, through the analysis of the electromyographic signal, may also help understand neuromotor response and the evolution of the diseases.[11]

This study presents limitations: a) the absence of a gold-standard fatigue visual scale for the pediatric population, translated and validated into Brazilian Portuguese; b) the level of physical activity of the participants was not related to HGP; c) handgrip pressure and fatigue in the preferred side were not assessed; d) children aged under 8 years and above12 years were not assessed; e) the validation of the handgrip fatigue test using dynamic contractions was not performed; and f) the electromyographic analysis was not performed simultaneously with the evaluation with a bulb dynamometer.

CONCLUSION

The dynamic contractions using handgrip was able to evoke fatigue in typical children and, in fact, induced a statistically significant decline in HGP associated with reporting maximum perceived effort. There was no sex-influence in the response and the time duration of the test ranged between 6 and 8 minutes. This protocol can be used in future studies to investigate the influence of other factors, such as sexual maturation and body composition, on motor fatigue in typical children and in the investigation of motor fatigue in patients with chronic diseases.

ACKNOWLEDGEMENTS

Our thanks to the participants and those responsible for participating in this research.

FINANCIAL SUPPORT

Financial support: Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), processos nº 2017/17596-4 e nº 2019/19553-6; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), processo nº 2020-00/88887.586702; Fundação de Apoio ao Ensino, Pesquisa e Assistência do Hospital das Clínicas da Faculdade de Medicina de Ribeirão Preto da Universidade de São Paulo (FAEPA).

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