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Original Article

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Effect of maximum grip strength on controlled force exertion measured by a computer-generated sinusoidal waveform in young adult males

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Abstract

Context: It is important to develop a method to accurately measure controlled force exertion (CFE). ***Objectives***: This study aimed to examine the effect of maximum grip strength on CFE measured by a sinusoidal waveform in 81 right-handed young males aged 15–29 years. ***Methods***: On the basis of grip strength measurements, participants were divided into the following three groups: low (males, 20; mean age, 19.5 years; standard deviation (SD) = 5.0 years), medium (males, 41; mean age, 22.8 years; SD = 4.2 years), and high (males, 20; mean age, 23.7 years; SD = 3.4 years). Participants adjusted the submaximal grip strength of the dominant hand with changes in the demand values that were displayed as a sinusoidal waveform with a frequency of 0.1 Hz on a computer screen. The abovementioned test was performed three times with a 1-min interval after one practice trial. Each trial lasted 40 s. The sum of the differences between the demand value and grip exertion strength value for 25 s was considered as the evaluation parameter. ***Results***: CFE values demonstrated insignificant correlations with age and maximum grip strength in all groups ($r = 0.07$; $r = -0.12$; $p > 0.05$). No significant differences were found between CFE mean scores that was adjusted for age and varying maximum grip strength in the three groups ($F = 1.95$; $p > 0.05$). ***Conclusions***: Based on the sinusoidal waveform display, we inferred that maximum grip strength has little effect on CFE evaluation in young males.

Key words: force output, grip strength, psychomotor performance, tracking paradigm, visuomotor processing

Main Text

Introduction

Accurate and efficient movements depend on the precise control of small muscle groups of the hand and fingers, but the magnitude and dynamic properties of force output are largely affected by neuromuscular function [1]. Precise, controlled force exertion (CFE) is essential to smoothly conduct daily living activities. It has been suggested that these force-control properties are influenced by physical maturation [1, 2], aging of neuromuscular pathways [3], and task constraints such as the magnitude of muscular force [4]. In particular, the voluntary movement coordination system, i.e., CFE, is intimately involved in achieving skillful and efficient movements that demand feedback such as manual dexterity, hand–eye coordination, etc. [5]

The CFE test is used to evaluate motor control function that coordinates force exertion during a task. Motor control function is considered to be excellent when muscle contraction and relaxation are performed smoothly and in accordance with the target movement that has low variability and high accuracy [6]. The test evaluates the rational and objective estimation of grading, spacing (space perception), and timing, which are important elements of CFE [7]. In addition, it requires grip control (gross motor control) and hand–eye coordination; therefore, it is useful to evaluate neuromuscular function in the elderly with impaired physical functions [8]. A decrease in CFE in the elderly prevents them from performing daily life activities independently. Hence, the effect of the magnitude of force output and visuomotor processing on age-related differences in CFE has been a topic of scientific inquiry. In addition, these studies have typically presented CFE tasks using visual tracking paradigms [3, 7]. In these paradigms, visual feedback of performance was presented as a sinusoidal waveform or bar-chart display.

During the CFE tasks, participants are required to perform a grip exertion task, attempting to match the grip strength value with a demand value that is relative to the maximum muscular strength. According to Nagasawa, Demura, and Kitabayashi [9], different abilities such as motor responsiveness, motor accuracy, and motor velocity are exerted depending on the type of demand value displayed, and their difference determines the response to sinusoidal waveform and bar-chart displays. Performances during the CFE test are considered to vary because of differences in information input from the central and peripheral nervous systems, which are related to control functions, the type of demand value displayed, and the magnitude of force output. Demura and Yamaji [10] reported that the tendency for decline differs with grip type, intensity (target forces) and the force outputs among the conditions. Nagasawa et al. [8] suggested that a decrease in CFE ability is related to an increase in CFE errors. Noguchi et al. [11] reported that the CFE test can evaluate force control better than the maximum grip strength test. It is important to detect early on any decline in cognitive function in clinical and rehabilitation settings; however, most test assess only the processing time of movement and the reaction time of action to identify any decline in cognitive function. The CFE test quantitatively estimates the circuit integrating sensory input (visual) with motor output efficiently, but it is not yet widely available. Therefore, it is necessary to develop an accurate method to measure CFE in both medical and rehabilitation settings. Because the CFE test uses the relative demand values of grip strength (which varied in the range of 5%–25% of maximum grip strength), the maximum grip strength may influence the outcome of the test. However, the relationship between performance during the CFE test and maximum grip strength has rarely been examined from the perspective of differences in maximum grip strength values. On the basis of the abovementioned studies, it was hypothesized that maximum grip strength had little effect on the CFE value measured by the sinusoidal waveform in young adults.

This study aimed to examine the effect of maximum grip strength on CFE values measured by the sinusoidal waveform.

Methods

Participants

We recruited 81 young, male university students and office workers (age, 15–29 years; mean age, 22.2 years; SD = 4.5 years) in Japan (Table 1). All were considered as right-handed based on the inventory by Demura, Sato, and Nagasawa [12]. For each age level, the mean values for height and body mass were similar to the Japanese normative values [13]. No participant reported previous wrist injuries or upper limb nerve damage, and all were in good health. Prior to measurement, the purpose and procedure of this study was explained in detail, and signed informed consent was obtained from all participants. This experimental protocol was approved by the Kyoto Pharmaceutical University Ethics Committee. No participant had previously undergone a CFE test.

*****Table 1 near here*****

Apparatus

Participants stood at a distance of 70 cm from the display and wore glasses when required. The size of the grip was set for effective squeezing. Grip strength and CFE were measured with a Smedley's handgrip mechanical dynamometer (GRIP-D5101; Takei, Tokyo, Japan) with an accuracy of ±2% in the range of 0–979.7 N (output range of 1–3 V). This information was transmitted to a computer at a sampling rate of 10 Hz through an RS-232C data output cable (Elecom, Tokyo, Japan) after A/D conversion with a quantization bit rate of 12 bits (input range of 1–5 V). Apparatus details have been previously described [7].

Estimation of maximum grip strength

Each participant's maximum grip strength was measured with the dominant hand at the beginning of the experimental session. The participant was instructed to produce the greatest possible isometric force by exerting a power grip with the wrist in a neutral position (between flexion and extension). Two 5-s maximal contractions were recorded with 1-min rest after each test. No verbal encouragement was given. The greater value of two trials was considered as the maximum grip strength value [7, 8].

Submaximal controlled force exertion task

The CFE test was similar to a commonly used grip strength test [14, 15] except for the prolonged submaximal grip exertion. Participants stood upright with the wrist in the neutral position and the elbow extended and close to the body.

As outlined in a preliminary study [7], a sinusoidal waveform on the display screen was used for all participants. The display showed both the demand and the actual grip strength values simultaneously. Changes in the actual grip-exertion value were displayed as left to right waveform changes with respect to space and time and the demand value. The demand values varied over a period of 40 s at a frequency of 0.1 Hz [16, 17]. Participants performed a grip exertion task, attempting to match the grip strength value with the demand value as displayed on the computer. Figure 1 shows the sinusoidal waveform display. A preliminary experiment confirmed that participants could track the demand values as displayed in a sinusoidal waveform.

*****Figure 1 near here*****

Relative demand values were used instead of absolute demand values because grip strength of each individual varies (a difference of approximately 5%–25% of the maximum grip strength) [9, 16]. This range was determined taking into consideration the effect of muscle fatigue [7]. The shape of the demand function was the same for all participants. A software program was designed to display the relative demand values within a constant range. The demand value used the sinusoidal wave targets, which varied cyclically due to high reliability and practical validity [9, 16] (see Figure 1).

During the submaximal force display task, the participant performed three trials after completing one practice trial. Demand values in the display were tracked, and performance was measured by the total sum of the percent of differences between the demand and grip exertion values. To minimize the effect of fatigue, a 1-min rest period was given after each trial. The sum of the percent of differences between the demand and grip strength values was used as an estimate of the CFE scores [7], with smaller differences indicating better performance. The duration of each trial was 40 s, and according to the previous study by Nagasawa et al. [8], the CFE scores were estimated using data from three trials, excluding the first 15 s of each trial. The dependent variable was the total sum of the percent of differences between the demand value and the grip exertion value for 25 s. Of the three trials, a mean of the second and third trial results was used for analysis [9].

Statistical analysis

Data were analyzed using SPSS version 14.0 for Windows software (SPSS Inc., Tokyo, Japan). Using ordinary statistical methods, data are reported as means (M) ± SD. Correlation analyses were used to identify relationships among CFE, age, and maximum grip strength. Participants were divided into the following three groups based on lower (402.1 N) and upper quartiles (521.7 N) of maximum grip strength: low (males, 20; mean age, 19.5 years; SD = 5.0 years), medium (males, 41; mean age, 22.8 years; SD = 4.2 years), and high (males, 20; mean age, 23.7 years; SD = 3.4 years). One-way analysis of variance was used to examine significant differences between mean age and differing maximum grip strength in the three groups. When a significant interaction or main effect was found, a multiple-comparison test was conducted using Tukey's honestly significant difference method for pair-wise comparisons. In addition, analysis of covariance (ANCOVA) that was adjusted for age was used to examine significant differences between mean age and CFE in the three groups. A p-value of <0.05 was considered to be significant for all tests.

Results

Insignificant correlations were found between CFE and age and maximum grip strength in all participants ($r = 0.07$, $r = -0.12$, $p > 0.05$). Figure 2 shows means and standard deviations for the CFE scores of the three groups with varying maximum grip strengths. Significant differences in the mean age among the three groups were found ($F = 5.79$; $p < 0.05$). Table 2 shows the ANCOVA that was adjusted for age and the CFE scores in the three groups. No significant differences were found for CFE scores in the three groups.

*****Figure 2 near here*****

*****Table 2 near here*****

Discussion

This study examined the effect of maximum grip strength on CFE measured by the sinusoidal waveform in 81 right-handed young males aged 15–29 years. Although the grip size during the CFE test was set for effective squeezing, most participants used the same grip size during the maximum grip-hold exertion test. Therefore, the grip size had a minor influence on CFE and the maximum grip strength test.

Nagasawa and Demura [18] reported that in individuals aged more than 50 years, CFE measured by the sinusoidal waveform shows a marked decrease. In the young-aged group in our study, the insignificant correlation between CFE and the maximum grip strength indicated that this group of participants experienced a similar difficulty with respect to CFE that is not dependent on the magnitude of force output. The correlation between CFE and maximum grip strength is considered to increase in young individuals because of excellent performance during the CFE test, measured by the sinusoidal waveform, compared with that in middle-aged individuals and small individual differences. However, we found no significant correlation between CFE and maximum grip strength. It was considered that participants in this study formed a homogeneous group for CFE (see Fig.2). Bemben et al. [19] reported that the young participants had superior muscular endurance according to an intermittent grip strength test. Voelcker-Rehage and Alberts [20] reported that young participants could perform better on the changing force-tracking task because of superior CFE (i.e., peripheral muscular responses to the changing target and the neuromuscular function exertion). In addition, during the CFE task using the demand values for generating sinusoidal waveforms, younger participants could constantly change and regulate their force exertion. In other words, the same motor unit activation pattern is used to control the output force in younger subjects. In contrast, during the maximum grip strength task, they only had to exert the ultimate level of output force. The dexterity depends mainly on nervous function related to experiences of fine movements of the hands and fingers, while the latter depends on skeletal muscle mass related to the frequency of exerting maximal strength [21]. This may explain why no relationship between the CFE scores obtained using the sinusoidal waveform display test and those obtained using the maximum grip strength test was found in the young group in our study. Therefore, it was inferred that CFE and muscular strength are independent functions.

Because the sinusoidal waveform display is a continuous tracking task that provides visual feedback regarding performance error and more feed-forward (e.g., anticipatory) strategies [1], it was hypothesized that in young adults, the maximum grip strength had little effect on CFE value measured by sinusoidal waveform. In general, muscular function generally peaks from the late teens to twenties, and then gradually declines after 30 years of age [22]. In the present study, groups with greater grip strength had a higher mean age. We examined the differences between CFE scores that were adjusted for age and mean age in the three groups. In accordance with the hypothesis, no significant differences were found for the CFE scores among the three groups. Therefore, it was inferred that participants of all groups could accurately regulate their CFE during a pursuit task, regardless of the difference in their maximum grip strength. The functional role related to movement performance may differ according to the nervous system region that controls each movement. The cerebellum is generally associated with skilled motor movements, and the basal ganglia, in particular, the striatonigral system is associated with gross motor behavior [23]. Reports by several researchers [1, 17, 18] confirm that aged-related differences in CFE are greater with pursuit movements, and CFE ability decreases with age. In the present study, tests were performed with submaximal muscular exertion with a moderate cycle (0.1 Hz) of changing demand value. Success in this test requires excellent hand–eye coordination and grip force that responds to feedback such as the sense of force exertion and visual target matching. The magnitude and dynamic properties of force output are indicative of neuromuscular function [1]. Muscular strength decreases with age because of changes in neuromuscular pathways and muscle fiber composition, spinal motor neuron apoptosis [3], and muscle atrophy [24]. Therefore, young participants aged less than 30 years of age demonstrated better force exertion control after fatigue and exercise, i.e., peripheral muscular responses and the execution of neuromuscular function in response to the changing target. Factors such as adaptability to a new task and difference in learning-skills are similarly considered to relate to performance during the sinusoidal waveform test, regardless of the difference in maximum grip strength. Thus, based on the sinusoidal waveform display, it was inferred that maximum grip strength has a minor influence on the CFE evaluation.

The participants in this study were healthy adult males aged between 15 and 29 years who had a mean maximum grip strength of greater than 464.8 N. A follow-up study will determine the relationship between the CFE value measured by the sinusoidal waveform and maximum grip strength and compare CFE in individuals with arm and muscular nervous dysfunction with that in healthy individuals.

In conclusion, there is an insignificant correlation between CFE and maximum grip strength, and the maximum grip strength has little effect on the CFE measured by the sinusoidal waveform in young males.

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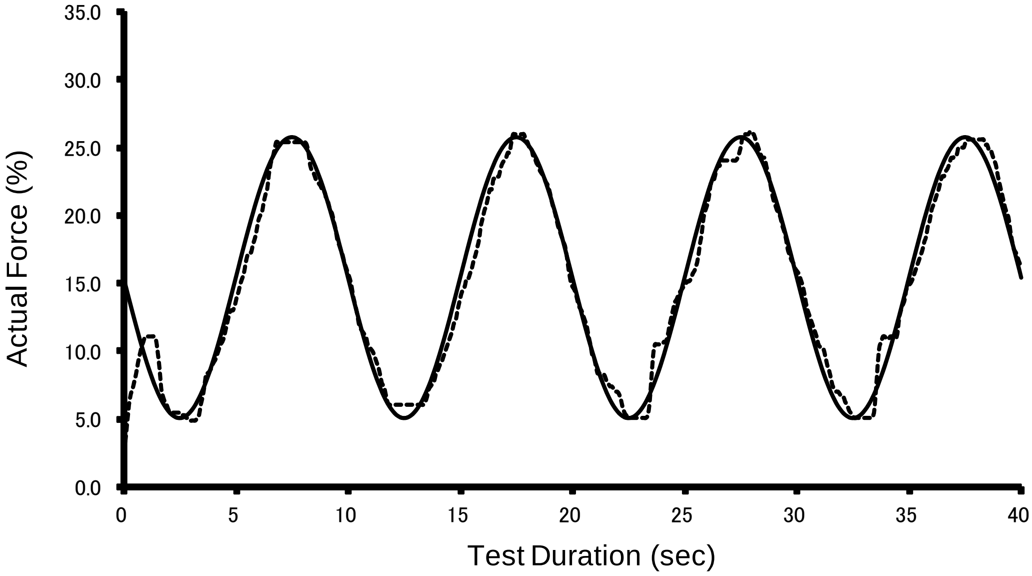

Figure 1. Sinusoidal waveform display (100 mm × 140 mm) of the demand value. The solid waveform (A) shows the demand value and the broken waveform (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in the range of 5%–25% of maximum grip strength. The length of the display is 33 mm from top to bottom. Frequency of change in demand value is 0.1 Hz. The test time was 40 s for each trial. The controlled force exertion was calculated using the data from 25 s of the trial following the initial 15 s of the 40-s period.

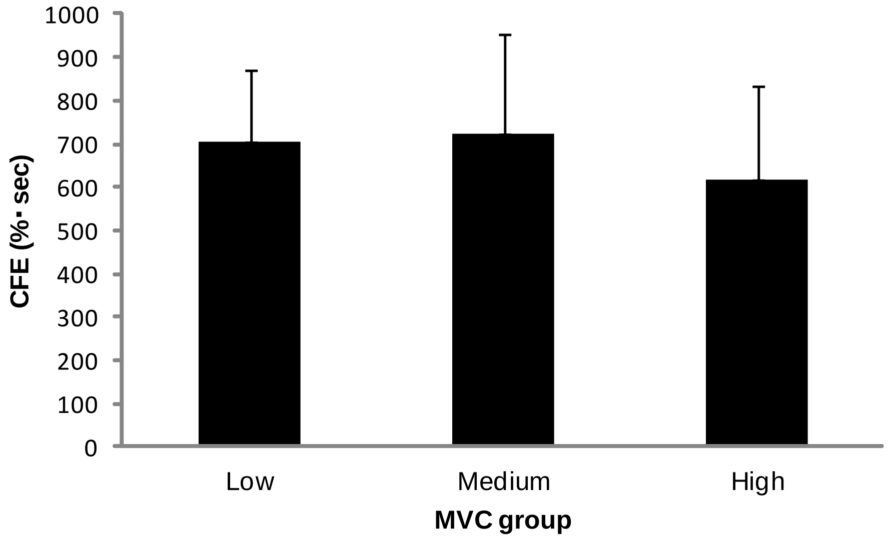

Figure 2. Mean values of controlled force exertion (CFE)

note) Low: MVC < 402.1N; Medium: 402.1N ≦ MVC < 521.7N; High: MVC ≧ 521.7N

Table 1. Physical characteristics of participants

MVC group	*n*	Age (years)		Height (cm)		Body mass (kg)		Grip strength (N)	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Low	20	19.5	5.00	169.3	4.75	58.4	5.23	360.0	32.20
Midium	41	22.8	4.22	171.8	5.21	68.4	7.07	469.6	36.83
High	20	23.7	3.39	174.2	3.42	72.4	7.12	560.7	35.98
Total	81	22.2	4.49	171.8	4.97	66.9	8.40	464.8	79.24

Table 2. The result of analysis of covariance (ANCOVA)

Factor	ANCOVA			
	df	*F*	η^2	*p*
MVC group	2	1.95	0.05	0.15
Error	77	(45878.46)[a]		

a: mean squared error