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Effect of Short-Term Exercise on Controlled Force Exertion in Young and Middle-Aged Adults

Yoshinori Nagasawa[1,*], Shinichi Demura[2]

[1]Department of Health and Sports Science, Kyoto Pharmaceutical University, Kyoto, Japan
[2]Graduate School of Natural Science & Technology, Kanazawa University, Kanazawa, Japan
*Corresponding author: ynaga@mb.kyoto-phu.ac.jp

Abstract It is important to develop a method to accurately measure controlled force exertion (CFE) in order to evaluate coordination of neuromuscular function. This study aimed at examining the effect of short-term exercise on controlled force exertion in healthy young and middle-aged adults. Ten young (mean age = 20.7 y) and 10 middle-aged (mean age = 49.8 y) adults were included in the study. All subjects had a healthy central nervous system and had no disability in terms of motor functions. Also, none had engaged in regular exercise in the year prior to the study. Everyone participated in a general muscle strength training and aerobic exercise program twice a week during a 3-week period. They exerted the grip strength of the dominant hand and adjusted the grip strength based on the changing demand values displayed as a bar chart with a frequency of 0.3 Hz on a computer screen. A sum of errors between the demand values and the grip exertion values for 25 s was used as the evaluation parameter. A two-way analysis of variance (group and period) was used to examine significant differences among the means. Significant differences of variance were calculated to examine individual differences between the two groups by period. The middle-aged group had significantly greater errors than the young group. The errors decreased by approximately 20% in the young group and by approximately 10% in the middle-aged group during the second and third weeks. The variation in the errors in the middle-aged group was significantly greater than that in the young group during each period. In conclusion, we report that a combination of a general muscle strength training and aerobic exercise improves CFE in middle-aged and young adults. This effect is, however, less pronounced in middle-aged adults who also displayed a particularly small interindividual difference in CFE.

Keywords: *force output, grip strength, psychomotor performance, tracking paradigm, visuomotor processing*

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1. Introduction

Controlled force exertion (CFE) is essential to smoothly conduct daily life activities. Restriction of force output, such as that provided by the magnitude and persistence time of force exertion [21], affects CFE. In particular, coordination between voluntary movements plays a critical role in achieving skillful and efficient CFE demanded feedback information such as manual dexterity and hand-eye coordination [9].

The CFE test developed by Nagasawa & Demura [11] is used to evaluate motor control function that coordinates force exertion during a task. Motor control function is considered as excellent when a person can smoothly adjust exertion values as per the changing demand values, albeit with small errors [3]. CFE involves grading, spacing (space perception), and timing, and the CFE test evaluates these composition elements rationally and objectively [11].

In addition, because this test demands the control of subjects' grip exertion (gross motor control) as well as hand-eye coordination, it is also useful for evaluating neuromuscular function of the elderly with impaired physical functions [16]. A decrease in CFE in the middle-aged and elderly adversely affects their independent daily life activities. Hence, it is extremely important to clarify age-dependent changes in CFE [8] and the effect of regular exercise on CFE [13].

The CFE test usually uses a visual tracking paradigm [8,11]. In this paradigm, the demand values with sinusoidal waveform or bar-chart are presented on display, and the errors between the demand and exertion values are provided to the subjects as visual feedback information.

Kalapotharakos et al. (2007) reported that CFE was improved by moderate resistance muscle strength training over a period of 10 weeks. In addition, Kubota et al. [10] reported that when using the CFE test for repeated training, CFE was improved after 3 weeks. The fact that CFE weakens with age suggests that the effect of exercise on CFE may also be age-dependent. Based on results from the above studies, we hypothesized that a short-term exercise program can improve CFE and that the effects would be greater in middle-aged adults.

2. Methods

2.1. Subjects

The sample group consisted of 12 adults (males and females, 6 each; age, 40–59 y; mean age, 49.8 y and SD =

6.7 y; mean height, 164.6 cm and SD = 9.2 cm; mean weight, 63.2 kg and SD = 13.4 kg). Two females were excluded from the analysis because of surgical disease or the inability to participate in the short-term exercise program. Ten young university students with grip strength values that were similar to those of the middle-aged adults were selected as the control group (males, 6 and females, 4; age, 19–23 y; mean age, 20.7 y and SD = 1.4 y; mean height, 170.1 cm and SD = 7.3 cm; mean weight, 67.3 kg and SD = 6.9 kg). All subjects were considered as right-handed based on the inventory by Demura et al. [5].

For each group, the mean values of height and body mass were similar to the Japanese normative values [20]. No subject reported previous wrist injuries or upper limb nerve damage, and all were in good health. None of the subjects had previously undergone a CFE test. Prior to the measurements, the purpose and procedure of this study were explained in detail, and signed informed consent was obtained from all subjects. This experimental protocol was approved by the Ethics Committee on Human Experimentation of Faculty of Education, Kanazawa University.

2.2. Short-term General Muscle Strength Training and Aerobic Exercise Program

The above-mentioned combined exercise program lasted for approximately 70 min and consisted of a 15-min warm-up, a 40-min primary exercise [20-min resistance training using a hydraulic machine (muscle strength training) and a 20-min aerobic exercise using a bicycle ergometer], a 5-min rest time, and a 10-min cooling down. The subjects performed the short-term combined exercise program at a frequency of two days per week for a total of three weeks.

2.3. CFE Measurement Apparatus

The grip size of this apparatus was set for effective squeezing. Grip strength and CFE were measured with a Smedley handgrip 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). The value of the grip strength 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). A detailed explanation of the CFE apparatus has been provided elsewhere [11].

2.4. Measurement of Maximal Grip Strength

Grip strength was measured twice before and after participation in the exercise program. The subject was instructed to be in an orthostatic body position and exert the greatest possible grip strength. They had to hang the dominant arm at the side of the body without shaking the grip dynamometer or bringing it into contact with the body. A 1-min intertrial interval was included. The subjects were not encouraged verbally. The greater value of the two trials was used as the maximum grip strength value [11,16].

2.5. Measurement of CFE

The CFE test was similar to the above-stated maximal grip strength test [19,23], except for the prolonged submaximal grip exertion (5%–25%).

A bar chart method was used in this study. Both the demand and grip strength exertion values were presented on the display screen simultaneously. Dimensions of the grip-exertion values, as with the demand values, were displayed as vertical bars. The demand values varied over a period of 40 s, with a frequency of 0.3 Hz [13,15]. The subjects stood at a distance of 70 cm from the display and wore glasses when required. They tracked the changing demand values displayed on the computer; the grip strength exertion values also changed accordingly (see Figure 1).

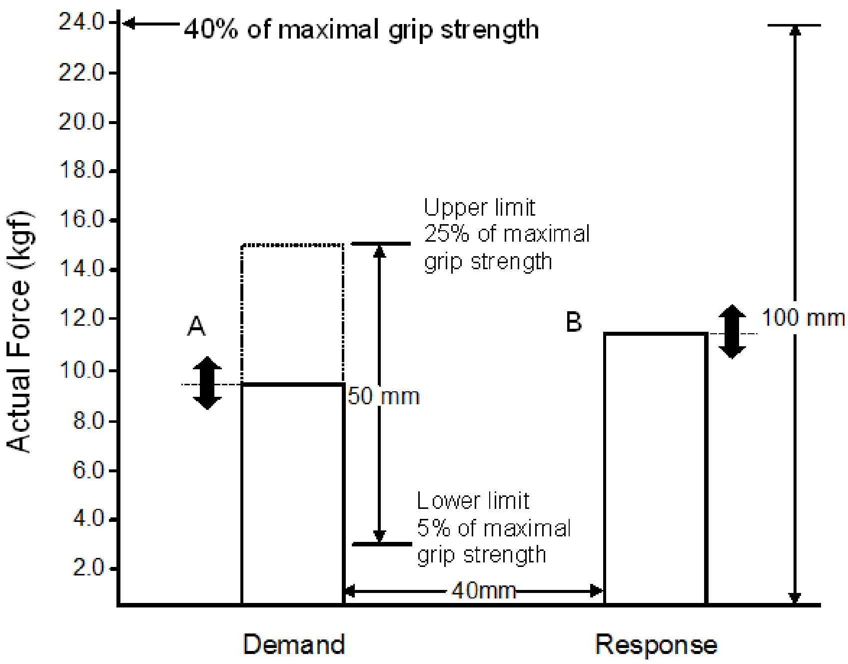

Figure 1. Bar chart display (100 mm X140mm) of demand value.[Left bar (A) shows rthe dem and value and right bar (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in s span of 50 mm on the display. The test time was 40 sec for each trial. The controlled force exertion was calculated using the data from 25 sec of the trial following the initial 15 sec of the 40 sec period. Actual force was shown on the dispiay, left.]

Relative, rather than absolute, demand values of maximum grip strength were used because grip strength differs between individuals [14,15]. A software was designed to display the relative demand values for all subjects within a constant range. The CFE test was performed over three trials. A 1-min intertrial interval was included after one practice trial before and after the exercise program participation. In the single practice trial, subjects' ability to perform the CFE test was confirmed.

According to a previous study by Nagasawa et al. [16], after excluding the first 15 s of the 40 s measurement-time, the total sum of errors between the demand and grip exertion values for 25 s was calculated. Of the three trials, a mean of the total sum of errors in the second and third trials was used as the CFE estimation variable [14], with smaller values indicating better performance [11].

2.6. Statistical Analysis

Data were analyzed using SPSS version 14.0 for Windows software (SPSS Inc., Tokyo, Japan). A two-way analysis of variance (group vs period) was used to examine significant differences among the means before and after the exercise program. When a significant interaction or primary effect was found, a multiple-comparison test was conducted using Tukey's honestly significant difference method for pair-wise comparisons. In addition, a test of homogeneity of variance (homoscedasticity) was conducted, and coefficient of variance was calculated to examine individual differences between the two groups by period. A p-value less than 0.05 was considered significant.

3. Results

Figure 2 shows changes over time (means and standard deviations) for errors in the young and middle-aged groups. In the results of the two-way analysis of variance, no significant interaction was found [$F(3, 54) = 0.21$; $p > 0.05$], but significances in the primary effects of group [$F(1, 18) = 10.19$; $p < 0.05$] and period [$F(3, 54) = 5.25$; $p < 0.05$] factors were found. The middle-aged group displayed larger CFE values than the young group. Moreover, these values decreased during the second and third weeks when compared to baseline values, indicating an improved performance.

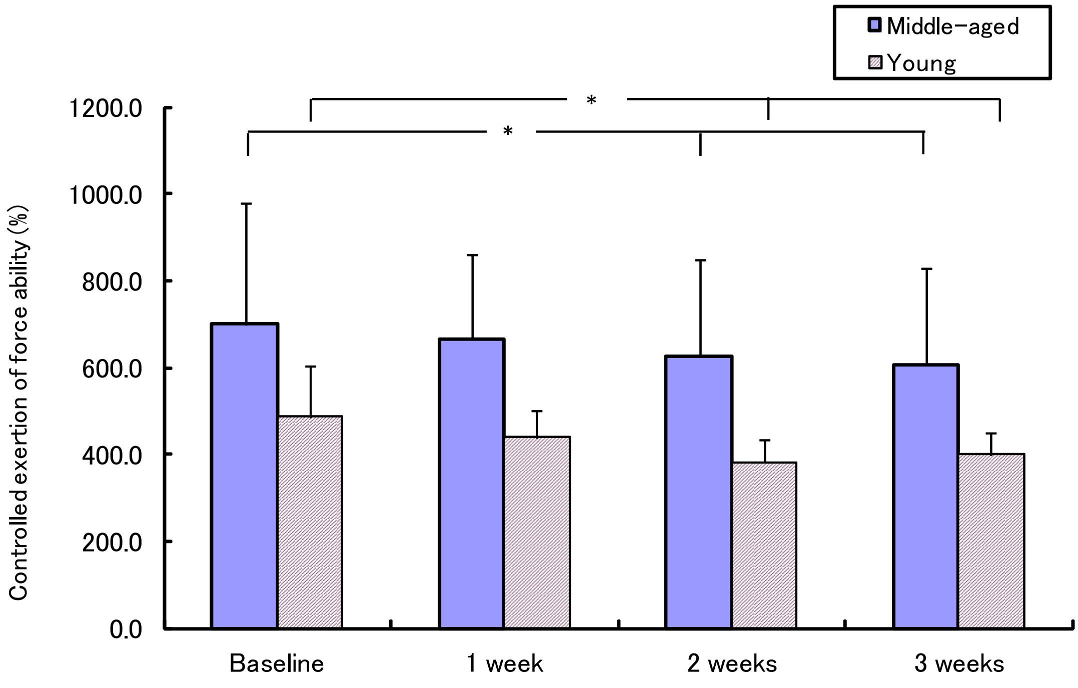

Figure 2. Effect of short-term exercise on CEFA (twice a week during the 3-week)

Figure 3 shows change-ratio over time (means and standard deviations) according to the baseline values for the errors in both groups. The errors scores decreased by approximately 20% in the young group and by approximately 10% in the middle-aged group during the second and third weeks. The variation in the errors in the middle-aged group was significantly greater than that in the young group during each testing period [baseline: $F(9,9) = 5.51$; the first week: $F(9,9) = 9.65$; the second week: $F(9,9) = 18.87$; the third week: $F(9,9) = 19.43$; $p < 0.05$). In addition, the coefficient of variance of grip strength and CFE errors at baseline (young group: $CV_{MVC} = 18.5$, $CV_{CFE} = 24.4$; middle-aged group: $CV_{MVC} = 35.2$, $CV_{CFE} = 39.8$) and the time point between the first and third weeks (young group: $CV_{MVC} = 18.6–19.0$, $CV_{CFE} = 12.6–14.4$; middle-aged group: $CV_{MVC} = 31.9–33.0$, $CV_{CFE} = 29.4–36.5$) was greater in the middle-aged group.

4. Discussion

4.1. Main Findings

There were two primary findings in this study. First, CFE improved after two weeks of general muscle strength training and aerobic exercise in both the young and middle-aged adults. Second, compared to young adults, middle-aged adults displayed larger CFE errors at each test period. The middle-aged adults also exhibited large individual differences.

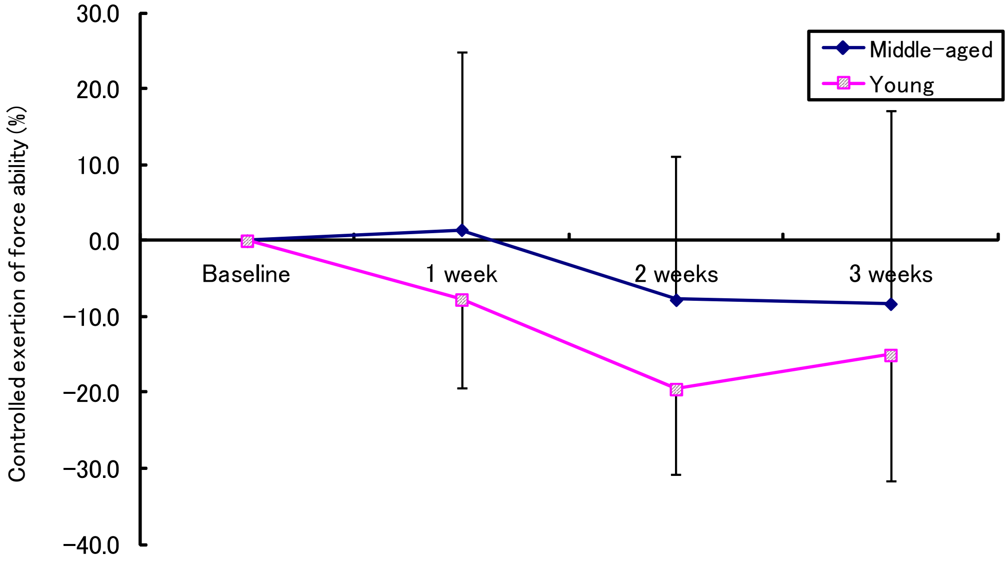

Figure 3. Effect of short-term exercise on CEFA (twice a week during the 3-week)

4.2. Age-Dependent Effect of Exercise on CFE

Several previous studies have suggested that muscle strength decreases with age (Dustman et al., 1984; Rikli and Busch, 1986; Rikli and Edwards, 1991; Welford, 1988). With age, a decrease in muscular function involves changes in neuromuscular pathways and muscle fiber composition, spinal motor neuron apoptosis [8], and muscle atrophy [4].

Stelmach, Goggin, and Garcia-Colera (1987) examined whether differences in the information provided before a particular motor task affects the response initiation and movement times in the elderly. They also reported that although both the elderly and the young process prior information in a similar manner to prepare for an upcoming movement, the elderly are inferior in peripheral muscular responses and coordination of neuromuscular function than young adults (Stelmach et al., 1987). They may need more time to specify a dimension when pursuing changing demand values. The present CFE test was performed by submaximal force exertion with a moderate cycle (0.3 Hz) of changing demand values. Performing this test requires large exertion of hand-eye coordination, which is controlled by a feed-forward strategy, such as anticipation and estimation, or feedback information such as "sense of force exertion," and "matching of target". Our results confirm that CFE is inferior in the middle-aged adults compared to that in the young adults. This difference between the age groups persisted despite the significant improvement following the general muscle strength training and aerobic exercise program. This may have been a result of inferior neuromuscular function in the middle-aged adults.

Also, Nakamura et al. (1995) reported that the learning effect of pursuit movements is associated with both the knowledge of a target-locus (declarative memory) and the improvement of procedure to pursue the movement of a target (procedural memory). Although the present CFE test was the same (same locus and speed) in all trials and the information given prior to response was also the same, an improvement was observed after exercise in both the young and middle-aged adults; the improvement was, however, smaller in the latter group. Indeed the test requires the subjects to process the visual and perceptual information (errors between demand and exerted values) from peripheral tissues in the brain and to coordinate grip strength exertion through motor commands from the brain [10]. It is thus inferred that because all of the above-mentioned brain processes are poorer in middle-aged adults than in young adults, the improvement in CFE following exercise occurs to a lesser extent in the older group.

4.3. Individual Differences in terms of Effect of General Exercise on CFE

It is known that physical fitness (neuromuscular function) generally decreases with age, and large individual differences are observed in the elderly [1]. Noguchi et al. [17] reported that subjects efficiently performed the motor task due to becoming accustomed to the task over several trials and thus having a better understanding of the test procedure. Butki (1994) reported that subjects need at least four trials to gain familiarity with a task and to show significant improvement. From the present results, individual differences in CFE were large before exercise in both the young and middle-aged adults (24.4 vs 39.8). The differences were small after exercise; however, the middle-aged adults showed a particularly small difference (12.6–14.4 vs 29.4–36.5). Therefore, experience with a task and practice effects influenced individual differences in CFE. In short, similar individual differences in CFE were observed even after the above-stated exercise.

In addition, after 3weeks, a great improvement was observed at baseline values in the weaker middle-aged adults compared to that in the stronger middle-aged adults in terms of CFE. In terms of adaptive function, some people are better than others. People with poorer adaptive functions may perhaps report small individual differences in performance. In contrast, people with better adaptive functions may quickly learn the task and produce large individual differences. It appears that such an increase in individual differences in measurements occurs in middle-aged adults.

4.4. Practice Effect of CFE

Regular muscle strength training and aerobic exercise generally provide a moderate stimulus to the body and have a favorable influence on the nervous system and muscle function (Dustman et al., 1984; Rikli & Edwards, 1991). Kalapotharakos et al. (2007) examined the effects of 10 weeks of moderate resistance strength training in older men aged 61–75 y using upper and lower body muscle groups at 60% of 1-Repetition Maximum (1-RM). They reported improvements in muscle strength and vertical jump performance. From the present results, it is inferred that stimuli arising from the afore mentioned combined exercise contributed to the improvement of CFE in the middle-aged adults.

On the other hand, in general, the tests that strongly involve neuromuscular function are greatly influenced by repeated trials (practice) at an early stage [17]. Nagasawa, Demura, and Nakada [15] examined the day-to-day variation (after 1 week) in the means of CFE tests for 25 s. They used the demand values of a sinusoidal waveform of 5%–25% of the maximal grip-strength value for university students and reported that the measurements on the second day decreased significantly. Kubota et al. [10] examined the effects of repeat training on means of CFE tests for 25 s. They used the demand values of a bar chart of 5%–25% of the maximal grip-strength value for male university students and reported that the estimates of CFE improved after 3 weeks. None of subjects in this study had undergone a CFE test previously. Therefore, we suggest that repetitive testing in the CFE trials may have contributed to the improvement in CFE observed in our results. In future, it will be necessary to examine the effect of a general exercise on CFE using larger samples and controls.

In conclusion, CFE improved following a general muscle strength training and aerobic exercise program over a period of 3 weeks in both young and middle-aged adults. The improvement, however, was less pronounced in middle-aged adults who also showed a particularly small interindividual difference in CFE.

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Statement of Competing Interests

The authors have no competing interests.

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