Title Page

Original Article

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Age and individual differences in controlled force exertion measured by a computer-generated sinusoidal and quasi-random display

Author names:

Yoshinori NAGASAWA[1)]

Shinichi DEMURA[2)]

Affiliations:

1) Kyoto Pharmaceutical University, Department of Health and Sports Sciences, 5 Nakauchi-cho, Misasagi, Yamashina-ku, Kyoto, Kyoto 607-8414 Japan
2) Kanazawa University, Graduate School of Natural Science & Technology, Kakuma, Kanazawa, Ishikawa 920-1164 Japan

Running head:

Age and individual differences: controlled force exertion

Address correspondence to

Yoshinori Nagasawa,

Department of Health and Sports Sciences,

Kyoto Pharmaceutical University,

5 Nakauchi-cho, Misasagi, Yamashina-ku, Kyoto, Kyoto 607-8414 Japan.

+81-75-595-4682 (Tel)

+81-75-595-4682 (Fax)

ynaga@mb.kyoto-phu.ac.jp (e-mail)

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The date of submission:

Friday 24 October 2008

The date of re-submission:

Sunday 14 June 2009

The date of re-submission:

Sunday 18 October 2009

Abstract

This study aimed to examine age group and individual differences in controlled force exertion by emulating sinusoidal and quasi-random waveforms in 222 right-handed female adults aged 20 to 86 years. The subjects matched their submaximal grip strength by the dominant hand to changing demand values displayed as either a sinusoidal or a quasi-random waveform appearing on the display of a personal computer. A total of the differences between the demanded value and grip exertion value for 25 seconds were used as an evaluation parameter. The measurements showed a tendency to increase across the age groups in both waveforms. Significant second order curve regressions were identified, but there was no significant difference in the increase rates of both waveforms. Analysis of variance showed nonsignificant differences among means of both waveforms in all age groups, and the differences between means in groups of participants over 50 and 20 to 24 year olds increased in both waveforms. Individual differences were almost the same in both waveforms.

Key words: humans, adult, hand strength, psychomotor performance

Text

Introduction

Nerve and muscle functions interact closely to control human motor performance. Because it is rare to exert maximal ability in daily activities, the efficient and continuous exertion of submaximal ability (Halaney & Carey, 1989) is likely to be important. In infants, elderly, and disabled people, it is particularly important and essential to estimate the main voluntary movement functions that contribute skillfully and efficiently to submaximal movements (Henatsch & Langer, 1985) because the exertion of maximal ability involves risks. Local movements which demand feedback such as hand-foot movements, hand-eye coordination, and so on, are closely involved in the coordination of the voluntary movement system, i.e., controlled force exertion (Henatsch & Langer, 1985). The controlled force exertion test is useful for the evaluation of motor control function, which coordinates force exertion according to each task. To smoothly exert motor control function, information from the central and peripheral nervous systems is integrated in the cerebrum for proper control of movements in each motor organ. Superior motor control function occurs when muscle contraction and relaxation are smoothly performed according to movement of a target with low variability and high accuracy (Brown and Bennett, 2002). The ability to control this motor function is acquired postnatally based on motor experiences.

Nagasawa and Demura (2002) focused on tracking action with submaximal exertion and developed a new test for controlled force exertion. The test for rational objective estimation of grading, spacing (space perception), and timing, which are important elements of controlled force exertion (Nagasawa and Demura, 2002) requires grip control (gross motor control) and hand-eye coordination; therefore, it is useful for the evaluation of the neuromuscular function of elderly persons (Nagasawa, Demura, Yamaji, Kobayashi, & Matsuzawa, 2000). Voelcker-Rehage and Alberts (2005) reported that younger subjects perform the variable force tracking task at a higher level than elderly subjects. Other factors such as fatigue, training, age (growth and development), etc. also influence controlled force exertion (Yamamoto, 1983). It is known that physical fitness (neuromuscular function) generally decreases with age, and its individual differences are large in the elderly (Bemben, Massey, Bemben, Misner, & Boileau, 1991).

Ranganathan, Siemionow, Sabgal, and Yue (2001) examined effects of aging on hand function, and reported that, compared with younger subjects, elderly subjects have weaker handgrip and maximum pinch force and decreased ability to maintain steady submaximal pinch force. They reported that the decrease in the ability to maintain steady submaximal pinch force is more pronounced in females than males.

On the other hand, when the demand value indicates a different locus each time, subjects are not able to memorize loci of demand values, allowing for an accurate measurement method (Nakamura, Ide, Sugi, Terada, & Shibasaki, 1995). However, the above problem has not been given the attention it deserves. According to Nagasawa, et al. (2004), the ability exerted by a type of displayed demand value is somewhat different. The age group and individual differences of the controlled force exertion test are the results of differences in the central and peripheral nervous systems, differences of control function, and the type of displayed demand value. However, the age group and individual differences on the sinusoidal and quasi-random waveforms have barely been examined. Because the quasi-random signal would prevent the subject from anticipating where the force would be in the future, the subject must adjust their force generation more closely to the demand value. On the other hand, because the sinusoidal signal has a predictable change, the subject can anticipate the force movement and adjust more quickly. Based on results of previous studies, we hypothesize that the controlled force exertion value increases with age, and its change aspect and individual difference also differ in both waveforms.

This study aimed to examine age group and individual differences of the measured values of the controlled force exertion by the sinusoidal and quasi-random waveforms and to inspect the above hypotheses.

Methods

Subjects

The subjects were 222 female (age = 44.7±18.1 yrs, height = 156.0±6.4 cm, weight = 52.9±7.1 kg) (mean ± s) adults aged 20 to 86 years. Their physical characteristics are summarized by age group in Table 1. All were regarded as right-handed, based on the Oldfield’s inventory (1971). Mean values of height and weight were similar to Japanese normative values (Laboratory Physical Education in Tokyo Metropolitan University, 1989) for each age level. No subject 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 were explained in detail, and written informed consent was obtained from all subjects. This experimental protocol was approved by the Ethics Committee

(Kanazawa University Health & Science Ethics Committee). No subject had previously performed a controlled force exertion test. The subjects over 60 years of age were defined as the elderly people in this study.

Table 1 near here

Test and Test Procedure

In this study, the subjects performed a grip exertion, attempting to minimize the differences between a demand value and the value of grip strength as presented on a computer display. This information was transmitted at a sampling rate of 10 Hz to a computer through an RS-232C data output cable after A/D conversion. Measurements of grip strength and controlled force exertion were measured with a Smedley's type handgrip mechanical dynamometer (GRIP-D5101; Takei, Tokyo, Japan), with an accuracy of ±2% in the range of 0 to 979.7 N.

Based on a preliminary investigation (Nagasawa & Demura, 2002), a waveform on the display screen was used. The display showed the demand value and the actual grip strength simultaneously. Changes in the actual grip exertion value were displayed as changes in the waveform from left to right visually and spatially with time, as with the demand value. The demand values varied over a period of 40 seconds at a frequency of 0.1 Hz. This rate of change is most easily imitated by the neuromuscular function (Hayashi, 1967; Meshizuka & Nagata, 1972). The demand value of the quasi-random waveform was changed randomly in π with amplitude and in $\pi/2$ with frequency, and increased and decreased at the same frequency as the sinusoidal waveform (range = 5 to 25% of maximal grip strength). Figures 1 and 2 show the displays of sinusoidal and quasi-random waveforms, respectively. Details of the apparatus used to measure the controlled force exertion have been previously described (Nagasawa & Demura, 2002). Sufficient rest was given to eliminate the influence of fatigue. Subjects wore glasses when required and sat at appropriate distances from the display. They tracked the demand values in the displays, and then measurements were performed. Subjects in a preliminary experiment were capable of tracking the demand values in either display.

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

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

Relative demand values, not absolute demand values, were used since physical fitness and muscular strength of each individual are different. The relative demand value varied around 5 to 25% of maximal grip strength. All subjects were presented with the same shape of demand function. The software program was designed to present the relative demand values within a constant range on the display regardless of differences in each subject’s maximal grip-strength. The demand value used the sinusoidal wave targets, which varied cyclically, and the quasi-random targets, which varied quasi-cyclically (see Figures.1 and 2).

The size of the grip was set so that the subject felt comfortable squeezing the grip. The subject performed maximal grip exertion with the dominant hand twice at 1-min intervals, and the greater value was taken as the value of maximal grip strength (Nagasawa, et al., 2000; Nagasawa & Demura, 2002). The test of controlled force exertion was performed in three trials at 1-min intervals after one practice trial. Measurements were not affected by poor vision or fatigue. The test of controlled force exertion was similar to a commonly used test of grip strength (Walamies & Turjanmaa, 1993; Skelton, Greig, Davies, & Young, 1994), except for the exertion of a prolonged submaximal grip. The subject stood upright with the wrist in the neutral position between flexion and extension and with the elbow straight and close to the body. The duration of each trial was 40 seconds, and the controlled force exertion was estimated using the data from three trials, excluding the first 15 seconds of each trial according to the previous study of Nagasawa, et al. (2000). The sum of the differences between the demand value and the grip strength was used as an estimate of controlled force exertion (Demura & Nagasawa, 2002), with smaller differences indicating better ability to control force exertion. Each subject was free to adopt a standing position most conducive to a clear view of the display (Demura & Nagasawa, 2002). Of three trials, the mean of the second and the third trials was used for analysis (Nagasawa, et al., 2004).

Statistical analysis

Data was analyzed using SPSS (Version 11.5 for Windows). To examine the variance of measurements due to age, second order curve regression coefficients were computed for both sinusoidal and quasi-random waveforms and then the difference was examined. Two-way analysis of variance (ANOVA) with repeated measures on waveforms was used to examine significant differences among age group means (7 x 2 matrix: age group x the sinusoidal and quasi-random waveform group). When a significant effect was found, a multiple-comparison test was done using Tukey's Honestly Significant Difference (HSD) method for pair-wise comparisons. In addition, the size of mean differences (effect size) between trials of the 20-24 yr. old group and each other age group were examined. Coefficients of variance were calculated to examine individual differences between age groups. Results are presented as mean and standard deviation unless otherwise specified. An alpha level of 0.05 was considered to be significant for all tests.

Results

Table 2 shows means of each age group for the sinusoidal and quasi-random waveforms. Figure 3 shows a graphical representation of performance curves. The means increased across the age groups in both waveforms, and a significant and high second order curve linear tendency was identified (r^2_{SW}=0.96, r^2_{RW}=0.96). The regression coefficients in both waveforms were not significantly different.

In the results of the two-way ANOVA, interaction was significant ($F_{6, 215}$=2.39, p<0.05), and the main effects of age groups ($F_{6, 215}$=28.43, p<0.05) and waveforms ($F_{1, 215}$=19.65, p<0.05) were significant. With *post hoc* tests, means in the sinusoidal waveform were lower in the 20-24 yr. old and the 25-29 yr. old groups than in the groups older than 50 years of age; lower in the 30-39 yr. old group than in the groups older than 60 years of age; and lower in the 40-49 yr. old, 50-59 yr. old, and 60-69 yr. old groups than in the group older than 70 years of age. In the quasi-random waveform, means were lower in the 20-24 yr. old group than in the groups older than 50 years of age; lower in the 25-29 yr. old, 30-39 yr. old and 40-49 yr. old groups than in the groups older than 60 years of age; and lower in the 50-59 yr. old and 60-69 yr. old groups than in the groups for those older than 70 years of age. There were no significant differences from the 20-24 yr. old to 40-49 yr. old groups in both waveforms. In addition, nonsignificant differences were found among means of both waveforms in all age groups.

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

*****Figure 3 near here*****

The coefficient of variance was the same range in all age groups in both waveforms (CV_{SW}=21.6～39.1, CV_{RW}=26.1～46.4), but showed the highest value in the groups after the 60-year age group. The effect size of differences between the means of 20-24 yr. old and the means of age groups older than 50 years of age showed high values over 1.0 in the sinusoidal and quasi-random waveforms (Table 2).

Discussion

The means of controlled force exertions increased in both the sinusoidal and quasi-random waveforms across the age groups; however the rate of increase did not show a marked difference. In addition, differences in both waveforms were not found in all age groups. The functional role related to movement performances may differ based on the region of the nervous system controlling movement. The cerebellum is generally associated with skilled motor behavior, and the basal ganglia, in particular, the striatonigral system, is associated with actual motor behavior (Kornhuber, 1974). Bemben, et al. (1996)

reported that the elderly show a noticeable decline in muscle activity in the periphery compared with young people, based on the measurement of muscular endurance using intermittent grip strength. From reports by many researchers (Dustman, et al., 1984; Rikli & Busch, 1986; Rikli & Edwards, 1991; Welford, 1988), it is clear that the reaction time of movement decreases with age. The measurements of the controlled force exertion test in this study were also confirmed to decrease with age. The present test was performed by submaximal muscular exertion with a moderate cycle (0.1 Hz) of changing demand value. Achievement of this test requires a high degree of hand-eye coordination (see methods) and the exertion function is controlled by feedback such as ‘sense of force exertion’, ‘matching of target’, and so on. The decrease in muscular strength is based on changes of neuromuscular pathways and muscle fiber composition, spinal motor neuron apoptosis (Galganski, Fuglevand, & Enoka, 1993) and by muscle atrophy with age (Cauley, et al., 1987). Therefore, the elderly people, as compared with the young people, have less control of force exertion due to the fatigue of exercise, i.e., peripheral muscular responses to the changing target and the exertion of neuromuscular function, and they require more time to specify a movement dimension (Stelmach, et al., 1987). The above functional developmental difference is considered to produce differences of exertion values or performances between the elderly and young people. Because the quasi-random waveform as compared to the sinusoidal waveform expresses a different locus of demand value with time, pursuing it was considered to be much more difficult. However, the difference between sinusoidal and quasi-random waveforms was not found in all age groups, and there was no difference in the improvement-rate of either display. Because no subjects had previously performed a controlled force exertion test, factors such as the development-difference of nerve mechanism on exercise, adaptability to a new task, and the learning-ability difference in the nerve mechanism (Nagasawa and Demura, 2008) should have little influence on the decreased rate of performance across age groups in either display.

Significant differences among age group means were found in either display, but the differences (effect sizes) between the 20-24 yr. old group and groups older than 50 years of age were large. Stelmach, et al. (1987) examined whether the difference in the information given prior to response affects the elderly’s response initiation time and movement time. They reported that, although the elderly persons use pre-information to prepare an upcoming movement similar to young people; the transaction times of information concerning the movement plan for arms (hands), direction and extension were markedly slower, and the elderly required longer movement times. Nakamura et al. (1995) reported that the learning effect of pursuing movements is associated with both the knowledge of a target-locus (declarative memory) and the improvement of the procedure to perceive movement of a target (procedural memory). Although the present controlled force exertion test had the same content (the same locus and speed) in all trials and the information given prior to response was the same, measured values still decreased across the age groups. Of the above memories, the latter decrease is considered to control learning and cause the exertion values to decrease with age. It was clear that means in groups older than 50 years of age increase in either display as compared with that of 20-24 yr. old group.

Individual differences showed a similar tendency in the sinusoidal and quasi-random waveforms, but tended to increase in the groups older than 60 years of age (the elderly) in either display. The display style examined in this study differs from that of previous studies, but the result of this study is similar to that of Nagasawa and Demura (2008). Experience and practice of the task influence controlled force exertion variables, and may result in individual differences. In addition, some elderly people may have poorer controlled force exertion due to the fatigue of exercise, perhaps contributing to a floor effect wherein individual differences in performance are small. In contrast, elderly subjects with superior controlled force exertion quickly learn the task and individual differences become larger. Namely, experience and adaptation to the controlled force exertion task may increase individual differences in performances in an elderly group.

On the other hand, Nagasawa and Demura (2002) reported that the reliability for the controlled force exertion test is higher in the 30-second test than in the 60-second test. In short, the influence on the measurements may differ by the length of measurement time even if a target of the same locus and speed cycle is used. It may be necessary to examine these using different experimental conditions (e.g., different test time) on either display.

Conclusion

The errors in controlled force exertion of the sinusoidal and quasi-random waveforms using the same amplitude and frequency tended to increase across the age groups, and the increase-rate was remarkable in groups older than 50 years of age. The change in individual differences was the same degree in both waveforms.

Acknowledgements

This study was supported in part by a Grant-in-Aid for Scientific Research (project number 13780048, 17700476, and 20500506) to Y. Nagasawa from the Ministry of Education, Culture, Sports, Science and Technology of Japan, which we gratefully acknowledge.

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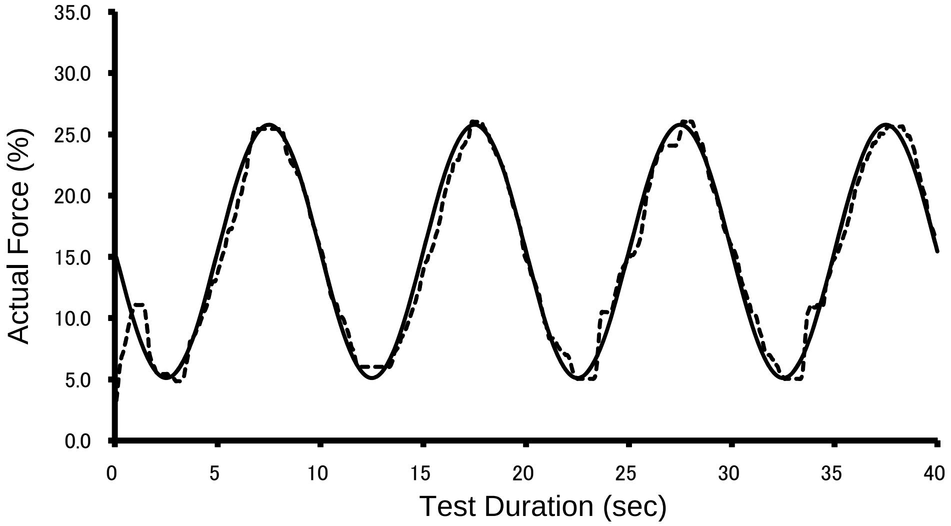

Figure 1. Sinusoidal waveform display (100 mm x 140 mm) of the demand value. The solid waveform (A) shows the demand value and the broken waveform (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in the range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

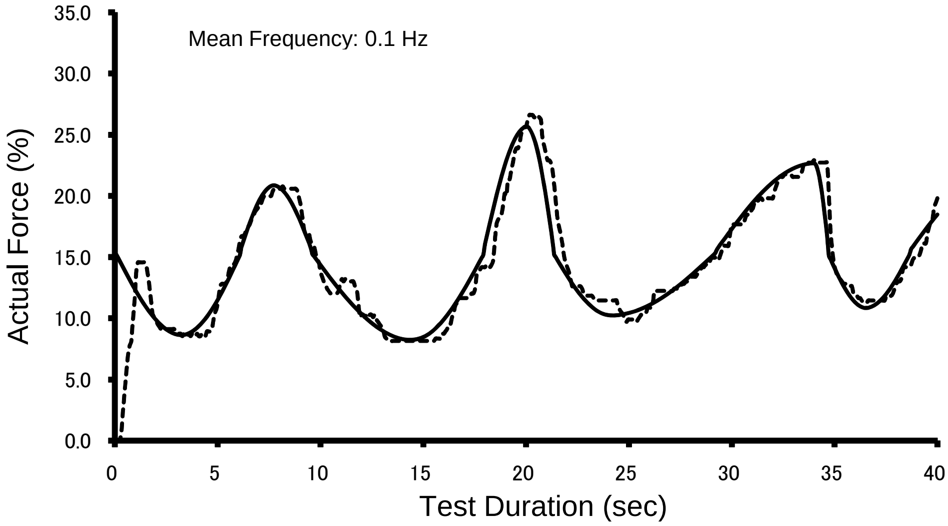

Figure 2. Quasi-random waveform display (100 mm x 140 mm) of the demand value. The solid waveform (A) shows the demand value and the broken waveform (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in the range of 5-25% of maximal grip strength value. The demand value was changed to random in π with amplitude and in π/2 with frequency, respectively. The test time was 40 sec for each trial. The coordinated exertion of force was calculated using the data from 25 sec of the trial following the initial 15 sec of the 40-sec period.

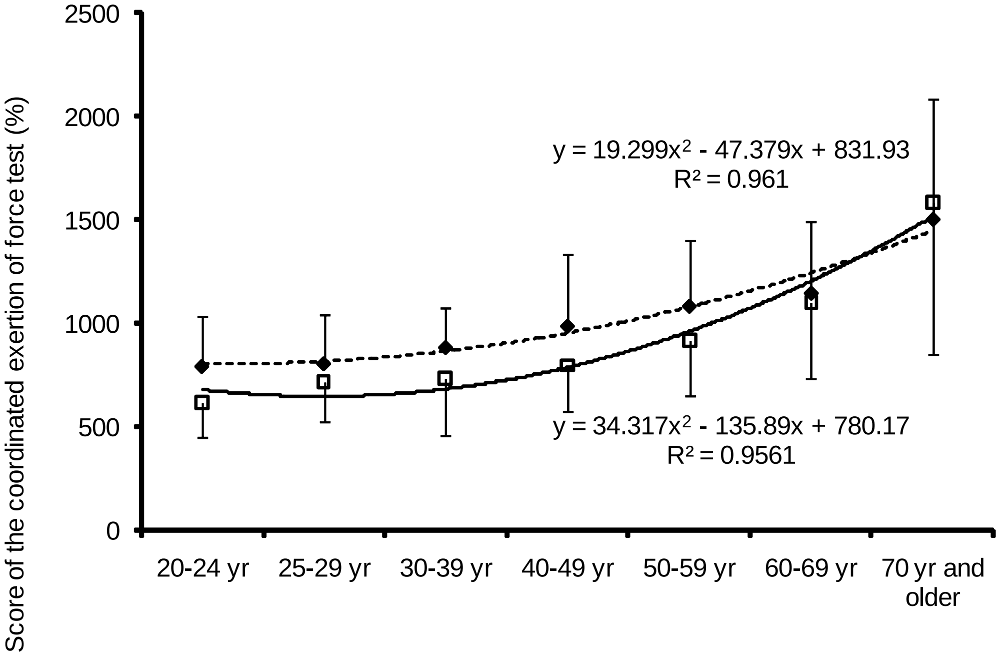

Figure 3. Age group means of the controlled force exertion test in the sinusoidal (◆) and random (□) demands. The solid line shows the linear regression of random demand, and the broken line is that of sinusoidal demand. *p<0.05.

Table 1. Physical characteristics of paticipants

Age group	Age (yr)		Height (cm)		Weight (kg)		Grip strength (kgf)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
20-24 yr (n=38)	22.2	1.31	160.1	4.70	52.8	5.31	31.8	4.44
25-29 yr (n=27)	27.0	1.43	159.3	5.75	51.0	6.42	30.8	4.94
30-39 yr (n=41)	35.1	2.61	158.4	4.78	51.8	7.35	29.4	3.94
40-49 yr (n=27)	44.6	2.73	157.0	4.98	52.3	5.92	30.0	3.83
50-59 yr (n=26)	53.2	2.97	154.7	5.18	54.8	7.47	28.9	4.38
60-69 yr (n=36)	63.7	2.75	153.0	6.00	55.6	8.30	25.1	6.51
70 yr and older (n=27)	74.9	3.99	147.6	4.39	51.7	7.84	20.4	4.75
F	1717.2 *		21.7 *		1.8		20.6 *	
Multiple comparison	20-24 yr <25-29 yr < 30-39 yr < 40-49 yr < 50-59 yr < 60-69 yr < 70 yr and older		20-24 yr > 50-59 yr, 60-69 yr, 70 yr and older 25-29 yr > 50-59 yr, 60-69 yr, 70 yr and older 30-39 yr > 60-69 yr, 70 yr and older 40-49 yr > 60-69 yr, 70 yr and older 50-59 yr > 70 yr and older 60-69 yr > 70 yr and older				20-24 yr > 60-69 yr, 70 yr and older 25-29 yr > 60-69 yr, 70 yr and older 30-39 yr > 60-69 yr, 70 yr and older 40-49 yr > 60-69 yr, 70 yr and older 50-59 yr > 60-69 yr, 70 yr and older 60-69 yr > 70 yr and older	
Total (n=222)	44.7	18.12	156.0	6.42	52.9	7.09	28.2	5.92

*p<0.05

Table 2. Means (%) of each age group for the controlled force exertion test in the sinusoidal and random demands

Age group	Sinusoidal demand				Random demand			
	M	*SD*	*CV*	*ES*	*M*	*SD*	*CV*	*ES*
20-24 yr	793.38	240.61	30.33	–	613.57	166.06	27.06	–
25-29 yr	806.40	237.48	29.45	0.05	713.49	186.30	26.11	0.57
30-39 yr	884.37	191.02	21.60	0.42	733.55	274.79	37.46	0.52
40-49 yr	986.69	343.39	34.80	0.67	794.96	221.71	27.89	0.95
50-59 yr	1082.37	315.83	29.18	1.06	915.16	262.48	28.68	1.43
60-69 yr	1145.26	346.24	30.23	1.19	1101.94	366.26	33.24	1.73
70 yr and older	1500.23	586.01	39.06	1.69	1588.15	737.29	46.42	1.99
Multiple comparison	20-24 yr < 50-59 yr, 60-69 yr, 70 yr and older				20-24 yr < 50-59 yr, 60-69 yr, 70 yr and older			
	25-29 yr < 50-59 yr, 60-69 yr, 70 yr and older				25-29 yr < 60-69 yr, 70 yr and older			
	30-39 yr < 60-69 yr, 70 yr and older				30-39 yr < 60-69 yr, 70 yr and older			
	40-49 yr < 70 yr and older				40-49 yr < 60-69 yr, 70 yr and older			
	50-59 yr < 70 yr and older				50-59 yr < 70 yr and older			
	60-69 yr < 70 yr and older				60-69 yr < 70 yr and older			

Note. - *CV*: coefficient of variance, *ES*: effect size, ES shows the effect size of mean differences between trials of those in their 20-24 yr and each age group trial.