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Age and sex differences: controlled force exertion

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Abstract

This study aimed to examine the age and sex differences in controlled force exertion measured by the bar chart display in 207 males (Age 42.1±19.8 yrs) and 249 females (Age 41.7±19.1 yrs) aged 15 to 86 years. The subjects matched their submaximal grip strength to changing demand values, which appeared as a moving bar chart on the display of a personal computer. The subjects performed the controlled force exertion test using the dominant hand 3 times with 1-min intervals (one trial was 40 sec.) after one practice trial. A total of the differences between the demand value and the grip exertion value for 25 sec. was used as the evaluation parameter. The errors in controlled force exertion showed a right-skewed distribution in both sexes but showed a normal distribution after logarithmic transformation (males: $W=0.06$, females: $W=0.74$ $p>0.05$). In addition, the errors in controlled force exertion tended to increase constantly with age in both sexes. Significant linear regressions were identified ($r^2_{males}=0.88$, $r^2_{females}=0.81$), but there was no significant difference in the increase rate of both sexes. The results of the analysis of variance and multiple comparisons showed insignificant sex differences among means, except for those in individuals older than 70 years, and significant differences between means in age groups older than 40 years and the 20 year old age group were found in both sexes. Individual differences were almost the same in both sexes ($CV_{males}=20.0\sim34.8$, $CV_{females}=17.7\sim36.2$). Errors in controlled force exertion showed a nonsignificant sex difference and increased gradually with age in both sexes but increased remarkably with age after 40 years of age.

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

Text

Introduction

Nervous and muscle functions work closely together to control motor performance in humans. Because it is rare to exert maximal ability during daily activities, it will be very important to determine whether submaximal ability is exerted efficiently or continually (Halaney & Carey, 1989). In elderly and developmentally delayed individuals, this is particularly important. In these individuals, it is essential to estimate the voluntary movement functions that primarily contribute to skillful and efficient submaximal movements (Henatsch & Langer, 1985), because the exertion of maximal ability involves risks. Local movements which demand feedback information, 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 one of the useful tests to evaluate motor control function, which acts to coordinate force exertion according to the demands of each task. To smoothly exert motor control function, information from the central and peripheral nervous systems is integrated in the cerebrum, which functions to properly control movements in each motor organ. Motor control function is interpreted to be superior when contraction and relaxation of muscles are smoothly performed according to the movement of a target. In this situation, variability decreases and accuracy increases (Brown & Bennett, 2002). The ability to control this exertion of motor function is postnatally acquired through learning based on motor experiences.

Nagasawa and Demura (2002) studied the tracking movement in submaximal strength exertion and developed a new test for rationally and objectively estimating grading, spacing, and timing, which are important elements of controlled force exertion. Their method involves using a grip dynamometer coupled with a personal computer. It was reported that the new test has a high reliability (Nagasawa, Demura, & Nakada, 2003) and that it measures the control of force rather than position tracking than that measured by the pursuit-rotor and pegboard tests (Nagasawa, Demura, & Kitabayashi, 2004). Hence, it is useful as a test to evaluate the neuromuscular function of the elderly (Nagasawa, Demura, Yamaji, Kobayashi, & Matsuzawa, 2000). On the other hand, factors such as fatigue, training, age (growth and development), etc. influence controlled force exertion (Yamamoto, 1983). It is known that physical fitness (neuromuscular function) generally decreases with age, and 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. Voelcker-Rehage and Alberts (2005) reported that younger subjects perform the variable force tracking task at a higher level than elderly subjects. Nagasawa et al. (2000) examined the characteristics of controlled force exertion by the bar chart display in 60 healthy older people (30 males, 30 females) aged 65 to 78 years and compared their performances with those of 60 healthy university students (30 males, 30 females). They reported that the elderly had inferior controlled force exertion to the young adults in both sexes. Furthermore, they found that elderly females were inferior to elderly males and that large individual differences were present. However, the above results on age group differences were examined based on a small sample. There are few reports on the change (decrease) of controlled force exertion with age or on the sex and individual differences of these decreases based on a large sample. Nagasawa et al. (2000) indicates that a decrease in the ability to exert controlled force will result in an increase in controlled force exertion errors. We hypothesized that the errors in controlled force exertion would increase gradually with age, and this tendency to increase would differ between the sexes, with sex and individual differences existing in the elderly subjects.

This study aimed to examine the age-level and sex differences in controlled force exertion and the above-stated hypotheses.

Method

Subjects

The subjects were 207 males (age 42.1±19.8 yrs, height 168.6±7.2 cm, weight 65.8±9.6kg) and 249 females (age 41.7±19.1 yrs, height 156.3±6.4 cm, weight 53.0 ±6.9kg) aged 15 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). Height and weight were similar to Japanese normative values (Laboratory Physical Education in Tokyo Metropolitan University, 1989) for each age-level in both sexes. There were no significant sex differences in the means of age in all age groups. The males had significantly greater mean maximal grip strength and standing height than the females in all age groups. The males had significantly greater mean weight than the females in all age groups except for 70 years or older. Significant correlations were not found among height, weight, age, or controlled force exertion in both sexes, except for the weight of the 15-19yr. old female group (r^2=0.281) and the height of the 60-69yr. old female group (r^2=0.123). Therefore, we judged that the influences of the above-stated factors on controlled force exertion could be neglected, and we did not control each variable by physique in a comparison of the measurements for these two groups. No subject reported previous wrist injuries or upper limb nerve damage, and all were in good health. Prior to enrollment, the purpose and procedure of this study were explained in detail. This protocol was approved by the Institutional Review Board, and informed written consent was obtained from all subjects. No subject previously experienced a controlled force exertion test. Neuromuscular function generally peaks, with the majority of changes occurring during the period from the late teens to twenties, and it then gradually decreases with age after the age of 30 (Bemben, et al., 1991). The subjects were grouped based on age as follows: 15-19 (27 males, 27 females), 20-24 (29 males, 38 females), 25-29 (25 males, 27 females), 30-39 (25 males, 41 females), 40-49 (25 males, 27 females), 50-59 (23 males, 26 females), 60-69 (27 males, 36 females), and 70 and older (26 males, 27 females).

*****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 the 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 taken 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 bar chart on the display screen was used. The display showed both the demand value and the actual grip strength simultaneously. The demand value increased and decreased at a constant frequency (range=5 to 25% of maximal grip strength). Changes in the actual grip-exertion value were displayed as vertical changes in that bar, as with the demand value. The demand values varied over a period of 40 sec. at a frequency of 0.3 Hz. This rate of change is most easily imitated by the neuromuscular function (Hayashi, 1967; Meshizuka & Nagata, 1972). Figure 1 shows the bar chart displays. Details of the apparatus to measure the controlled force exertion have been described (Nagasawa & Demura, 2002). Sufficient rest time was given to eliminate the influence among the tests and the subjects' fatigue (Nagasawa & Demura, 2002). 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. Measurements were not affected by poor vision or fatigue. Subjects in a preliminary experiment were capable of tracking the demand values in the displays.

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

Relative demand values, not absolute demand values, were utilized, since physical fitness and the muscular strength of each individual are different. The relative demand value varied around 5 to 25% of maximal grip strength. The relative demand value was exactly altered to present the same shape of demand function to all subjects, despite the differences in the scale range (grip strength) observed among subjects. The software program was designed to present the relative demand values within a constant range on the display, regardless of whether maximal grip-strength values were large or small. The demand values in this study used bar chart targets which varied cyclically (see Figure 1).

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. 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 prolonged submaximal grip. The subject stood upright with the wrist in the neutral position between flexion and extension and the elbow straight and close to the body when exerting the grip. The duration of each trial was 40 sec., and the controlled force exertion was estimated using the data from three trials, excluding the first 15 sec. of each trial, according to the previous study of Nagasawa et al. (2000). The total sum of the percent of differences between the demand value and the grip strength was used as an estimate of controlled force exertion (Demura & Nagasawa, 2002). Smaller differences were interpreted to be a 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 were analyzed using SPSS (Version 11.5 for Windows). The characteristics of the distribution were evaluated for coefficients of skew, kurtosis, and normality (goodness of fit test: Shapiro-Wilk's W-test) in both the sum total and age groups. To examine the variance of the measurements with age, linear regression coefficients were computed for both males and females, and then the difference was examined. To examine significant differences among the means of the age groups (8 x 2 matrix: age-grade x sex group), two-way analysis of variance (ANOVA) was used after logarithmic based 10 transformation. When a significant main effect was found, a multiple-comparison test was done using a Tukey's Honestly Significant Difference (HSD) method for pair-wise comparisons. In addition, the size of mean differences (effect size) between trials of those in their 20-24yr. 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 deviations unless otherwise specified. An alpha level of 0.05 was taken to be significant for all tests.

Results

Table 2 shows the distribution characteristics of each age group for the controlled force exertion values by sex. Skew values of each age group were all positive values, except for the 20-24yr. old group (0.0) in males. The measurements also showed a right-skewed distribution in both sexes. Normality cannot be assumed in both sexes (males: W=0.87, females: W=0.79, p<0.05), but the measurements in both sexes showed a normal distribution after logarithmic transformation (males: W=0.06, females: W=0.74, p>0.05).

Table 2 near here

Table 3 shows the means of each age group for males and females. Figure 2 shows a graphical representation of means and the results of regression analysis after logarithmic transformation by sex. The means increased with age in both sexes, and a significant and high linear tendency was identified (r^2_{males}=0.88, $r^2_{females}$=0.81, p<0.05). The regression coefficients in both sexes showed an insignificant difference. In the results of two-way ANOVA, interaction was insignificant ($F_{7,\,440}$=1.43, p>0.05), but the main effects of age ($F_{7,\,440}$=70.15, p<0.05) and sex ($F_{1,\,440}$=44.85, p<0.05) were significant. With *post hoc* analyses, means were lower for males in the 15-19yr. old, 20-24yr. old, 25-29yr. old, 30-39yr. old and 40-49yr. old groups than in the groups older than 50 years of age. The means were also lower for males in the 50-59yr. old group than those in the group older than 70 years of age. Means were lower for females in the 15-19yr. old, 30-39yr. old and 40-49yr. old groups than in the groups older than 60 years of age, for those in the 20-24yr. old and 25-29yr. old groups than in the groups older than 40 years of age, and for those in the 50-59yr. old and 60-69yr. old groups than those 70 years and older. There were insignificant differences from the 15-19yr. old to 40-49yr. old groups in both sexes. In addition, females showed significantly higher values over males only in the 70 years and older group.

Table 3 near here

Figure 2 near here

The coefficient of variance was in the same range for all age groups in both sexes

(CV_{males}=20.0～34.8, $CV_{females}$=17.7～36.2), but showed a high value for those older than 40 years of age in males and for those older than 60 years of age in females. The effect size of differences between the mean of 20-24yr. old and the means of age groups older than 40 years of age showed large values over 0.8 in both sexes (Table 3).

Discussion

The mean value of controlled force exertion increased at an almost constant rate in males and females with age, and their increase rate hardly showed a difference between the sexes. In addition, the remarkable differences in both sexes were not found in all age groups, except for the 70 years and older group. The functional role related to movement performances may differ based on the region of the nervous system controlling it, i.e. 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, Massey, Bemben, Misner, & Boileau (1996) reported that the elderly show a noticeable decrease in peripheral muscle activity compared with young people, based on measurements of muscular endurance using intermittent grip strength. From reports by many researchers (Rikli & Busch, 1986; Rikli & Edwards, 1991; Welford, 1988), including Dustman, Ruhling, Russell, Shearer, Bonekat, Shigeoka, Wood, & Bradford (1984), it has been clarified that the reaction time of muscles decreases with age. Controlled force exertion was confirmed to decrease after 40 years of age in both sexes. The present test was performed by submaximal muscular exertion with a moderate cycle (0.3 Hz) of changing demand values. The achievement of this test requires strong hand-eye coordination in feedback such as 'sense of force exertion', 'matching of target', and so forth (see method). 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, Petrini, LaPorte, Sandler, Bayles, Robertson, & Slemenda, 1987). Therefore, elderly people are inferior in controlled force exertion due to exercise (i.e., peripheral muscular responses to the changing target and the exertion of neuromuscular function) to young people, and they require more time to specify a movement dimension (Stelmach, Goggin, & Garcia-Colera, 1987). The above-stated functional developmental difference may produce decreases in exertion values or performance with age.

According to studies by Aniansson, Rundgren, and Sperling (1980), Sperling (1980), Ruff and Parker (1993), and Speller, Trollinger, Maurer, Nelson, and Bauer (1997), males are superior in manual dexterity to females. Houx and Jolles (1993) examined the sex differences in movement speed to reaction time using a manual function in 20 to 80 year olds and reported that the males were superior in movement speed to females in all age groups. Because females are inferior in manual dexterity and movement speed to males, their controlled force exertion was also considered to be inferior (Nagasawa, et al., 2000). However, a difference between males and females was not found in the majority of the age groups or in the improvement rate. Factors such as the above development difference of neuromuscular function controlling exercise, adaptability to a new task, and the sex difference in learning skill for both sexes may influence very little the rate of decrease in performance with age group, because none of subjects previously experienced a controlled force exertion test. Speller et al. (1997) reported that the assessment of movement performance for a manual dexterity task is more appropriate in males with more experience (manual dexterity). From the above, it is inferred that because manual dexterity and movement speed are closely associated with movement experience in daily activities, the sex difference in movement experience has an effect on controlled force exertion. It is possible that continual exercise prevents the decrease in central nervous system function related to high-level information processing, including judgment, muscle volume, and motor performances, and improves controlled force exertion (Skelton, et al., 1994). In the future, it will be necessary to examine the sex difference of movement experience on controlled force exertion and the relationship between controlled force exertion and exercise frequency in daily life.

The differences (effect sizes) between the 20-24yr. old group and groups older than 40 years of age were large in both sexes. Stelmach et al. (1987) examined whether the difference in information prior to the task response affects the elderly's response time and movement time. They reported that, although the elderly persons use pre-information similar to young people to prepare an upcoming movement, the transaction times of information on the movement plan for arms (hands), direction and extension were markedly slower, and the elderly persons required longer movement times. Nakamura, Ide, Sugi, Terada, and Shibasaki (1995) reported that the learning effect of pursuit movements is associated in 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 controlled force exertion test was the same content (the same locus and speed) in all trials and the information in advance was the same, the controlled force exertion still decreased with age. Of the two memory types, declarative and procedural, the latter is considered to control learning and to make exertion values decrease with age. The present results clarified that the mean in groups older than 40 years of age enlarges in both sexes as compared with that of 20-24yr. old group.

Individual differences of the errors in controlled force exertion showed a similar tendency in males and females and tended to increase in individuals older than 60 years of age (the elderly) in both sexes. The exertion type of muscular strength examined in this study differs from that of previous studies, but Butki (1994) reported that subjects need 4 trials to gain some familiarity and to show a significant improvement. Experience with a task and the practice effect influence controlled force exertion and may produce the individual difference. Some elderly people may have poorer adaptive functions, perhaps contributing to a floor effect wherein individual differences in performance are small. In contrast, elderly subjects with superior adaptive functions quickly learn the task and individual differences become larger. It appears that such an increase in individual differences in performance occurs in an elderly group. Nagasawa et al. (2004) reported that the ability exerted by a type of displayed demand value is somewhat different in the controlled force exertion test. Hence, when the demand values differ, the above test will need to be examined in terms of age and sex differences. Moreover, it is necessary to establish an evaluation standard value which can present demand values according to sex and age to diagnose arm function and physical fitness of the aged in medical and rehabilitation fields.

In conclusion, the errors in controlled force exertion tended to increase constantly with age, but the rate of increase was significant for those greater than 40 years of age in both sexes. The change in individual differences was similar for both sexes.

Acknowledgements

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

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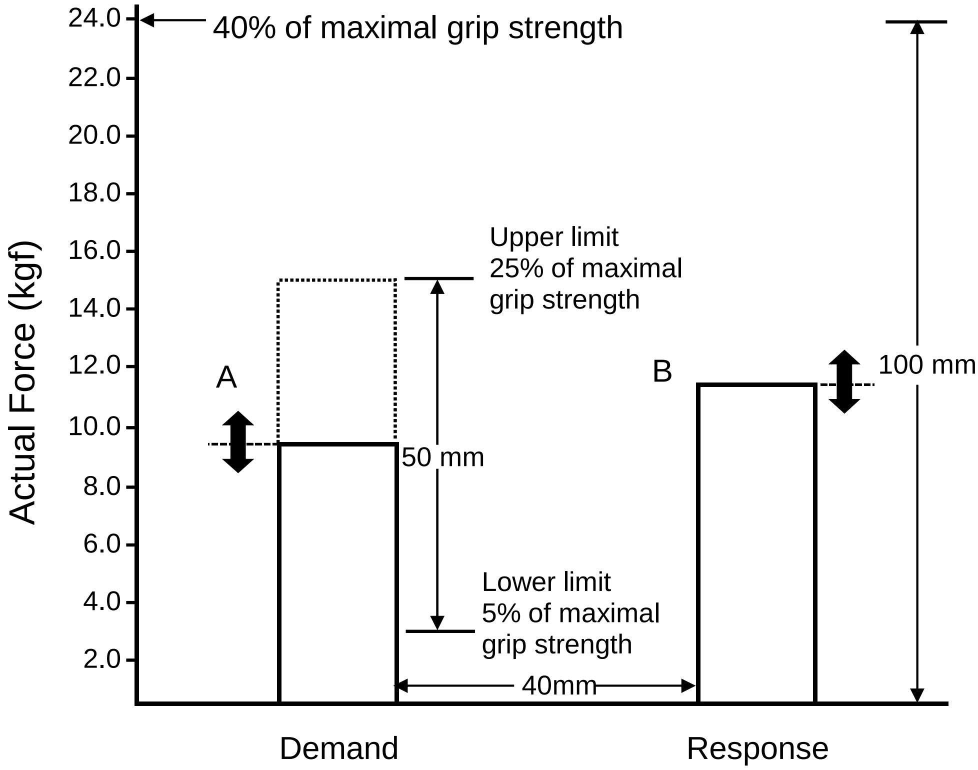

Figure. 1. Bar chart display (100 mm X 140 mm) of demand value. [Left bar (A) shows the demand value and right bar (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in a span of 50 mm on the display. The test 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 display, left.]

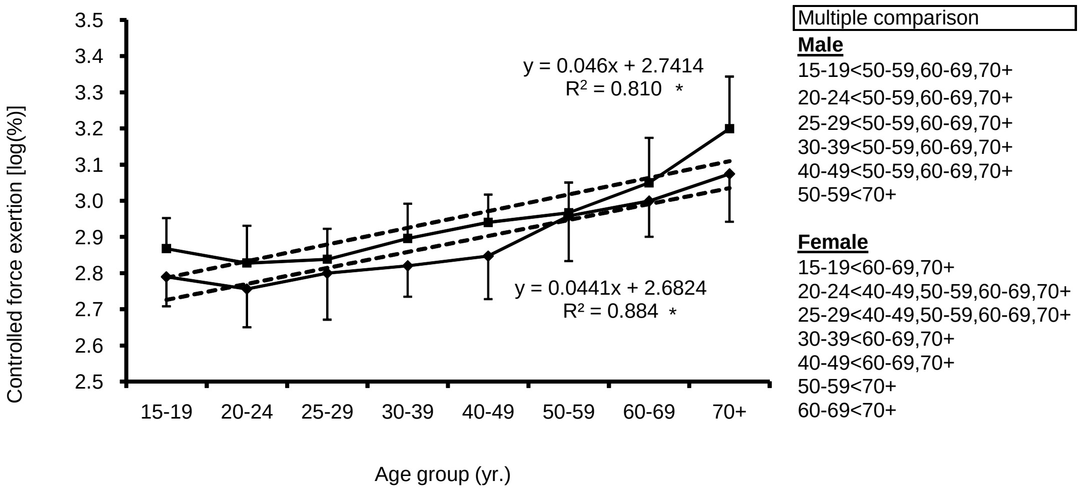

Figure 2. Age-group means of the controlled force-exertion test of the bar chart demand in males (◆) and females (■). *p<0.05.

Table 1. Physical characteristics of participants

Age Group (yr.)	*n*	Age (yr.)		Height (cm)		Weight (kg)		Grip strength (kgf)	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Male									
15-19	27	17.2	1.5	171.4	5.4	63.3	9.0	42.0	7.1
20-24	29	21.9	1.4	171.1	4.6	68.2	7.1	51.2	6.3
25-29	25	27.8	1.3	172.9	5.0	69.4	8.2	48.8	8.0
30-39	25	34.4	3.0	173.1	5.7	72.1	10.8	48.0	7.7
40-49	25	44.9	2.8	169.2	7.0	67.4	7.2	46.4	7.7
50-59	23	54.5	2.9	166.2	6.2	65.8	8.4	41.1	7.3
60-69	27	64.3	3.0	165.0	6.2	63.4	9.3	37.0	7.8
70+	26	74.6	4.2	159.8	6.7	57.0	9.9	27.7	7.7
Total	207	42.1	19.8	168.6	7.2	65.8	9.7	42.8	10.3
Female									
15-19	27	17.1	1.4	159.1	5.2	53.4	5.3	29.1	4.9
20-24	38	22.2	1.3	160.1	4.7	52.8	5.3	31.8	4.4
25-29	27	27.0	1.4	159.3	5.8	51.0	6.4	30.8	4.9
30-39	41	35.1	2.6	158.4	4.8	51.8	7.3	29.4	3.9
40-49	27	44.6	2.7	157.0	5.0	52.3	5.9	30.0	3.8
50-59	26	53.2	3.0	154.7	5.2	54.8	7.5	28.9	4.4
60-69	36	63.7	2.8	153.0	6.0	55.6	8.3	25.1	6.5
70+	27	74.9	4.0	147.6	4.4	51.7	7.8	20.4	4.7
Total	249	41.7	19.1	156.3	6.4	53.0	6.9	28.3	5.8

Table 2. Distribution characteristics of controlled force-exertion scores

Age group (yr.)	*n*	Upper quartile	*Mdn*	Lower quartile	Skew	Kurtosis	Shapiro-Wilk's W	*P*
Male								
15-19	27	678.0	602.8	561.3	1.1	1.3	0.90	0.01
20-24	29	712.0	585.6	480.8	0.0	-1.1	0.95	0.24
25-29	25	783.3	581.8	507.5	1.3	1.4	0.89	0.01
30-39	25	771.4	647.5	566.6	0.6	0.0	0.96	0.42
40-49	25	851.0	666.0	572.0	0.9	0.1	0.91	0.02
50-59	23	1107.5	903.6	705.1	1.1	1.1	0.92	0.06
60-69	27	1245.7	958.2	833.9	0.5	-0.8	0.95	0.21
70+	26	1359.2	1084.2	954.3	1.5	1.4	0.83	<0.01
Total	207	956.9	730.4	582.5	1.8	4.6	0.87	<0.01
Female								
15-19	27	798.0	758.9	683.9	1.2	2.7	0.86	<0.01
20-24	38	814.0	648.0	557.7	1.0	0.6	0.92	0.01
25-29	27	808.9	672.7	582.0	1.0	0.9	0.94	0.10
30-39	41	894.5	796.7	688.0	0.8	1.6	0.96	0.22
40-49	27	979.0	900.6	731.3	0.3	-0.5	0.96	0.33
50-59	26	1072.4	900.1	814.8	0.9	0.9	0.93	0.09
60-69	36	1446.7	1110.6	907.2	0.6	-0.5	0.95	0.12
70+	27	1787.1	1506.9	1282.6	1.2	0.7	0.87	<0.01
Total	249	1067.9	829.9	694.8	2.4	8.2	0.79	<0.01

Table3. Means, standard deviations (%), and coefficients of variation and effect size by age group for controlled force-exertion score in the bar chart demand

Age group (yr.)	*n*	*M*	*SD*	*CV*	*ES*
Male					
15-19	27	627.8	125.2	19.95	0.31
20-24	29	587.1	137.8	23.47	—
25-29	25	659.8	214.3	32.47	0.40
30-39	25	674.6	135.4	20.07	0.64
40-49	25	730.6	212.5	29.09	0.80
50-59	23	946.1	289.0	30.54	1.59
60-69	27	1024.4	235.8	23.02	2.26
70+	26	1246.5	433.4	34.77	2.05
Female					
15-19	27	751.6	153.0	20.35	0.36
20-24	38	692.3	173.8	25.10	—
25-29	27	702.1	142.3	20.26	0.06
30-39	41	806.2	180.7	22.41	0.64
40-49	27	885.1	157.0	17.74	1.16
50-59	26	943.9	190.5	20.18	1.38
60-69	36	1168.0	336.6	28.82	1.78
70+	27	1675.1	607.1	36.24	2.20

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