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Original Article

Age and sex differences of controlled force exertion measured by a computer-generated quasi-random target-pursuit system

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Abstract

Objectives: This study examined age and sex differences of controlled force exertion measured by a computer-generated quasi-random target-pursuit system in 207 males and 249 females aged 15 to 86 years. **Methods:** The participants matched submaximal grip exertion of their dominant hand to changing demand values, appearing as a moving quasi-random waveform on the display of a personal computer. They performed the test three times with 1-min intervals (one trial was 40 sec). The total sum of the percent of differences between the demand value and the grip exertion value for 25 sec was used as an evaluation parameter. **Results:** The errors in controlled force exertion tended to increase constantly with age in both sexes. Significant linear regressions were identified, but there was no significant difference in the rate of increase in both sexes. Analysis of variance showed nonsignificant sex differences among means, except for those in individuals older than 60 years; significant differences between means in the groups older than the 40 yr.-old age group and the 20-24 yr.-old group were found in both sexes. **Conclusions:** Controlled force exertion did not show a significant sex difference and decreased gradually with age in both sexes, but decreased remarkably after 40 years of age.

Keywords: Humans, Adult, Hand Strength, Psychomotor Performance, Sex Difference

Introduction

The nervous and musculoskeletal systems are responsible for the control of human motor performances. Because it is rare to exert maximal effort in daily activities, the efficiency or continuity of submaximal performances[1] is likely to be important. In the elderly and the developmentally delayed, the above is particularly important. It is essential for these individuals to estimate the voluntary movement functions that primarily contribute to skillful and efficient submaximal movements[2], because the exertion of maximal ability involves risks. Skillful and efficient movements that demand feedback, such as manual dexterity, hand-eye coordination, etc., are closely involved in the coordination of the voluntary movement system, i.e., controlled force exertion[2]. The controlled force exertion test evaluates motor control function which coordinates force exertion during a task[3]. To exert motor control smoothly, information from the central and peripheral nervous systems is integrated in the cerebrum[4]. Motor control function is interpreted as superior when muscle contraction and relaxation are smoothly performed in accord with movement of a target with low variability and high accuracy[5]. Grading, space perception, and timing are important elements of controlled force exertion and the test for rational objective estimation of controlled force exertion developed by Nagasawa and Demura[3] requires individual's grip control (gross motor control) and hand-eye coordination. Thus, it is useful for the evaluation of neuromuscular function in elderly persons[6].

Factors such as fatigue, training, age (growth and development), etc. are related to controlled force exertion[7]. Physical fitness (neuromuscular function) generally decreases with age, and individual differences are large in elderly groups[8]. Ran-

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Age Group (yr.)	*n*	Age (yr.) *M*	Age (yr.) *SD*	Height (cm) *M*	Height (cm) *SD*	Weight (kg) *M*	Weight (kg) *SD*	Grip strength (kgf) *M*	Grip strength (kgf) *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 1. Physical characteristics of participants.

ganathan et al.[9] 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 in males. Voelcker-Rehage and Alberts[10] reported that younger subjects were capable of performing the variable force tracking task at a higher level than elderly subjects. Nagasawa et al.[6] examined the characteristics of controlled force exertion by bar chart display in 60 healthy elderly people (30 males, 30 females) aged 65 to 78 years and compared their performance with that of 60 healthy university students (30 males, 30 females) as a control group. They reported that elderly subjects have weaker controlled force exertion than younger subjects of both sexes, and elderly females have significantly weaker controlled force exertion than elderly males, and large individual differences were observed. Nagasawa and Demura[11] established a provisional norm for the controlled force exertion test for each age group using a bar chart display. However, they examined the age group differences of a small sample or the females only. The change (decrease) of controlled force exertion on the quasi-random waveforms with age, sex or individual differences based on a large sample has not been examined in detail. Because the quasi-random signal would prevent subjects from anticipating a demand value, they must exert their force quickly in correspondence to the demand value. On the other hand, because the sinusoidal signal has a predictable change for subjects, they can adjust more easily. Nagasawa et al.[6] noted that a decrease in the ability to exert controlled force will result from an error in controlled force exertion. It will be necessary to establish evaluation standards corresponding to sex and age based on a large sample.

In this study we hypothesized that errors in controlled force exertion would increase with age, and this tendency would differ in both sexes, with sex differences and individual differences existing in the elderly subjects. The purposes of this study were to examine age group and sex differences under controlled force exertion, and to examine the above hypotheses.

Materials and Methods

Participants

Two hundred seven healthy male (*M* age= 42.1 yr., *SD*= 19.8; *M* height= 168.6 cm, *SD*= 7.2 cm; *M* weight= 65.8 kg, *SD*= 9.6) and 249 healthy female volunteers aged 15 to 86 years (*M* age= 41.7yr., *SD*= 19.1, *M* height= 156.3 cm, *SD*= 6.4, *M* weight= 53.0 kg, *SD*= 6.9; see Table 1) without former specific motor skill training, were recruited from high school and university students, office workers, and elderly in Japan. Subjects were not paid for their participation. All were right-handed, based on the Oldfield inventory[12]. Mean values of height and weight were similar to Japanese normative values[13] for each age group and both sexes. There were no significant sex differences in all mean age groups. Males had significantly greater mean maximal grip strength and standing height than females in all age groups. The

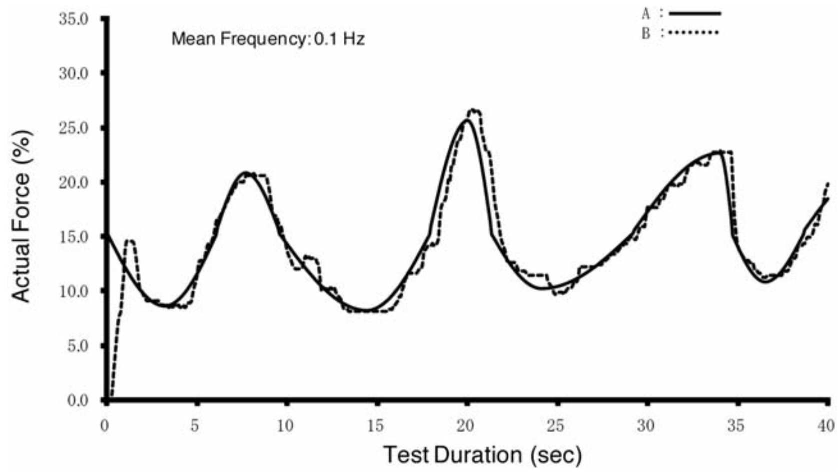

Figure 1. Quasi-random waveform display (100 mm x 140 mm) of the demand value. The solid waveform (**A**) shows the demand value and the broken waveform (**B**) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in the range of 5 to 25% of maximal grip strength value. The demand value was changed to random in π with amplitude and in π/2 with frequency. 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.

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, and the controlled force exertion in both sexes, except for the weight of the 15-19 yr.-old female group (r^2= 0.281) and the height of the 60-69 yr.-old female group (r^2= 0.123). Therefore, we judged that the influences of the above factors on controlled force exertion could be neglected, so each variable was not controlled in a comparison of the measurements for these two groups. No participant reported previous wrist injuries or upper limb nerve damage, and all were in good health, with no history of central or peripheral neurological disease. Prior to enrollment, the purpose and procedure were explained in detail. This protocol was approved by the Ethics Committee (Kanazawa University Health and Science Ethics Committee), and written informed consent was obtained from all participants. No participant had previously performed a controlled force exertion test. Neuromuscular function generally peaks, with the majority of changes occurring from the late teens to twenties, and then gradually decreases across age groups after age 30[8]. The participants were grouped based on age (yr.) as follows: 15-19, 20-24, 25-29, 30-39, 40-49, 50-59, 60-69, and 70-and-older. Participants over 60 year of age were defined as elderly in this study.

Test and Test Procedure

In this study, the participants performed a grip exertion, attempting to minimize the differences between a demand value and the value of grip exertion 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 (Elecom, Tokyo, Japan) after A/D conversion with a quantization bit rate of 12 bits (input range of 1 to 5V). Measurements of grip exertion and controlled force exertion were measured with a Smedley-type mechanical handgrip dynamometer (GRIP-D5101; Takei, Tokyo, Japan), with an accuracy of ±2% in the range of 0 to 979.7 N (output range of 1 to 3V).

Based on a preliminary investigation[3], a waveform was used on the display screen. The display showed both the demand value and the actual grip exertion 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 sec. at a frequency of 0.1 Hz. This rate of change is most easily imitated by the neuromuscular function[14,15]. The demand values of the quasi-random waveform changed at random in π with amplitude and in π/2 with frequency, and increased and decreased in the range of 5 to 25% of maximal grip exertion. Figure 1 shows the quasi-random waveform displays.

Rest periods occurred at 1-min. intervals among trials to eliminate the influence of previous tests and fatigue[3]. Participants 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 (Landolt ring chart) or fatigue (Borg's 10 scales). Comparable individuals in a preliminary experiment were capable of tracking the demand values in the displays.

Relative demand values, not absolute demand values, were utilized, since physical fitness and the muscular strength of each individual are different. The value varied from 5 to 25% of maximal grip exertion. The demand value was exactly altered to present the same shape of demand function to all participants, despite the differences in the scale range (grip strength) observed among individuals. The software program was designed to present the demand values within a constant range on the display,

Age group (yr.)	*n*	Upper quartile	*Mdn*	Lower quartile	Skew	Kurtosis	Shapiro-Wilk's W	*P*
Male								
15-19	27	649.5	574.4	475.8	0.2	-0.1	0.99	0.96
20-24	29	610.4	521.7	405.2	0.1	-0.6	0.98	0.88
25-29	25	684.5	597.1	500.8	1.7	6.2	0.86	<0.01
30-39	25	841.2	595.1	499.1	1.4	1.8	0.87	<0.01
40-49	25	780.0	707.3	549.2	0.2	-0.3	0.98	0.85
50-59	23	919.2	788.0	611.3	0.6	0.1	0.95	0.36
60-69	27	929.3	746.4	646.5	2.1	4.8	0.78	<0.01
70+	26	1557.1	1018.9	791.0	0.6	-1.2	0.85	<0.01
Total	207	802.5	654.2	541.5	1.7	3.7	0.85	<0.01
Female								
15-19	27	862.8	725.3	571.3	1.0	1.2	0.94	0.15
20-24	38	670.6	591.2	513.1	1.4	3.9	0.92	0.01
25-29	27	799.9	694.0	582.9	0.9	1.9	0.94	0.15
30-39	41	852.5	686.3	565.9	3.3	15.9	0.73	<0.01
40-49	27	852.7	751.9	651.0	1.3	2.6	0.89	0.01
50-59	26	1180.0	872.7	722.8	0.3	-0.8	0.95	0.27
60-69	36	1249.4	1073.8	844.8	1.2	2.5	0.92	0.02
70+	27	1879.7	1327.3	1106.6	2.1	6.1	0.79	<0.01
Total	249	1020.1	782.9	620.1	3.0	15.7	0.78	<0.01

Table 2. Distribution characteristics of controlled force-exertion scores.

regardless of whether maximal grip-strength values were large or small. The demand values in this study used the quasi-random wave targets, which varied cyclically (see Figure 1).

Grip width was individually adjusted to achieve a 90°angle with the subject's proximal-middle phalanges. The subject performed maximal grip-hold exertion with the dominant hand twice at 1-min. intervals, and the greater value was taken as the value of maximal grip strength[3,6]. The test of controlled force exertion was performed in three trials at 1-min. intervals after one practice trial. The size of the grip was set so that the subject easily controlled the grip. The test of controlled force exertion was similar to a commonly used test of grip strength[16,17], except for the exertion of prolonged submaximal grip. The participants stood upright with the wrist in the neutral position between flexion and extension and the elbow extended and close to the body and then exerted the grip. No participants complained of hand pain during the procedure.

The duration of each trial was 40 sec. 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.[6]. The total sum (the value accumulated for 25 sec.) of the percent of differences between the demand value and the grip exertion was used as an estimate of controlled force exertion[3]. Smaller differences were interpreted as superior capability to control force exertion. Each subject was free to adopt a standing position most conducive to a clear view of the display[3]. Of the three trials, the mean of the second and third trials was used for analysis[18].

Statistical analysis

Data were analyzed using SPSS (Version 11.5 for Windows). The characteristics of distribution were evaluated for coefficient of skew, kurtosis, and normality (goodness of fit test: Shapiro-Wilks test) in both sum total and age groups. To examine the variance of measurements with age, linear regression coefficients were computed for both males and females and then the difference was examined. To examine significant differences among age group means (8 x 2 matrix: age group x sex group), two-way analysis of variance was used after logarithmic 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 the 20-24 yr.-old group and each age group trial 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 used for all tests.

Results

Table 2 shows distribution characteristics of each age group for the controlled force exertion values by sex. Skew values of each age group were all positive and the measurements showed a right-skewed distribution in both sexes. Normality

Age group (yr.)	*M*	*SD*	*CV*	*ES*
Male				
15-19	577.0	132.94	23.0	0.49
20-24	508.9	144.22	28.3	–
25-29	599.2	193.49	32.3	0.53
30-39	677.6	251.31	37.1	0.82
40-49	685.7	156.92	22.9	1.17
50-59	792.2	229.66	29.0	1.48
60-69	847.3	354.31	41.8	1.25
70+	1128.2	392.73	34.8	2.09
Female				
15-19	754.5	245.24	32.5	0.67
20-24	613.6	166.06	27.1	–
25-29	713.5	186.30	26.1	0.57
30-39	733.5	274.79	37.5	0.53
40-49	795.0	221.71	27.9	0.93
50-59	915.2	262.48	28.7	1.37
60-69	1101.9	366.26	33.2	1.72
70+	1588.1	737.29	46.4	1.82

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

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

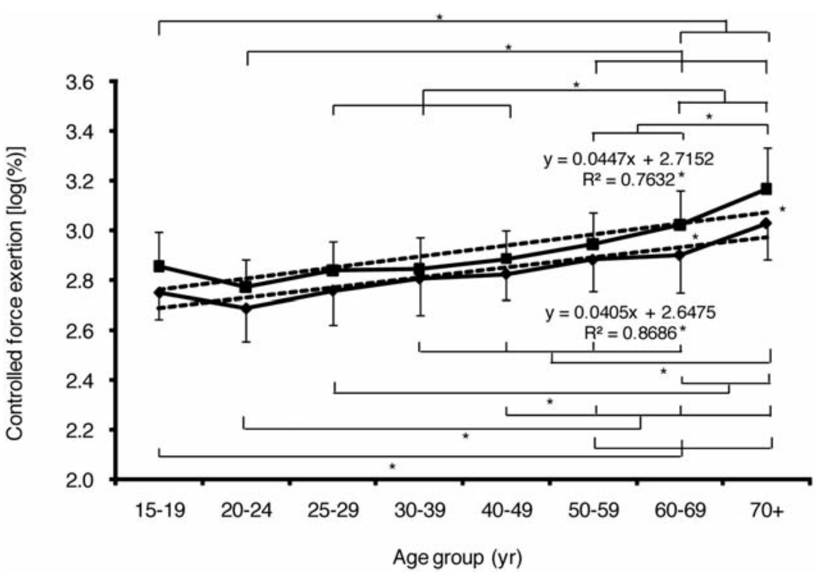

Figure 2. Age group means of the controlled force exertion test with quasi-random wave demand in males (◆) and females (■). *p<0.05.

could not be assumed (Males: W= 0.85, Females: W= 0.78, p<0.05), but their measurements showed a normal distribution after logarithmic transformation in both sexes (Males: W= 0.09, Females: W= 0.09, p>0.05).

Table 3 shows means of each age group for males and females. Figure 2 gives a graphic representation of means after logarithmic transformation and the results of regression analysis by sex. The means increased with age in both sexes, and a significant and high linear tendency was identified (Males: r^2= 0.87, Females: r^2= 0.76, p<0.05). The regression coefficients for both sexes were not significantly different. In a two-way analysis of variance, interaction was nonsignificant ($F_{7,440}$= 0.94, p>0.05), but the main effects of age groups ($F_{7,440}$= 43.94, p<0.05) and sexes ($F_{1,440}$= 49.11, p<0.05) were significant.

With *post hoc* analysis, means in males were lower in the 20-24 yr.-old group than in the 40-49 yr.-old group. The 15-19 yr.-old and the 20-24 yr.-old groups had lower means than the 50-59 yr.-old group. The 15-19 yr.-old, 20-24 yr.-old, and 25-29 yr.-old groups had lower means than the 60-69 yr.-old group. The groups younger than 60 years of age had lower means than the group older than 70 years of age. In females, means were lower in the 20-24 yr.-old group than in the 50-59yr.-old group. The 15-19 yr.-old, 20-24 yr.-old, 30-39 yr.-old and 40-49yr.-old groups had lower means than the 60-69 yr.-old group. The groups younger than 60 years of age had lower means than the group older than 70 years of age. There were nonsignificant differences between groups younger than 40 years of age in both sexes. In addition, females showed significantly high values only in the 60-69 yr.-old and the group older than 70 years of age.

The coefficient of variance was in the same range for all age-groups in both sexes (Males: CV= 22.9 to 41.8, Females: CV= 26.1 to 46.4), but showed a high value in the groups older than 60 years of age in males as well as in the groups older than 70 years of age in females. The effect size of mean differences between the groups of 20-24yr.-old and each other age showed high values over 0.9 in age groups older than 40 years in both sexes (Males: ES= 1.17 to 2.09, Females: CV= 0.93 to 1.82; see Table 3).

Discussion

Although the grip size of the controlled force exertion test was set so that the subject easily controlled the grip, most participants used the same grip size as that for maximal grip-hold exertion. Therefore, we judged that the influences of the selected grip size on age group and sex differences were small. The means of errors in controlled force exertion increased with a constant rate in males and females with age, and the rate of increase hardly showed a marked difference. In addition, the differences in both sexes were not found in all age groups, except for the groups older than 60 years of age. The functional role related to movement performances may differ based on the region of the nervous system controlling each 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[4,19]. Bemben et al.[20] reported that elderly persons show a noticeable decrease in periphery muscle activity compared with that of young people, based on the measurement of muscular endurance using intermittent grip exertion. From reports by many researchers[21-24], it is clear that the reaction time of movement decreases with age. The 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 (0.1 Hz) of changing demand values. Performance of this test requires strong hand-eye coordination (see Methods) and function exertion is controlled by feedforward such as prediction and estimation or feedback such as "sense of force exertion," "matching of target," and so forth. The decrease in muscular strength is based on changes of neuromuscular pathways and muscle fiber composition, spinal motor neuron apoptosis[25], and by muscle atrophy with age[26]. Therefore, elderly people, as compared with young people, have less control of force exertion due to fatigue and exercise, i.e., peripheral muscular responses to the changing target and the exertion of neuromuscular function, and require more time to specify a movement dimension[27]. The above functional developmental difference is thought to produce differences in exertion values or performances with age.

According to studies on manual dexterity with respect to nervous function by Ruff and Parker[28], and Speller et al.[29], manual dexterity of the males was superior to that of the females. Houx and Jolles[30] reported that the movement speed to reaction time using manual dexterity was superior in males among subjects in all age groups in 20- to 80-year olds. Because females have inferior manual dexterity and movement speed, the controlled force exertion was considered to be inferior[6]. However, no sex difference was found in almost all age groups, and there was no difference in the improvement rate of both sexes. Factors such as the above development difference of neuromuscular function controlling exercise, adaptability to a new task, and a sex difference in learning skill may not affect performance greatly across age groups, because none of participants had previously performed a controlled force exertion test. Speller et al.[29] reported that the assessment of movement performances for a manual dexterity task is most appropriate for a population of males with more movement experience (manual dexterity). In these circumstances, it is inferred that the sex difference in movement experience has an effect on the controlled force exertion because manual dexterity and movement speed, etc. are closely associated with movement experience in daily activities. It is suggested that continued exercise will prevent the decrease of the central nervous system function that participates in high-level information processing, such as judgment, muscle volume and motor performance, and improve controlled force exertion[17]. Therefore, it will be necessary to examine the subjects for crosswise differences in controlled force exertion and the relationship between controlled force exertion and aspects of living conditions such as frequency of exercise.

The differences in the current study between the 20-24 yr.-old group and groups older than 40 years of age were large in both sexes. Stelmach et al.[27] examined whether differences in information given prior to a task response affect elderly persons' response initiation and movement times. They reported that although the elderly, like the young, use pre-information to prepare an upcoming movement, information processing of the movement plan for the arms (hands), direction and extension were markedly slower in elderly persons than in the younger persons. Thus an elderly group requires longer movement times. Although the present controlled force exertion test was the same (same locus and speed) in all trials and the information given prior to response was the same, measured values increased with age. Although the present findings can not be directly compared with the work of Stelmach et al.[27] because their task primarily depends on online controls, it is inferred that a decrease of movement time related to grip control influences learning and increases exertion values with age. The measurements of the controlled force exertion test were confirmed to increase greatly after 40 years of age in both sexes.

Individual differences showed a similar tendency in males and females, and seemed to increase in groups older than 60 years of age (the elderly) in both sexes. Butki[31] reported that subjects need several trials to gain familiarity with a task and to show significant improvement. Experience with a task and practice influence controlled force exertion measurements, and may influence observed individual differences. Some elderly people may have poorer adaptive functions, perhaps contributing to a floor effect wherein individual differences in performance are small. In contrast, elderly persons with superior adaptive functions can learn the task quickly and observed individual differences become larger. It appears that such an increase of individual differences in performance occurs in an elderly group. On the other hand, Nagasawa et al.[18] reported that the ability exerted by a type of displayed demand value is somewhat different in the controlled force exertion test. Hence, when using other demand values, it may be necessary to examine separately age group and sex differences on the controlled force exertion test. Moreover, it is necessary to establish an evaluation standard value corresponding to sex and age according to a type of displayed demand value to diagnose arm and neuromuscular functions in the aged in the medical and rehabilitation fields.

In conclusion, the controlled force exertion tends to decrease constantly with age, but the decrease is remarkable with after 40 years of age in both sexes. The change in individual differences is similar for both sexes.

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