Journal of
PHYSIOLOGICAL
ANTHROPOLOGY

Age and Sex Differences of Controlled Force Exertion Measured by a Computer-generated Sinusoidal Target-pursuit System

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Abstract This study examined age and sex differences of controlled force exertion in 207 males and 249 females aged 15 to 86 years. The subjects matched the submaximal grip strength of their dominant hand to changing demand values, appearing as a sinusoidal waveform on the display of a personal computer. The total difference (%) between the demand value and the grip exertion value for 25 sec was used as an evaluation parameter. Significant linear regressions were identified, but there was no significant difference in the rate of increase of both sexes. Analysis of variance showed insignificant differences among the means of both sexes, except for those of the 20–24yr-old group, and the differences between means of subjects greater than 50 years of age and 20 years of age increased in both sexes. Individual differences were almost the same in both sexes. The errors in controlled force exertion did not show a significant sex difference and tended to increase with age in both sexes. However, their rates of increase were significant only after 50 years of age. *J Physiol Anthropol 28(4): 199–205, 2009* http://www.jstage.jst.go.jp/browse/jpa2
[DOI: 10.2114/jpa2.28.199]

Keywords: humans, adult, hand strength, psychomotor performance, sex difference

Introduction

The nervous and musculoskeletal systems are responsible for the control of human motor performance. Because it is rare to exert maximal effort in daily activities, the efficiency or continuity of submaximal performance (Halaney and Carey, 1989) is likely to be important. For infants, elderly persons, and the developmentally delayed, it is essential to estimate primary voluntary movement functions which are typically skillful and efficient submaximal movements (Henatsch and Langer, 1985). Local movements which demand feedback, such as hand-foot movements, hand-eye coordination, etc., are closely involved in the coordination of the voluntary movement system, i.e., controlled force exertion (Henatsch and Langer, 1985). The controlled force exertion test evaluates motor control function which coordinates force exertion during a task. To exert motor control smoothly, information from the central and peripheral nervous systems is integrated in the cerebrum. 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 (Brown and Bennett, 2002). The test for rational objective estimation of grading, 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. Thus, it is useful for the evaluation of neuromuscular function in elderly persons (Nagasawa et al., 2000).

Factors such as fatigue, training, age (growth and development), etc. influence controlled force exertion (Yamamoto, 1983). Physical fitness (neuromuscular function) generally decreases with age, and individual differences are large in elderly groups (Bemben et al., 1991). Ranganathan et al. (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 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. Therefore, it is believed that elderly subjects have weaker controlled force exertion than younger subjects, as well as manual control and grip control. However, the mechanism and sex difference behind the increase in errors in controlled force exertion remains unexamined.

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

Methods

Subjects

The subjects were 207 males (*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 females (*M* age=41.7 yr, *SD*=19.1; *M* height=156.3 cm, *SD*=6.4, *M* weight=53.0 kg, *SD*=6.9) aged 15 to 86 years (see Table 1). All were right-handed, based on the Oldfield inventory (1971). Mean values of height and weight were similar to Japanese normative values (Laboratory of Physical Education, Tokyo Metropolitan University, 1989) for each age group and both sexes. There were no significant sex differences in 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, 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 subject 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 subjects. No subject 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 (Bemben et al., 1991). The subjects 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. Subjects over 60 year of age were defined as elderly people in this study.

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 with a quantization bit rate of 12 bits (input range of 1 to 5 V). Measurements of grip strength and controlled force exertion were measured with a Smedley-type

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

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 3 V).

Based on a preliminary investigation (Nagasawa and Demura, 2002), a waveform was used on the display screen. The display showed both 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 sec at a frequency of 0.1 Hz. This rate of change is most easily imitated by the neuromuscular function (Hayashi, 1967; Meshizuka and Nagata, 1972). Figure 1 shows the sinusoidal waveform displays. Details of the apparatus used to measure the controlled force exertion have been described previously (Nagasawa and Demura, 2002).

Rest periods occurred at 1 min intervals among trials to eliminate the influence of previous tests and fatigue (Nagasawa and Demura, 2002). The measurement condition was standardized. 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. Comparable subjects 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 relative demand value varied from 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 the sinusoidal wave targets, which varied cyclically (see Fig. 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 (Nagasawa et al., 2000; Nagasawa and Demura, 2002). 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 (Walamies and Turjanmaa, 1993; Skelton et al., 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 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,

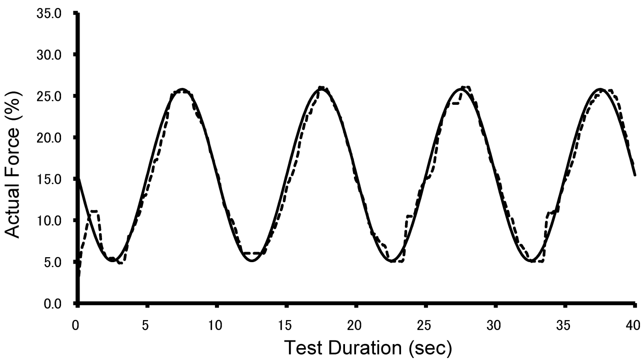

Fig. 1 Sinusoidal waveform display (100 mm×140 mm) of the demand value. The solid waveform (A) shows the demand value and the broken waveform (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in the range of 5–25% of 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.

excluding the first 15 sec of each trial, according to the previous study of Nagasawa et al. (2000). The total sum (the value accumulated for 25 sec) of the percent of differences between the demand value and the grip strength was used as an estimate of controlled force exertion (Demura and Nagasawa, 2002). 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 (Demura and Nagasawa, 2002). Of the three trials, the mean of the second and 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 distribution were evaluated for coefficient of skew, kurtosis, and normality test (goodness of fit test: Shapiro–Wilks test) in both sum total and age groups. To examine the variance with age of measurements, linear regression coefficients were computed for both males and females and then the difference was examined. To examine significant differences among age group means (8×2 matrix: age group×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.

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	854.4	635.7	563.0	1.2	1.5	0.91	0.03
20–24	29	790.6	641.2	491.3	0.7	0.2	0.95	0.23
25–29	25	934.8	647.2	595.9	0.1	−0.4	0.97	0.64
30–39	25	1007.6	733.1	597.3	1.3	2.4	0.88	0.01
40–49	25	907.9	756.7	609.2	0.0	−0.8	0.98	0.81
50–59	23	1082.9	958.4	802.9	0.8	2.1	0.94	0.19
60–69	27	1180.3	968.8	873.1	0.7	0.6	0.93	0.06
70+	26	1525.6	1295.7	905.4	1.3	2.2	0.90	0.01
Total	207	1008.5	829.8	628.4	1.9	6.7	0.89	<.01
Female								
15–19	27	929.5	820.5	711.6	1.0	1.7	0.93	0.08
20–24	38	1000.8	759.8	632.9	0.4	−1.0	0.93	0.02
25–29	27	1008.0	755.1	649.3	1.0	0.1	0.90	0.01
30–39	41	1070.3	890.1	745.7	1.7	5.5	0.89	<.01
40–49	27	1127.8	883.8	786.1	1.4	1.7	0.87	<.01
50–59	26	1206.0	1070.1	896.1	1.6	3.3	0.86	<.01
60–69	36	1399.6	1110.6	981.7	1.9	4.3	0.82	<.01
70+	27	1748.6	1302.7	1091.2	1.7	2.7	0.83	<.01
Total	249	1159.6	951.6	757.3	2.2	7.9	0.84	<.01

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 except for the 40–49 yr-old group (0.0) in females and the measurements showed a right-skewed distribution in both sexes. Kurtosis values were all less than or equal to three except for the male 30–39 yr-old (5.5), 50–59 yr-old (3.3), and 60–69 yr-old (4.3) groups, and the distributions were platykurtic. The skew and kurtosis for the distribution of all males were 1.9 and 6.7, respectively, and normality could not be assumed ($W=0.89$, $p<0.05$). Upper quartile, median (*Mdn*), and lower quartile were 628.4%, 829.8%, and 1008.5%, respectively. The skew and kurtosis for the distribution of all females were 2.2 and 7.9, respectively, and normality could not be assumed ($W=0.84$, $p<0.05$). Upper quartile, median (*Mdn*), and lower quartile were 757.3%, 951.6%, and 1159.6%, respectively. Their measurements showed a normal distribution after logarithmic transformation in both sexes (Males: $W=0.09$, Females: $W=0.08$, $p>0.05$).

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: $r^2=0.85$, Females: $r^2=0.89$, $p<0.05$). The regression coefficients for both sexes were similar and not significantly different. In a two-way analysis of variance, interaction was insignificant ($F_{7,440}=0.40$, $p>0.05$), but the main effects of age groups ($F_{7,440}=33.51$, $p<0.05$) and sexes ($F_{1,440}=41.95$, $p<0.05$) were significant. With *post hoc* analysis, means in males were lower in the 15–19 yr-old, 20–24 yr-old, and 25–29 yr-old groups than in the groups older than 50 years of age. The 30–39 yr-old, 40–49 yr-old, and the 50–59 yr-old groups had lower means than the group of 70 years or older. In females, means were lower in the 15–19 yr-old and 30–39 yr-old groups than in the groups older than 60 years of age. The 20–24 yr-old and 25–29 yr-old groups had lower means than the groups older than 50 years of age. The 40–49 yr-old and 50–59 yr-old groups had lower means than the group older than 70 years. There were insignificant differences between groups younger than 50 years of age in both sexes. In addition, females showed significantly high values only in the 20–24 yr-old group.

Table 3 Means, standard deviations (%), and coefficients of variation and effect size by age group for controlled force-exertion score

Age Group (yr.)	*n*	*M*	*SD*	*CV*	*ES*
Male					
15–19	27	706.7	199.4	28.21	0.25
20–24	29	652.3	230.9	35.39	
25–29	25	726.2	216.4	29.80	0.33
30–39	25	794.2	249.2	31.37	0.59
40–49	25	770.3	194.3	25.23	0.55
50–59	23	959.5	212.6	22.16	1.38
60–69	27	1012.4	279.2	27.58	1.41
70+	26	1340.4	521.4	38.90	1.71
Female					
15–19	27	852.0	222.9	26.16	0.23
20–24	38	802.4	213.2	26.57	
25–29	27	833.7	249.1	29.87	0.13
30–39	41	915.9	241.8	26.40	0.50
40–49	27	995.0	290.0	29.15	0.76
50–59	26	1109.1	318.4	28.71	1.13
60–69	36	1227.8	411.0	33.47	1.30
70+	27	1498.9	609.1	40.63	1.53

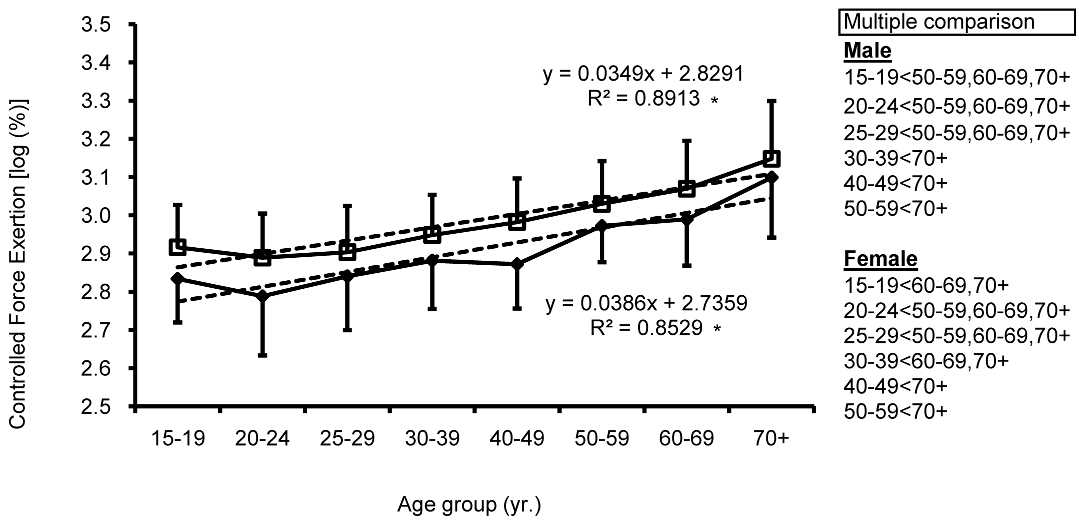

Fig. 2 Age-group means for the controlled force-exertion test with sinusoidal demand in male (◆) and female (□). $*p<0.05$.

The coefficient of variance was in the same range for all age-groups in both sexes (Males: $CV=22.2$ to 38.9, Females: $CV=26.2$ to 40.6), but showed a high value in the groups younger than 30 years of age and in the groups older than 60 years of age in males as well as in the groups older than 60 years of age in females. The size of mean differences (effect size) between the groups of 20–24 yr-old and each other age group showed high values over 1.0 in age groups older than 50 years in both sexes (Table 3).

Discussion

Although the grip size of the controlled force exertion test was set so that the subject easily controlled the grip, most subjects used the same grip size as that for maximal grip-hold exertion. Therefore, we judged the influences of the selected grip size on age group and sex differences to be small. The means errors in controlled force exertion increase with an almost constant rate in males and females with age, and their rate of increase hardly showed a marked difference. In addition, the marked differences in both sexes were not found in all age groups, except for the 20–24 yr-old 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 et al. (1996) 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 strength. From reports by many researchers (Rikli and Busch, 1986; Rikli and Edwards, 1991; Welford, 1988), including Dustman et al. (1984), it is clear that the motor time of muscles decreases with age. The controlled force exertion was confirmed to decrease after 50 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 (Galganski et al., 1993), and by muscle atrophy with age (Cauley et al., 1987). Therefore, elderly people have an inferior nerve mechanism of 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 (Stelmach et al., 1987). 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 Aniansson et al. (1980), Sperling (1980), Ruff and Parker (1993), and Speller et al. (1997), manual dexterity of the males was superior to that of the females. Houx and Jolles (1993) examined sex differences in movement speed to reaction time using a manual function in 20 to 80 year olds and reported that the movement speed of males was superior to that of females among subjects in all age groups. Because females have inferior manual dexterity and movement speed, the controlled force exertion was considered to be inferior (Nagasawa et al., 2000). However, there was no sex difference 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 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 most appropriate for a population of males with more movement experience (manual dexterity). In these circumstances, it is inferred that the sex difference in experience with movement 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, and also prevent decreases in muscle volume and motor performance, and improve controlled force exertion (Skelton et al., 1994). Therefore, it is necessary to examine for the subject the crosswise difference 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 50 years of age were large in both sexes. Stelmach et al. (1987) examined whether differences in information given prior to task response affects elderly persons' response initiation and movement times. It is reported that, although elderly persons use such information as young people do in preparing for upcoming movement, the transaction times of information in the movement plans for the arm (hand), direction and extension were markedly slower among elderly persons than in the younger subjects. Thus an elderly group requires longer movement times. Nakamura et al. (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 movement of a target (procedural memory). Although the present controlled force exertion test was the same (the same locus and speed) in all trials and the information given prior to response was the same, measured accuracy decreased with age. Of the above memories, the latter decrease is considered to control learning and make exertion values decrease with age. The measurements of the controlled force exertion test are confirmed to decrease largely after 50 years of age in both sexes.

Individual differences showed a similar tendency in men and women, and seemed to increase in groups older than 60 years of age (the elderly) in both sexes. Butki (1994) 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 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. On the other hand, 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, it may be necessary to examine another age group and sex differences on the controlled force exertion test. Moreover, it is necessary to establish by a type of displayed demand value an evaluation standard value corresponding to sex and age to diagnose arm functions and physical fitness in the aged in the medical and rehabilitation fields.

Conclusion

The errors in controlled force exertion tended to increase constantly with age, but the rate of increase was significant for those greater than 50 years of age in both sexes. The change in individual differences was similar for both sexes.

Acknowledgement This study was supported in part by a grant-in-aid for Scientific Research (project number 17700476 and 20500506) to Y. Nagasawa from the Ministry of Education, Science and Culture of Japan.

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Received: February 24, 2009
Accepted: June 3, 2009

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