Provisional norms by age group for Japanese males on the controlled force exertion test using a quasi-random display

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Title Page

Original Article

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Running title:

Norm of controlled force exertion measurement

Abstract

Objectives: This study aimed to examine age group and individual differences in the controlled force exertion test by quasi-random display and to propose a provisional norm in 207 males who were right-handed and aged 15 to 86 years. **Methods:** The subjects matched exertion values of their submaximal grip strength to changing demand values, appearing as a quasi-random wave on the display of a personal computer. The quasi-random waveform was changed in π with amplitude and in π/2 with frequency (peak and mean frequency were 0.1 Hz in both waveforms). The subjects performed the controlled force exertion test three times at 1-min intervals (single trials were 40 sec), after one practice trial using the dominant hand. The total of the differences (%) between the demand value and the grip exertion value for 25 sec was used as an evaluation parameter. **Results:** The measurements showed a right-skewed distribution, which was normal after logarithmic transformation. Analysis of variance showed significant differences among means of each age group, and test performance decreased after 40 years of age. Norms for each age group were established. **Conclusions:** An individual's controlled force exertion by the provisional norm devised in this study can be properly evaluated.

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

Text

Introduction

The functions of the nervous and musculoskeletal systems are responsible for the control of human motor performance. Because it is rare for a person to exert maximal ability during typical daily activities, the efficiency or continuity of submaximal ability [1] is likely to be important. For infants, the elderly and the developmentally delayed, it is essential to estimate the primary voluntary movement functions that determine skillful and efficient submaximal movements [2]. Local movements that 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[2]. The controlled force exertion test can evaluate motor control function, which coordinates force exertion for each motor task. To smoothly exert motor control, information from the central and peripheral nervous systems is integrated in the cerebrum. Motor control function is interpreted to be superior when muscle contraction and relaxation are smoothly coordinated according to the movement of a target, with low variability and high accuracy [3].

Nagasawa and Demura [4] studied the tracking movement in submaximal strength exertion and developed a new test for the rational objective estimation of grading, spacing, and timing, which are important elements of controlled force exertion, by using a grip dynamometer coupled with a personal computer. This new test was reported to have high reliability [5] and to measure a somewhat different ability from that measured by the pursuit-rotor and pegboard tests [6]. It requires grip control (gross motor control) and hand-eye coordination; hence, it is useful as a test to evaluate the neuromuscular function of the elderly [7].

It has been known that physical fitness (neuromuscular function) generally decreases with age, and its individual variation is large among the elderly [8]. Nagasawa, et al. [7] reported that elderly subjects had weaker controlled force exertion than younger subjects. Individual measurements are evaluated by standards or norms. Hence, to use the controlled force exertion test to evaluate the characteristics and recovery conditions of movement functions, we must make up rightly standardized evaluation criteria for each age group. Nagasawa and Demura [9] established a provisional norm for the controlled force exertion test for each age group using a bar chart display. It is desirable that the demand value shows a different locus each time to avoid memorization of the locus of the demand values by the subjects; furthermore, an accurate measurement method must be developed [10]. However, this problem has been examined little. According to Nagasawa, et al. [6], the ability exerted in response to a displayed demand value differs with age. We hypothesized that the controlled force exertion value decreases with age.

The purposes of this study were to examine age group and individual differences in the measurements of the controlled force exertion test by the quasi-random waveform display and to propose an analytical procedure and semantic interpretation of a norm for Japanese male adults.

Materials and Methods

Subjects

The subjects were 207 males aged 15 to 86 years (*M* age = 42.1yr., SD = 19.8, *M* height = 168.6 cm, SD = 7.2, *M* weight = 65.8 kg, SD = 9.7) (See Table 1). All were right-handed, as assessed by Oldfield's inventory [11]. Height and weight were similar to Japanese normative values [12] for each age-level. 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 had previously performed a controlled force exertion test. Neuromuscular function generally reaches a peak with marked changes from the late teens to twenties and then gradually decreases with age after 30 [8]. The subjects were grouped according to age as follows: 15-19, 20-24, 25-29, 30-39, 40-49, 50-59, 60-69, and 70 and older.

*****Table 1 near here*****

Test and Test Procedure

In this study, the subjects performed grip exertion, attempting to minimize the differences between a demand value and the value of their 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 (Elecom, Tokyo, Japan) after A/D conversion. 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 previous study [4], 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 and the demand value were displayed as changes in the waveforms from left to right visually and spatially with time. 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 muscle-nerve function [13, 14]. 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 strength. Figure1 shows the displays of quasi-random waveforms. Details of the apparatus to measure the controlled force exertion have been previously described [4]. A sufficient rest period was given to eliminate the influence among the tests and from the subjects' 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. Measurements were not affected by poor vision or fatigue. In a pilot experiment, it was confirmed that subjects are capable of tracking the demand values in both displays.

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

Relative demand values, not absolute demand values, were used since the physical fitness and muscular strength of each individual are different. The relative demand value varied in the range of 5 to 25% of maximal grip strength. All subjects were presented with the same shape 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 quasi-random targets, which varied quasi-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 a 1 min rest between tests, and the greater value was taken as the maximal grip strength [4, 7]. The test of controlled force exertion was performed over 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 [15, 16], except for the exertion of prolonged submaximal grip. The subject stood upright with his wrist in the neutral position between flexion and extension with the elbow straight and close to the body and exerted the grip in this position. None of the 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. [7]. 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 the controlled force exertion [4]. Smaller differences between the demand and exertion values were interpreted as superior ability to control force exertion. Each subject was free to adopt a standing position most conducive to a clear view of the display [4]. Of three trials, the mean of the second and the third trials was used for analysis [6].

Statistical analysis

Data were analyzed using SPSS (Version 11.5 for Windows; SPSS Japan, Tokyo, Japan). The characteristics of the distribution were evaluated for coefficient of skew, kurtosis, and normality test (goodness of fit test: Shapiro-Wilk's test) according to both the total group and each age group. To examine significant differences among age group means, one-way analysis of variance (ANOVA) was used after logarithmic transformation. When showing a significant age group difference, 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 20-24 year old and each age group trial was examined. Coefficients of variation were calculated to examine individual differences between age groups. Means (M) and standard deviations (SD) of the logarithmic transformed measurements were calculated, and a rating scale with 5 levels of values was devised based on means and 0.5 SD in each age group (rating scale value 1:>=M+1.5SD, 2: $<M$+1.5SD and >=M+0.5SD, 3: $<M$+0.5SD and >=M-0.5SD, 4: $<M$-0.5SD and >=M-1.5SD, 5: $<M$-1.5SD). The evaluation norm was established in each age group after exponential transformation. Results are presented as mean and standard deviation unless otherwise specified. An alpha level of 0.05 was used for all tests.

Results

Table 2 shows the distribution characteristics of each age group for the controlled force exertion values. Skew values of each age group were all positive, and the measurements showed a right-skewed distribution except for the 25-29 year old group and the 60-69 year old group. The skew and kurtosis for the distribution of all subjects were 1.7 and 3.7, respectively, and normality could not be assumed (W = 0.85, $p<0.05$). Their measurements showed a normal distribution after logarithmic transformation (W = 0.09, $p>0.05$).

Table 2 near here

Table 3 shows means of each age group for the quasi-random waveform. Figure 2 shows a graphical representation of means after logarithmic transformation, and the region of rating scale values. In the results of one-way ANOVA, the difference of age groups was significant ($F_{7, 199}$=17.61, $p<0.05$). With *post hoc* analyses, means were lower in the 20-24 year old group than in the groups older than 30-39 years and 40-49 years; the groups younger than 25-29 years of age had lower means than the 50-59 year and the 60-69 year old groups; and the groups younger than 60 years of age had lower means than the group of 70 years or older.

Table 3 near here

Figure 2 near here

The coefficient of variation was larger in groups older than 60 years of age. The size of mean differences (effect size) between trials of the 20-24 year old group and each age group showed higher values over 1.0 in all age groups older than 40 years (Table 3). Table 4 shows norms of each age group for the controlled force exertion values.

Table 4 near here

Discussion

The measurements were not a normal distribution, but a right-skewed distribution for the total score and the scores of each age group [17]. Logarithmic transformation of the measurements of the controlled force exertion test was judged to be necessary to produce a normal distribution.

The functional role related to movement performance may differ based on the part of the nervous system controlling the movement, i.e., the cerebellum or basal ganglia. For instance, the cerebellum is generally associated with skilled motor behavior while the basal ganglia, in particular the striatonigral system, is associated with motor behavior itself [18]. Bemben, et al. [19] reported that the elderly show a marked decrease in peripheral muscle activity compared with young people, based on the measurement of muscular endurance using intermittent grip strength. From reports by many researchers [20, 21, 22, 23], it is clear that the reaction time of muscles decreases with age. Nagasawa, et al. [7] reported that elderly subjects had weaker controlled force exertion than younger subjects and that hand-eye coordination decreased with age. The present results showed the differences between the 20-24 year old group and the groups older than 40 years of age (ES = 1.17 to 2.09). The measurements of controlled force exertion may largely decrease after 40 years of age.

The present test was performed by submaximal muscular exertion with a moderate cycle (0.3 Hz) of changing demand values. The performance of this test requires strong hand-eye coordination (see Methods), and the function exertion is controlled by feedback, including 'sense of force exertion', 'matching of target', and so forth. Stelmach, et al. [24] examined whether differences in the information given prior to the task affects the response initiation and movement times in the elderly. They reported that, although the elderly use such information in a similar manner to young people in preparing an upcoming movement, the transaction times of the information in the movement plans for the arm (hand) direction and extension were markedly slower in the elderly. Thus, the elderly require longer movement times. The decrease of muscular strength with age is caused by changes in the neuromuscular pathways and muscle fiber composition, spinal motor neuron apoptosis [25] as well as by muscle atrophy [26]. Therefore, the elderly have inferior nerve mechanisms for exercise, i.e., peripheral muscular responses to the changing target and the exertion of nerve-muscle function, compared to young people. The elderly thus require more time to specify a movement dimension [24]. The above functional difference is thought to produce differences of exertion values or performances between the elderly and young people. Although the present controlled force exertion test was performed under the same conditions (i.e. locus and speed) in all trials and the information given prior to the response was the same, measured accuracy decreased with age.

Individual differences tended to increase in groups older than 60 years of age. The result of this study is similar to that of Nagasawa and Demura [9]. Butki [27] reported that subjects need several trials to gain familiarity with a task and to show significant improvement. Experience with a task and the practice effect influence controlled force exertion measurements, and this fact may influence the observed individual differences. Some elderly people may have poorer adaptive functions, perhaps causing a floor effect where individual differences in performances are small. In contrast, elderly subjects with superior adaptive functions can quickly learn the task, and individual differences become larger. Such an increase of individual differences in performances may have occurred in the elderly.

Direct comparison of measurements without criteria for evaluation is meaningless [28]. As stated before, because age group differences were found in the controlled force exertion test, individual measurements in all age groups cannot be evaluated with the same criteria. It will be thus necessary to devise evaluation criteria corresponding to the range of observed individual differences in each age group. While regression evaluations may be used to develop evaluation criteria, a 5-point scale was used in this study (Table 4). If the measurement of controlled force exertion was 1385.5% in the 60-69 year old group, it would be rated as 1 and judged as the most inferior on the 5-point scale by age, as seen in Table 4. Such a person would need treatment to enhance their voluntary movement function. Functional disorders could produce sudden changes in ratings. In the case of people suffering from a nerve disorder, the devised evaluation criteria could be used as an indicator of the recovery of voluntary movement during rehabilitation. As stated above, it is possible to evaluate the characteristics and recovery conditions of movement function based on the evaluation criteria, although clinical case studies are necessary to validate such judgments.

In conclusion, the controlled force exertion of the quasi-random waveform shows a marked decrease at ages greater than 40. We can evaluate individual controlled force exertion based on the devised provisional evaluation norm.

Acknowledgements

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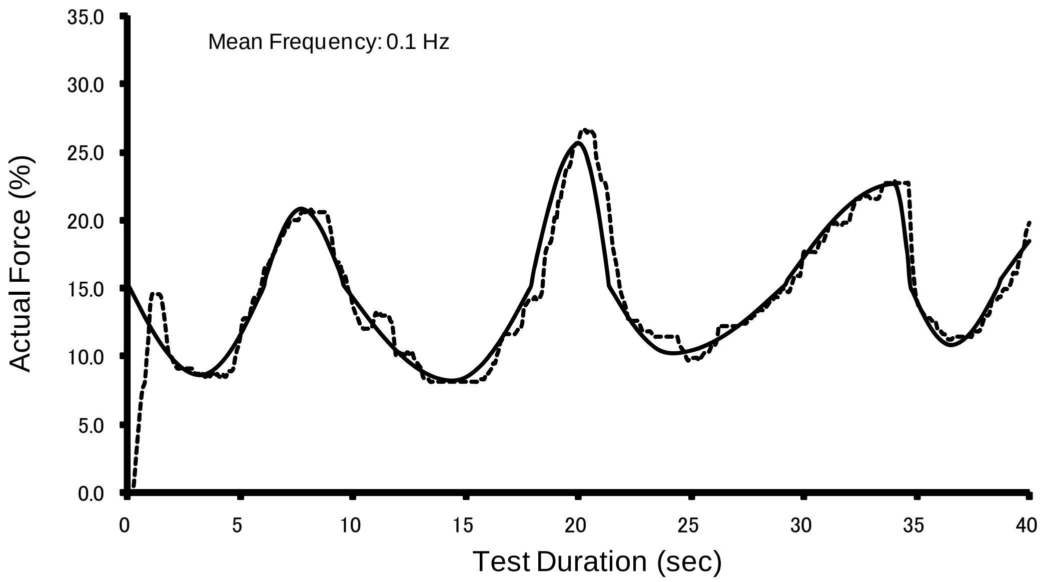
Figure legends

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 5-25% 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.

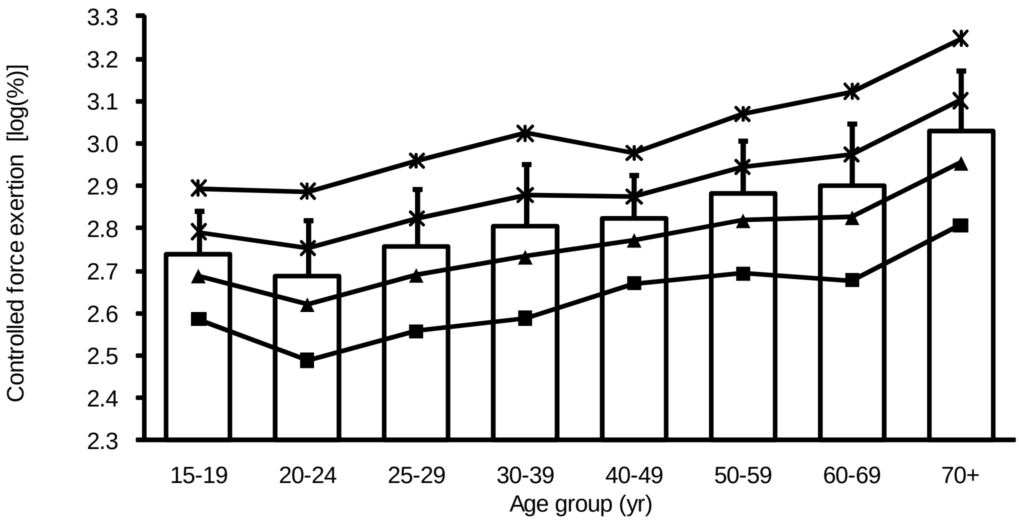
Figure 2. Age group means and rating scale values for the controlled force exertion test with quasi-random demand. The solid lines show the region of rating scale values: M+1.5SD (＊－), M+0.5SD (×-), M-0.5SD (▲－), M-1.5SD (■－).

Figure 1



Mean Frequency: 0.1 Hz
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Actual Force (%)
0
5
10
15
20
25
30
35
40
Test Duration (sec)

Figure 2



3.3
3.2
3.1
3.0
2.9
2.8
2.7
2.6
2.5
2.4
2.3
Controlled force exertion [log(%)]
15-19
20-24
25-29
30-39
40-49
50-59
60-69
70+
Age group (yr)

Table1. Physical characteristics of paticipants

Age group (yr)	n	Age (yr)		Height (cm)		Weight (kg)		Grip strength (kgf)	
		M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
15-19	27	17.2	1.45	171.4	5.38	63.3	8.97	42.0	7.11
20-24	29	21.9	1.42	171.1	4.58	68.2	7.06	51.2	6.31
25-29	25	27.8	1.25	172.9	4.95	69.4	8.18	48.8	8.03
30-39	25	34.4	2.96	173.1	5.68	72.1	10.78	48.0	7.73
40-49	25	44.9	2.75	169.2	6.97	67.4	7.16	46.4	7.68
50-59	23	54.5	2.87	166.2	6.23	65.8	8.36	41.1	7.25
60-69	27	64.3	2.99	165.0	6.21	63.4	9.28	37.0	7.81
70+	26	74.6	4.24	159.8	6.73	57.0	9.87	27.7	7.71
Total	207	42.1	19.82	168.6	7.22	65.8	9.65	42.8	10.31

Table 2. Distribution characteristics of controlled force exertion scores

Age group (yr)	n	Upper quartile	Median	Lower quartile	Skew	Kurtosis	Shapiro-Wilk's W	
								P
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	0.00
30-39	25	841.2	595.1	499.1	1.4	1.8	0.87	0.00
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	0.00
70+	26	1557.1	1018.9	791.0	0.6	-1.2	0.85	0.00
Total	207	802.5	654.2	541.5	1.7	3.7	0.85	0.00

Table 3. Means (%) by age group for controlled force exertion

Age group (yr)	n	*M*	*SD*	*CV*	*ES*
15-19	27	577.0	132.94	23.0	0.49
20-24	29	508.9	144.22	28.3	—
25-29	25	599.2	193.49	32.3	0.53
30-39	25	677.6	251.31	37.1	0.82
40-49	25	685.7	156.92	22.9	1.17
50-59	23	792.2	229.66	29.0	1.48
60-69	27	847.3	354.31	41.8	1.25
70+	26	1128.2	392.73	34.8	2.09

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

Table 4. Norms (%) by age group for controlled force exertion test

Age group (yr)	Rating scale value				
	5	4	3	2	1
15-19	under 385.7	385.7 – 488.9	488.9 – 619.8	619.8 – 785.7	over 785.7
20-24	under 308.3	308.3 – 418.6	418.6 – 568.3	568.3 – 771.6	over 771.6
25-29	under 360.5	360.5 – 490.7	490.7 – 667.9	667.9 – 909.1	over 909.1
30-39	under 387.3	387.3 – 541.4	541.4 – 756.7	756.7 – 1057.7	over 1057.7
40-49	under 468.3	468.3 – 593.4	593.4 – 751.9	751.9 – 952.8	over 952.8
50-59	under 494.3	494.3 – 659.3	659.3 – 879.3	879.3 – 1172.8	over 1172.8
60-69	under 476.4	476.4 – 670.4	670.4 – 943.4	943.4 – 1327.7	over 1327.7
70+	under 642.7	642.7 – 1207.2	901.0 – 1262.9	1262.9 – 1770.3	over 1770.3

Note.- Means (M) and standard deviations (SD) of the logarithmic transformed measurements were calculated, and then the rating scale with 5 levels of values was devised based on means and 0.5 SD in each age group; rating scale value 1:>=M+1.5SD, 2: <M+1.5SD and >=M+0.5SD, 3: <M+0.5SD and >=M-0.5SD, 4: <M-0.5SD and >=M-1.5SD, 5: <M-1.5SD. The evaluation norm was established in each age group after exponential transformation.