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Paper

Provisional norm and age group differences of controlled force exertion measurements by a computing sinusoidal target-pursuit system in Japanese male adults

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This study aimed to examine age group and individual differences of the controlled force exertion test by sinusoidal waveforms and to propose a provisional norm in 207 male adults who were right-handed and aged 15 to 86 years (mean = 42.1±19.8 yrs). The subjects matched their submaximal grip strength to changing demand values, appearing with a sinusoidal waveform on the display of a personal computer. The subjects performed the controlled force exertion test three times with 1-min intervals (one trial lasted 40 s), after one practice trial using the dominant hand. A total of the differences between the demand value and the grip exertion value for 25 s was used as an evaluation parameter. The measurements showed a right-skewed distribution without a normal distribution. They showed a normal distribution after logarithmic transformation ($W=0.09$, $p>0.05$). The result of the analysis of variance showed significant differences in the means of each age group ($F=16.43$, $p<0.05$), and test performance tended to decrease after 50 years of age. Considering the above-stated age group difference, the norm of each age group was established. The controlled force exertion value by the sinusoidal waveform decreases markedly after 50 years of age. An individual's controlled force exertion for the devised provisional norm was evaluated in this study.

Key words : grip strength, total sum of differences, one-way analysis of variance, norm

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1. Introduction

Nervous and muscle functions are closely related to the control of human motor performance. Because it is rare to exert maximal ability in daily activities, the efficiency or continuity of submaximal ability (Halaney and Carey, 1989) is likely to be important. In infants, old-aged and developmentally delayed people, it is particularly important and essential to estimate the voluntary movement functions that mainly determine skillful and efficient submaximal movements (Henatsch and Langer, 1985), because the exertion of maximal ability involves risks. Local movements which demand feedback, such as hand-foot movements, hand-eye coordination, and so on, are closely involved in the coordination of the voluntary movement system, i.e., the controlled force exertion (Henatsch and Langer, 1985). The controlled force exertion test is one useful test to evaluate the motor control function, which coordinates force exertion according to each task. To smoothly exert motor control function, information from central and peripheral nervous systems is integrated in the cerebrum and properly controls movements in each motor organ. Motor control function is interpreted to be superior when contraction and relaxation of muscles are smoothly performed according to movement of a target and there is decreased variability and increased accuracy (Brown and Bennett, 2002). The ability to control 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 rational objective estimation of grading, spacing, and timing, important elements of the controlled force exertion, by using a grip dynamometer coupled with a personal computer. The new test has a high reliability (Nagasawa, et al., 2003), is superior to the pursuit-rotor and pegboard tests (Nagasawa, et al., 2004), and is valid as a test of nerve-muscle function for the elderly (Nagasawa, et al., 2000).

It is known that physical fitness (muscle-nerve function) generally decreases with age, and individual differences are large in the elderly (Bemben, et al., 1991). Nagasawa, et al. (2000) reported that the elderly subjects had weaker controlled force exertion than the young subjects, although large individual differences were observed. On the other hand, it is important to develop a test to estimate individual's measurements based on certain kinds of standards. However, because the measurements vary with age, it is difficult to make up a common standard for all age groups. In order to devise evaluation criteria for each age group, it is necessary to examine the age group differences of controlled force exertion values. The controlled force exertion test evaluates the characteristics and recovery conditions of movement, based on devised evaluation criteria. According to Nagasawa, et al. (2004), the ability exerted by a type of a displayed demand value is somewhat different. In this study, the age group differences of controlled force exertion values on the sinusoidal waveform were examined. Based on results of previous studies, 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 sinusoidal waveform and to propose analytical procedures and semantic interpretation for a norm in Japanese male adults.

2. Methods

2.1. Subjects

The subjects were 207 male adults aged 15 to 86 years (Age 42.1±19.8 yrs, Height 168.6±7.2 cm, Weight 65.8±9.6kg). Their physical characteristics are summarized by age group in Table 1. All were 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. 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. Muscle-nerve function generally peaks with the majority of changes occurring from the late teens to twenties, and 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, 20-25, 25-29, 30-39, 40-49, 50-59, 60-69, and 70 and older.

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

Based on a preliminary investigation (Nagasawa and Demura, 2002), a waveform on the display screen was used. 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

Table 1 Physical characteristics of the subjects (mean (*M*) and standard deviation (*SD*))

Variable	10 yr late (n=27)		20 yr early (n=29)		20 yr late (n=25)		30 yr (n=25)		40 yr (n=25)		50 yr (n=23)		60 yr (n=27)		70 yr over (n=26)		Total (n=207)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Age, yr	17.2	1.45	21.9	1.42	27.8	1.25	34.4	2.96	44.9	2.75	54.5	2.87	64.3	2.99	74.6	4.24	42.1	19.82
Height, cm	171.4	5.38	171.1	4.58	172.9	4.95	173.1	5.68	169.2	6.97	166.2	6.23	165.0	6.21	159.8	6.73	168.6	7.22
Weight, kg	63.3	8.97	68.2	7.06	69.4	8.18	72.1	10.78	67.4	7.16	65.8	8.36	63.4	9.28	57.0	9.87	65.8	9.65
Grip strength, kgf	42.0	7.11	51.2	6.31	48.8	8.03	48.0	7.73	46.4	7.68	41.1	7.25	37.0	7.81	27.7	7.71	42.8	10.31

with time, as with the demand value. The demand values varied over a period of 40 s at a frequency of 0.1 Hz. This rate of change is most easily imitated by the muscle-nerve function (Hayashi, 1967; Meshizuka and Nagata, 1972). Figure 1 displays the sinusoidal waveforms. Details of the apparatus used to measure the controlled force exertion have been described (Nagasawa and Demura, 2002). Sufficient rest was given 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 effected by poor vision and fatigue.

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 that 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 and 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 and Turjanmaa, 1993; Skelton, et al., 1994), except for the exertion of prolonged submaximal grip. The subject stood upright with his wrist in the neutral position between flexion and extension and the elbow straight and close to the body and exerted the grip. The duration of each trial was 40 s, and the controlled force exertion was estimated using the data from three trials, excluding the first 15 s of each trial, according to the previous study of Nagasawa, et al. (2000). The total

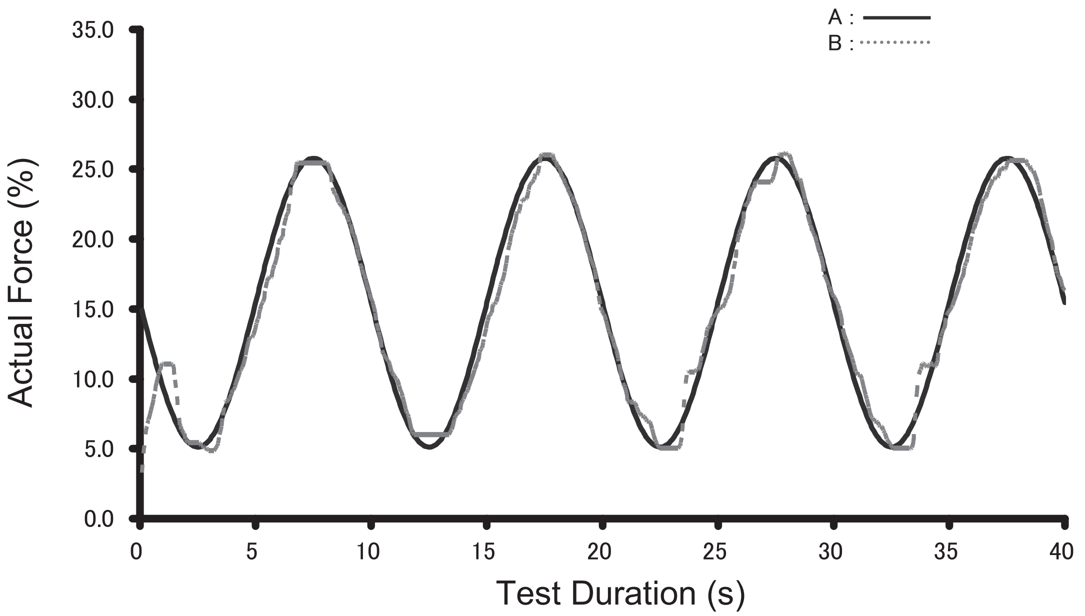

Figure 1 Sinusoidal waveform display (100mm x 140mm) of the demand value.
The solid waveform (A) shows the demand value and the broken waveform (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in the range 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 s for each trial. The coordinated exertion of force was calculated using the data from 25 s of the trial following the initial 15 s of the 40-s period.

sum 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 better in their ability 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 three trials, the mean of the second and the third trials was used for analysis (Nagasawa, et al., 2004).

2.3. 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-Wilk's W-test) in both sum total and age groups. To examine significant differences among age group means, one-way analysis of variance (ANOVA) was used after logarithmic transformation. When a significant age group difference 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 early 20s and each age group trial were examined. Coefficients of variance were calculated to examine individual differences between trials. Means and standard deviations were calculated and rating scale values of 5 levels were devised using the logarithmic transformed variables in each age group. 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 taken to be significant for all tests.

3. Results

Table 2 shows distribution characteristics of each age group for the controlled force exertion values. Skew values of each age group were all positive except for the 40-year old group (0.0) and the measurements showed a right-skewed distribution. Kurtosis values were all less than or equal to three and the distributions were platykurtic. The skew and kurtosis for the distribution of all subjects

Table 2 Distribution characteristics of the controlled force exertion scores: skew, kurtosis, and normality test

Variable	10 yr late (n=27)		20 yr early (n=29)		20 yr late (n=25)		30 yr (n=25)		40 yr (n=25)		50 yr (n=23)		60 yr (n=27)		70 yr over (n=26)		Total (n=207)	
		P		P		P		P		P		P		P		P		P
Upper quartile	854.4		790.6		934.8		1007.6		907.9		1082.9		1180.3		1525.6		1008.5	
Median	635.7		641.2		647.2		733.1		756.7		958.4		968.8		1295.7		829.8	
Lower quartile	563.0		491.3		595.9		597.3		609.2		802.9		873.1		905.4		628.4	
Skew	1.2		0.7		0.1		1.3		0.0		0.8		0.7		1.3		1.9	
Kurtosis	1.5		0.2		-0.4		2.4		-0.8		2.1		0.6		2.2		6.7	
Shapiro-Wilk's W	0.91	0.03	0.95	0.23	0.97	0.64	0.88	0.01	0.98	0.81	0.94	0.19	0.93	0.06	0.90	0.01	0.89	0.00

Table 3 Means (in %) of each age group for the controlled force exertion test in the sinusoidal demand

Age grade	Sinusoidal Demand			
	M	*SD*	*CV*	*ES*
10 yr late	706.67	199.37	28.21	0.25
20 yr early	652.32	230.86	35.39	
20 yr late	726.16	216.43	29.80	0.33
30 yr	794.16	249.16	31.37	0.59
40 yr	770.27	194.33	25.23	0.55
50 yr	959.49	212.64	22.16	1.38
60 yr	1012.39	279.19	27.58	1.41
70 yr over	1340.39	521.45	38.90	1.71

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

were 1.9 and 6.7, respectively, and the normality could not be assumed (W=0.89, p<0.05). Upper quartile, median, and lower quartile were 628.4%, 829.8%, and 1008.5%, respectively. Their measurements showed a normal distribution after logarithmic transformation (W=0.09, p>0.05).

Table 3 shows means of each age group for the sinusoidal waveform. Figure 2 shows a graphical representation of means and the region of rating scale values after logarithmic transformation. In the results of one-way ANOVA, the difference of age groups was significant ($F_{7, 199}$= 16.43, p<0.05). With post hoc analyses, means were lower in the late 10 year old, early 20 year old, and late 20 year old groups than in the groups older than 50 years. They were also lower in the 40-year old group than in the 60-year old group, and in the 30, 40, 50 and 60-year old groups than in the group of 70 years and older.

The coefficient of variance showed a high value in groups under 30 years of age and older than 60 years of age. The size of mean differences (effect size) between trials of early 20 year olds and each age group showed high values over 1.0 in age groups older than 50 years (Table 3). Table 4 shows norms of each age group for the controlled force exertion values.

4. Discussion

The measurements were not a normal distribution and a right-skewed distribution was noted for the sum total score and the scores of each age group. Their

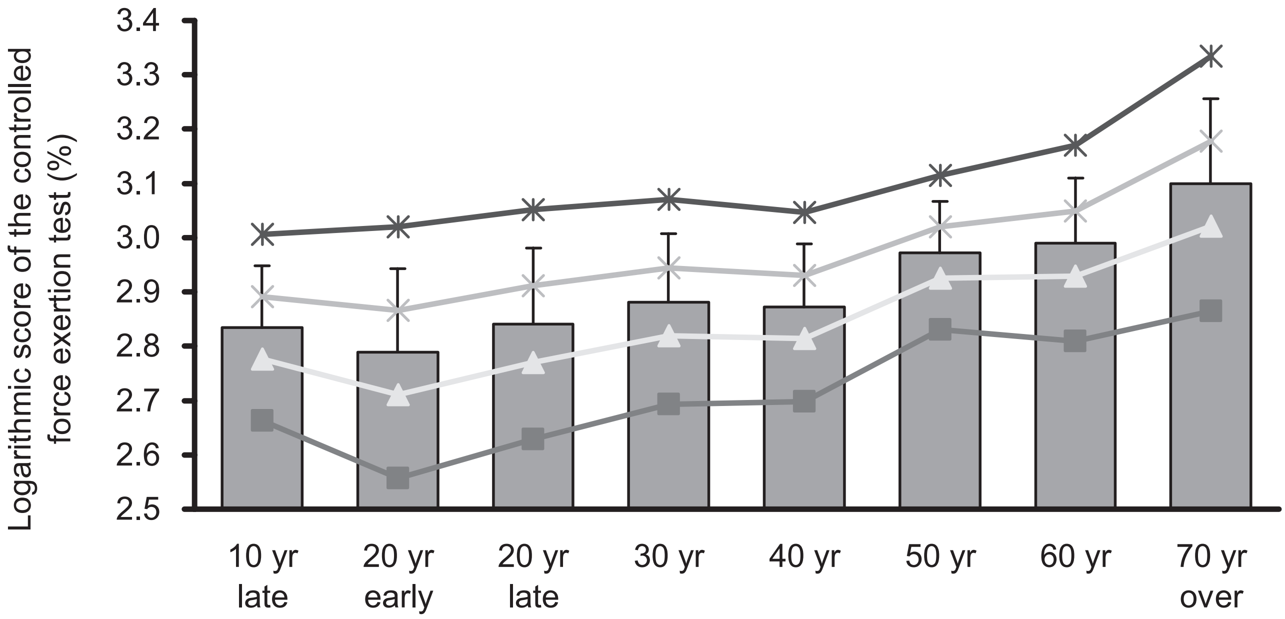

Figure 2 Age group means and rating scale values for the controlled force exertion test in the sinusoidal demand. The solid lines show the region of rating scale values: M+1.5SD (∗ —), M+0.5SD (× —), M-0.5SD (▲ —), M-1.5SD (■ —).

Table 4 Norm measurement (%) of each age group for the controlled force exertion test in the sinusoidal demand

Rating scale value	5	4	3	2	1
10 yr late	~ 459.9	459.9 ~ 598.4	598.4 ~ 778.6	778.6 ~ 1013.0	1013.0 ~
20 yr early	~ 360.6	360.6 ~ 514.4	514.4 ~ 733.8	733.8 ~ 1046.8	1046.8 ~
20 yr late	~ 425.8	425.8 ~ 589.0	589.0 ~ 814.8	814.8 ~ 1127.0	1127.0 ~
30 yr	~ 493.1	493.1 ~ 658.8	658.8 ~ 880.1	880.1 ~ 1175.8	1175.8 ~
40 yr	~ 499.3	499.3 ~ 652.2	652.2 ~ 851.9	851.9 ~ 1112.8	1112.8 ~
50 yr	~ 676.3	676.3 ~ 841.0	841.0 ~ 1045.9	1045.9 ~ 1300.6	1300.6 ~
60 yr	~ 644.3	644.3 ~ 849.9	849.9 ~ 1121.2	1121.2 ~ 1479.0	1479.0 ~
70 yr over	~ 731.6	731.6 ~ 1049.2	1049.2 ~ 1504.5	1504.5 ~ 2157.5	2157.5 ~

measurements showed a normal distribution after logarithmic transformation. It is generally noted that the measurements, such as liver enzymes (ex. GOT and GPT), white blood cell count, and intensity of light, had a right-skewed distribution and approached a relatively symmetric distribution (a normal distribution) after logarithmic transformation (Uesaka, 1995). The results of this study were similar to the above-mentioned findings, and thus, the measurements of the controlled force exertion test seemed to be necessary to produce a norm after logarithmic transformation.

The functional role related to movement performances may differ in the nerve mechanism of exercise (cerebellum and basal ganglia); the cerebellum is, generally, associated with skilled motor behavior, and the basal ganglia, in particular the striatonigral system, with motor behavior itself (Kornhuber, 1974). Bemben, et al. (1996) reported that the elderly show a noticeable 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 (Rikli and Busch, 1986; Rikli and Edwards, 1991; Welford, 1988), including Dustman, et al. (1984), it is clear that the reaction time of muscles decreases with age. Nagasawa, et al. (2000) reported that the elderly subjects had weaker controlled force exertion than the young subjects, and hand-eye coordination decreased with age. The differences (effect sizes) between the early 20 year old group and groups older than 50 years were large. The measurements of the controlled force exertion test were confirmed to decrease after 50 years of age. The present test was performed by submaximal muscular exertion with a moderate cycle (0.1 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 such as ‘sense of force exertion’, ‘matching of target’, and so forth. Stelmach, et al. (1987) examined whether differences in the information given prior to task response affects the elderly’s response initiation and movement times. It is reported that, although the elderly use pre-information similar to young people to prepare an upcoming movement, the transaction times of information on the movement plan for arm (hand), direction and extension were markedly slower in the elderly than the young people, and the elderly need longer movement times. The decrease of muscular strength is caused by changes of neuromuscular pathways and muscle fiber composition, and by muscle atrophy with age (Cauley, et al., 1987). Therefore, the elderly as compared with young people have inferior nerve mechanisms of exercise, i.e., peripheral muscular responses to the changing target and the exertion of nerve-muscle 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 between the elderly and young people. In addition, Nakamura, et al. (1995) reported that the learning effect of pursuit movements is associated with 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 values decreased with age. Of the above memories, the latter decrease is considered to control learning and make exertion values decrease with age.

Individual differences tended to increase between groups under 30 years of age (the young) and groups older than 60 years (the elderly). 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 familiarity and to show a significant improvement. Experience with a task and the practice effect influence controlled force exertion variables, and may produce individual differences. In addition, the elderly may have delayed function of the above nerve mechanism during exercise and in adaptation to a task. Thus, individual differences are small. However, the subjects with superior hand-eye coordination become quickly accustomed to the task, and individual differences enlarge. Namely, it is inferred that individual differences exist in experience and adaptation to the controlled force exertion task, and it appears that there is an increase of individual differences in performances in the elderly and young people.

Direct comparison of measurements without criteria for evaluation is futile (Thomas and Nelson, 1987). As stated before, because age group differences were found in the controlled force exertion, we cannot properly evaluate individual measurements in all age groups with the same criterion. It is necessary to devise evaluation criteria corresponding to individual differences in each age group.

On the other hand, while there are regression evaluations, three point scales and so on, with evaluation criteria, a general 5-point scale was utilized in this study (Table 4). Thus, if the measurement of controlled force exertion was 1200.5% in the 40 year old group, it would be impossible to evaluate. However, the value is rated as one and judged as the most inferior on the 5-point scale separated by age in Table 4. That is, it will be necessary to enhance voluntary movement-function by some method. Moreover, if the value of a 60 year old was rated as 4 and judged as one after a few months, it may indicate a functional disorder. In the case of people suffering from a nerve disorder, the devised evaluation criteria can also be used as an indicator of voluntary movement-function recovery during rehabilitation. As above, it is possible to evaluate the characteristics and recovery conditions of movement function, based on the evaluation criteria.

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 will be necessary to examine other age group differences on the controlled force exertion test.

In summary, with the controlled force exertion of the sinusoidal waveform, the rate of decrease is remarkable at ages greater than 50. This study allows for the evaluation of individual controlled force exertion based on the devised provisional evaluation norm.

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