

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

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3	<u>Original Article</u>
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5	Article title:
6	Provisional norms by age group for Japanese males on the controlled force exertion
7	test using a quasi-random display
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10	Running title:
11	Norm of controlled force exertion measurement

12 **Abstract**

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

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

28 **Text**

29

30 **Introduction**

31 The functions of the nervous and musculoskeletal systems are responsible for
32 the control of human motor performance. Because it is rare for a person to exert
33 maximal ability during typical daily activities, the efficiency or continuity of
34 submaximal ability [1] is likely to be important. For infants, the elderly and the
35 developmentally delayed, it is essential to estimate the primary voluntary movement
36 functions that determine skillful and efficient submaximal movements [2]. Local
37 movements that demand feedback, such as hand-foot movements, hand-eye
38 coordination, etc, are closely involved in the coordination of the voluntary movement
39 system, i.e., controlled force exertion². The controlled force exertion test can evaluate
40 motor control function, which coordinates force exertion for each motor task. To
41 smoothly exert motor control, information from the central and peripheral nervous
42 systems is integrated in the cerebrum. Motor control function is interpreted to be
43 superior when muscle contraction and relaxation are smoothly coordinated according
44 to the movement of a target, with low variability and high accuracy [3].

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

53 It has been known that physical fitness (neuromuscular function) generally
54 decreases with age, and its individual variation is large among the elderly [8].
55 Nagasawa, et al. [7] reported that elderly subjects had weaker controlled force
56 exertion than younger subjects. Individual measurements are evaluated by
57 standards or norms. Hence, to use the controlled force exertion test to evaluate the
58 characteristics and recovery conditions of movement functions, we must make up
59 rightly standardized evaluation criteria for each age group. Nagasawa and Demura
60 [9] established a provisional norm for the controlled force exertion test for each age
61 group using a bar chart display. It is desirable that the demand value shows a
62 different locus each time to avoid memorization of the locus of the demand values by
63 the subjects; furthermore, an accurate measurement method must be developed [10].
64 However, this problem has been examined little. According to Nagasawa, et al. [6],
65 the ability exerted in response to a displayed demand value differs with age. We
66 hypothesized that the controlled force exertion value decreases with age.

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

71

72 **Materials and Methods**

73 *Subjects*

74 The subjects were 207 males aged 15 to 86 years (M age = 42.1yr., SD = 19.8, M
75 height = 168.6 cm, SD = 7.2, M weight = 65.8 kg, SD = 9.7) (See Table 1). All were
76 right-handed, as assessed by Oldfield's inventory [11]. Height and weight were
77 similar to Japanese normative values [12] for each age-level. No subject reported

78 previous wrist injuries or upper limb nerve damage, and all were in good health.
79 Prior to enrollment, the purpose and procedure of this study were explained in
80 detail. This protocol was approved by the Institutional Review Board, and informed
81 written consent was obtained from all subjects. No subject had previously
82 performed a controlled force exertion test. Neuromuscular function generally
83 reaches a peak with marked changes from the late teens to twenties and then
84 gradually decreases with age after 30 [8]. The subjects were grouped according to
85 age as follows: 15-19, 20-24, 25-29, 30-39, 40-49, 50-59, 60-69, and 70 and older.

86

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

88

89 *Test and Test Procedure*

90 In this study, the subjects performed grip exertion, attempting to minimize the
91 differences between a demand value and the value of their grip strength as presented
92 on a computer display. This information was transmitted at a sampling rate of 10 Hz
93 to a computer through an RS-232C data output cable (Elecom, Tokyo, Japan) after
94 A/D conversion. Grip strength and controlled force exertion were measured with a
95 Smedley's type handgrip mechanical dynamometer (GRIP-D5101; Takei, Tokyo,
96 Japan), with an accuracy of $\pm 2\%$ in the range of 0 to 979.7 N.

97 Based on a previous study [4], a waveform on the display screen was used. The
98 display showed the demand value and the actual grip strength simultaneously.
99 Changes in the actual grip exertion value and the demand value were displayed as
100 changes in the waveforms from left to right visually and spatially with time. The
101 demand values varied over a period of 40 sec at a frequency of 0.1 Hz. This rate of
102 change is most easily imitated by the muscle-nerve function [13, 14]. The demand

103 values of the quasi-random waveform changed at random in π with amplitude and in
104 $\pi/2$ with frequency and increased and decreased in the range of 5 to 25% of maximal
105 grip strength. Figure1 shows the displays of quasi-random waveforms. Details of the
106 apparatus to measure the controlled force exertion have been previously described [4].
107 A sufficient rest period was given to eliminate the influence among the tests and
108 from the subjects' fatigue. Subjects wore glasses when required and sat at appropriate
109 distances from the display. They tracked the demand values in the displays, and then
110 measurements were performed. Measurements were not affected by poor vision or
111 fatigue. In a pilot experiment, it was confirmed that subjects are capable of tracking
112 the demand values in both displays.

113

114

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

115

116 Relative demand values, not absolute demand values, were used since the
117 physical fitness and muscular strength of each individual are different. The relative
118 demand value varied in the range of 5 to 25% of maximal grip strength. All subjects
119 were presented with the same shape demand function. The software program was
120 designed to present the relative demand values within a constant range on the
121 display regardless of differences in each subject's maximal grip-strength. The
122 demand value used quasi-random targets, which varied quasi-cyclically (see Figure
123 1).

124 The size of the grip was set so that the subject felt comfortable squeezing the
125 grip. The subject performed maximal grip exertion with the dominant hand twice a 1
126 min rest between tests, and the greater value was taken as the maximal grip
127 strength [4, 7]. The test of controlled force exertion was performed over three trials at

128 1 min intervals after one practice trial. The test of controlled force exertion was
129 similar to a commonly used test of grip strength [15, 16], except for the exertion of
130 prolonged submaximal grip. The subject stood upright with his wrist in the neutral
131 position between flexion and extension with the elbow straight and close to the body
132 and exerted the grip in this position. None of the participants complained of hand
133 pain during the procedure. The duration of each trial was 40 sec. The controlled force
134 exertion was estimated using the data from three trials, excluding the first 15 sec of
135 each trial, according to the previous study of Nagasawa, et al. [7]. The total sum (the
136 value accumulated for 25 sec) of the percent of differences between the demand value
137 and the grip strength was used as an estimate of the controlled force exertion [4].
138 Smaller differences between the demand and exertion values were interpreted as
139 superior ability to control force exertion. Each subject was free to adopt a standing
140 position most conducive to a clear view of the display [4]. Of three trials, the mean of
141 the second and the third trials was used for analysis [6].

142

143 *Statistical analysis*

144 Data were analyzed using SPSS (Version 11.5 for Windows; SPSS Japan, Tokyo,
145 Japan). The characteristics of the distribution were evaluated for coefficient of skew,
146 kurtosis, and normality test (goodness of fit test: Shapiro-Wilk's test) according to
147 both the total group and each age group. To examine significant differences among
148 age group means, one-way analysis of variance (ANOVA) was used after logarithmic
149 transformation. When showing a significant age group difference, a
150 multiple-comparison test was done using a Tukey's Honestly Significant Difference
151 (HSD) method for pair-wise comparisons. In addition, the size of mean differences
152 (effect size) between trials of those in 20-24 year old and each age group trial was

153 examined. Coefficients of variation were calculated to examine individual differences
154 between age groups. Means (M) and standard deviations (SD) of the logarithmic
155 transformed measurements were calculated, and a rating scale with 5 levels of
156 values was devised based on means and 0.5 SD in each age group (rating scale value
157 1: $\geq M+1.5SD$, 2: $<M+1.5SD$ and $\geq M+0.5SD$, 3: $<M+0.5SD$ and $\geq M-0.5SD$, 4:
158 $<M-0.5SD$ and $\geq M-1.5SD$, 5: $<M-1.5SD$). The evaluation norm was established in
159 each age group after exponential transformation. Results are presented as mean and
160 standard deviation unless otherwise specified. An alpha level of 0.05 was used for all
161 tests.

162

163 Results

164 Table 2 shows the distribution characteristics of each age group for the
165 controlled force exertion values. Skew values of each age group were all positive, and
166 the measurements showed a right-skewed distribution except for the 25-29 year old
167 group and the 60-69 year old group. The skew and kurtosis for the distribution of all
168 subjects were 1.7 and 3.7, respectively, and normality could not be assumed ($W =$
169 0.85 , $p < 0.05$). Their measurements showed a normal distribution after logarithmic
170 transformation ($W = 0.09$, $p > 0.05$).

171

172 *****Table 2 near here*****

173

174 Table 3 shows means of each age group for the quasi-random waveform. Figure 2
175 shows a graphical representation of means after logarithmic transformation, and the
176 region of rating scale values. In the results of one-way ANOVA, the difference of age
177 groups was significant ($F_{7, 199} = 17.61$, $p < 0.05$). With *post hoc* analyses, means were

178 lower in the 20-24 year old group than in the groups older than 30-39 years and
179 40-49 years; the groups younger than 25-29 years of age had lower means than the
180 50-59 year and the 60-69 year old groups; and the groups younger than 60 years of
181 age had lower means than the group of 70 years or older.

182

183 *****Table 3 near here*****

184 *****Figure 2 near here*****

185

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

191

192 *****Table 4 near here*****

193

194

195 **Discussion**

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

200 The functional role related to movement performance may differ based on the
201 part of the nervous system controlling the movement, i.e., the cerebellum or basal
202 ganglia. For instance, the cerebellum is generally associated with skilled motor

203 behavior while the basal ganglia, in particular the striatonigral system, is associated
204 with motor behavior itself [18]. Bemben, et al. [19] reported that the elderly show a
205 marked decrease in peripheral muscle activity compared with young people, based on
206 the measurement of muscular endurance using intermittent grip strength. From
207 reports by many researchers [20, 21, 22, 23], it is clear that the reaction time of
208 muscles decreases with age. Nagasawa, et al. [7] reported that elderly subjects had
209 weaker controlled force exertion than younger subjects and that hand-eye
210 coordination decreased with age. The present results showed the differences between
211 the 20-24 year old group and the groups older than 40 years of age ($ES = 1.17$ to 2.09).
212 The measurements of controlled force exertion may largely decrease after 40 years of
213 age.

214 The present test was performed by submaximal muscular exertion with a
215 moderate cycle (0.3 Hz) of changing demand values. The performance of this test
216 requires strong hand-eye coordination (see Methods), and the function exertion is
217 controlled by feedback, including 'sense of force exertion', 'matching of target', and so
218 forth. Stelmach, et al. [24] examined whether differences in the information given
219 prior to the task affects the response initiation and movement times in the elderly.
220 They reported that, although the elderly use such information in a similar manner to
221 young people in preparing an upcoming movement, the transaction times of the
222 information in the movement plans for the arm (hand) direction and extension were
223 markedly slower in the elderly. Thus, the elderly require longer movement times.
224 The decrease of muscular strength with age is caused by changes in the
225 neuromuscular pathways and muscle fiber composition, spinal motor neuron
226 apoptosis [25] as well as by muscle atrophy [26]. Therefore, the elderly have inferior
227 nerve mechanisms for exercise, i.e., peripheral muscular responses to the changing

228 target and the exertion of nerve-muscle function, compared to young people. The
229 elderly thus require more time to specify a movement dimension [24]. The above
230 functional difference is thought to produce differences of exertion values or
231 performances between the elderly and young people. Although the present controlled
232 force exertion test was performed under the same conditions (i.e. locus and speed) in
233 all trials and the information given prior to the response was the same, measured
234 accuracy decreased with age.

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

245 Direct comparison of measurements without criteria for evaluation is
246 meaningless [28]. As stated before, because age group differences were found in the
247 controlled force exertion test, individual measurements in all age groups cannot be
248 evaluated with the same criteria. It will be thus necessary to devise evaluation
249 criteria corresponding to the range of observed individual differences in each age
250 group. While regression evaluations may be used to develop evaluation criteria, a
251 5-point scale was used in this study (Table 4). If the measurement of controlled force
252 exertion was 1385.5% in the 60-69 year old group, it would be rated as 1 and judged

253 as the most inferior on the 5-point scale by age, as seen in Table 4. Such a person
254 would need treatment to enhance their voluntary movement function. Functional
255 disorders could produce sudden changes in ratings. In the case of people suffering
256 from a nerve disorder, the devised evaluation criteria could be used as an indicator of
257 the recovery of voluntary movement during rehabilitation. As stated above, it is
258 possible to evaluate the characteristics and recovery conditions of movement
259 function based on the evaluation criteria, although clinical case studies are necessary
260 to validate such judgments.

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

264

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270

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344

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 $\pi/2$ 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 (x-), M-0.5SD (▲ -), M-1.5SD (■ -).

Figure 1

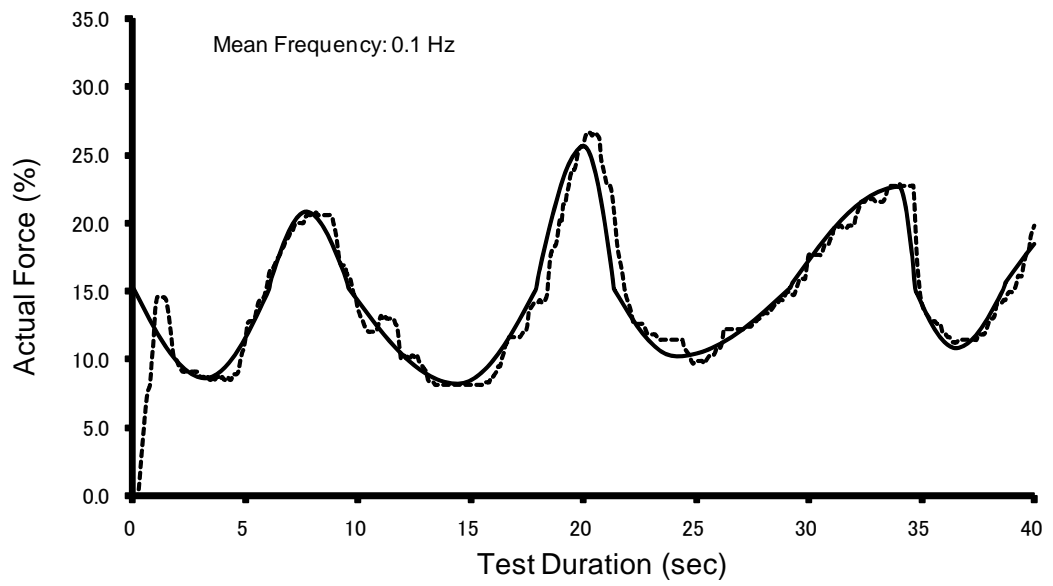


Figure 2

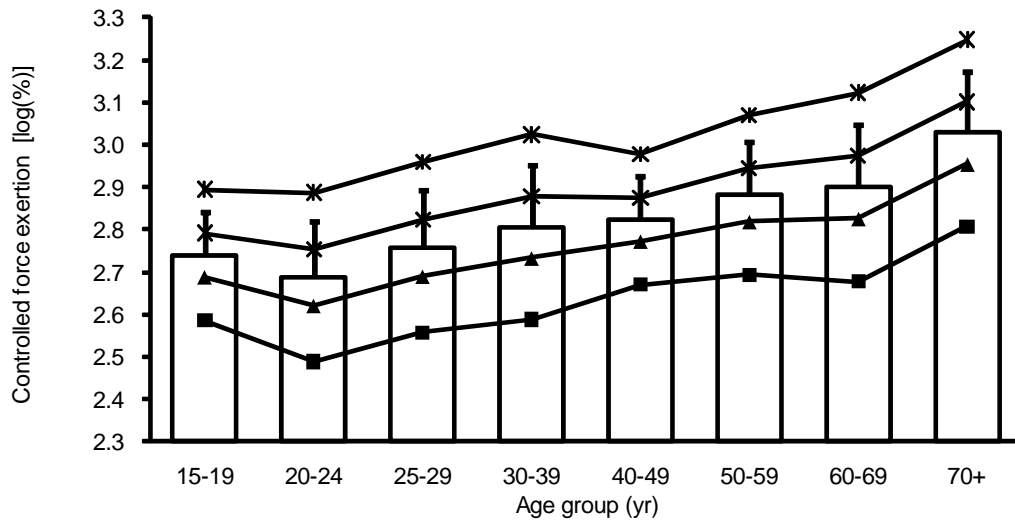


Table1. Physical characteristics of participants

Age group (yr)	n	Age (yr)		Height (cm)		Weight (kg)		Grip strength (kgf)	
		<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
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	<i>M</i>	<i>SD</i>	<i>CV</i>	<i>ES</i>
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: $\geq M+1.5SD$, 2: $<M+1.5SD$ and $\geq M+0.5SD$, 3: $<M+0.5SD$ and $\geq M-0.5SD$, 4: $<M-0.5SD$ and $\geq M-1.5SD$, 5: $<M-1.5SD$. The evaluation norm was established in each age group after exponential transformation.