Age differences between the controlled force exertion measured by a computer-generated sinusoidal and a bar chart display

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Original Research Article

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Age differences between the controlled force exertion measured by a computer-generated sinusoidal and a bar chart display

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Running head:

Age corresponding relationships: controlled force exertion

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Abstract

It is important to develop an accurate method of measuring controlled force exertion. This study examined the age differences between the controlled force exertion measured by a sinusoidal waveform and a bar chart display. The participants comprised 175 right-handed male adults aged 20–86 years. The participants were divided into three age groups: young (n = 53), middle-aged (n = 71), and elderly (n = 51). They matched the submaximal grip strength exerted by their dominant hand to changing demand values displayed as either a sinusoidal waveform or a bar chart appearing on a personal computer screen. The participants performed the controlled force exertion test three times with a 1-min inter-trial interval using their dominant hand. The dependent variable was the total sum of the percentage values of the differences between the demand value and grip exertion value for more than 25 seconds. The coefficient of variance had almost the same range in all age groups in both displays (CV_{SW} = 28.0–36.9, CV_{BC} = 29.1–32.6), but the elderly group showed a somewhat higher value with the sinusoidal waveform. Significant correlations were found between the scores with sinusoidal waveform and bar chart displays in the young, middle-aged, and elderly groups (r = 0.47–0.68), but the correlations did not differ significantly between the age groups. Scores over 1500% in sinusoidal and bar chart display were found in one and two participants, respectively, in the middle-aged group and in 12% and 16% of the participants, respectively, in the elderly group. Furthermore, among all participants, only 8% of participants in the elderly group scored over 1500% in both displays. Scores over 1500% in both displays are considered to be considerably worse in controlled force exertion than lower scores.

Text

1. Introduction

Accurate and efficient movements depend on the precise control of small muscle groups related to hands and fingers, but the magnitude and dynamic properties of force output are affected largely by neuromuscular function (Ofori et al., 2010). Ranganathan et al. (2001) examined the effects of aging on hand function and reported that compared with the young, the elderly are weaker in handgrip and maximum pinch force and are less able to maintain a steady submaximal pinch force. It is suggested that these force control properties are influenced by maturation (Deutssch and Newell, 2001; Ofori et al., 2010), and that neuromuscular pathways are affected by age (Galganski et al., 1993) and task constraints such as the magnitude of muscular force (Sosnoff and Newell, 2008).

To exert motor control function smoothly, information from the central (e.g. visuomotor processing) and peripheral (e.g. motor unit firing rate) nervous systems is integrated in the cerebrum (Doyon and Benali, 2005), and proper control of movements in each component of the motor system is required. Thus, neuromuscular function contributes to the control of human motor performance. In particular, skillful and efficient movements that demand feedback, such as manual dexterity and hand-eye coordination, are closely involved in the ability to control voluntary movements, i.e. controlled force exertion (Henatsch and Langer, 1985).

The controlled force exertion test evaluates the motor control function that coordinates force exertion during a task. Motor control function is interpreted to be superior when muscle contraction and relaxation are performed smoothly in accordance with the movement of a target with low variability and high accuracy (Brown and Bennett, 2002). Nagasawa and Demura (2002) focused on the tracking action with submaximal exertion and developed a new test for controlled force exertion. The test makes rational objective estimation of grading, spacing (space perception), and timing, which are important elements of controlled force exertion (Nagasawa and Demura, 2002). Further, it requires grip control (gross motor control) and hand-eye coordination, and therefore is useful for the evaluation of neuromuscular function in the elderly (Nagasawa et al., 2000).

Studies that visually present controlled force exertion tasks typically use tracking paradigms (Galganski et al., 1993; Nagasawa and Demura, 2002). Within these paradigms, visual feedback of performance is presented through sinusoidal waveform or bar chart display. The sinusoidal waveform signal is periodic and displayed as changes in the waveform from left to right visually and spatially over time; thus, participants can anticipate a demand value (i.e. a target) after the first period. Therefore, a force can be exerted quickly to correspond with the demand value. On the other hand, the bar chart signal changes only a large target vertically, and hence the participant can fit its movement and easily adjust the force exerted. Consequently, a sinusoidal waveform display allows participants to use more visual information regarding performance error and more feed-forward (e.g. anticipatory) strategies during a continuous tracking task (Ofori et al., 2010).

According to Nagasawa et al. (2004), different abilities such as motor responsiveness, accuracy, and velocity are exerted depending on the type of displayed demand value, and their difference determines the response to sinusoidal waveform and bar chart displays. The relationships among age groups in the controlled force exertion test are considered to differ according to the information received from the central and peripheral nervous systems, the difference in control function concerned, and the type of displayed demand value. However, there has been little examination of the effects of age on the relationships between the sinusoidal waveform and bar chart displays. Nagasawa et al. (2000) suggested that a decrease in the ability to exert controlled force contributes to an increase of errors in controlled force exertion. It is important to have means of early detection of a decline in cognitive function in the clinical and rehabilitation fields, but this method relies on tests used in neuropsychological examination, such as those measuring processing time for movements and reaction time for actions. The controlled force test, which estimates quantitatively the circuit integrating sensory input (visual) and motor output, has not been widely used. Because the development of an accurate method of measuring controlled force exertion would be desirable in both medical and rehabilitation fields, it is important to examine age differences in the relationships between the two types of display. Based on previous studies, it was hypothesized that the differences in controlled force exertion between the two displays would decrease with age.

This study examined age differences in the relationship between controlled force exertion variables measured by sinusoidal waveform and bar chart displays in order to develop an accurate method of measuring controlled force exertion.

2. Methods

2. 1. Participants

The following participants were recruited from among university students, office workers, and the elderly in Japan: 53 young males aged 20–29 years (mean age 25, SD = 3.3 years), 71 middle-aged males aged 30–59 years (mean age 44, SD = 8.7 years), and 51 elderly males aged 60–86 years (mean age 69, SD = 6.4 years). Their age, grip strength, and physical characteristics (height, body mass) are presented by age groups in Table 1. All the participants were regarded as right-handed based on Demura et al.'s inventory (2009). The mean values for height and body mass were similar to Japanese normative values for each age level ([Laboratory of Physical Education, Tokyo Metropolitan University, 1989]). No participant reported previous wrist injuries or upper limb nerve damage, and all were in good health. Prior to measurement, the purpose and procedure of this study were explained in detail, and written informed consent was obtained from all participants. The experimental protocol was approved by the Kyoto Pharmaceutical University Ethics Committee. No participant had previously experienced a controlled force exertion test. In this study, participants over 60 years of age were defined as elderly.

Table 1 near here

2. 2. Apparatus

Participants wore glasses when required and stood 70 cm away from the display. The size of the grip was set such that the participant felt comfortable squeezing it. 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 $\pm 2\%$ in the 0–979.7 N range (output range of 1–3V). This information was transmitted to a computer at a sampling rate of 10 Hz through an RS-232C data output cable (Elecom, Tokyo, Japan) after A/D conversion with a quantization bit rate of 12 bits (input range of 1–5V). Apparatus details have been previously described (Nagasawa and Demura, 2002).

2. 3. Estimation of maximal grip strength

Each participant's maximal grip strength was determined with the dominant hand at the beginning of the experimental session. The participant was then instructed to produce his greatest possible isometric force by exerting a power grip with the wrist in a neutral position between flexion and extension. Two five-second maximal contractions were recorded, with a minute's rest after each test. No verbal encouragement was given to the participants. The greater value from the two trials was taken as the value of maximal grip strength (Nagasawa and Demura, 2002; Nagasawa et al., 2000).

2. 4. Submaximal controlled force exertion task

The test of controlled force exertion was similar to a commonly used test of grip strength (Walamies and Turjanmaa, 1993; Skelton et al., 1994), with the exception of the exertion of a prolonged submaximal grip. Participants stood upright with the wrist in a neutral position between flexion and extension and with the elbow straight and close to the body.

As outlined in a preliminary investigation (Nagasawa and Demura, 2002), two types of a sinusoidal waveform and a bar chart display were used for all

participants. The displays simultaneously showed both the demand value and the actual grip strength, but differed in the way these variables were displayed. That is, both the demand value and changes in the actual grip-exertion value were displayed as changes in the waveform from left to right visually and spatially with time in the case of a sinusoidal waveform and as vertical changes in the bar in the case of a bar chart. The demand values of the sinusoidal waveform and bar chart varied over a period of 40-seconds at a frequency of 0.1 Hz and 0.3 Hz, respectively (Nagasawa and Demura, 2009; Nagasawa et al., 2003). The participants attempted to minimize the difference between the demand value and the value of their grip strength as presented on the computer display. Figures 1 and 2 show the sinusoidal waveform and bar chart displays, respectively. Participants in a preliminary experiment were capable of tracking the demand values in both displays.

Figure 1 near here

Figure 2 near here

Relative demand values rather than absolute demand values were used, because individuals differ in their physical fitness and muscular strength. The relative demand value varied by approximately 5%–25% of maximal grip strength (Nagasawa et al., 2003, 2004). All participants were presented with the same shape of demand function. The software program was designed to present the relative demand values within a constant range on the computer display. The demand value used the sinusoidal waveform and the bar chart targets varying cyclically (see Figures 1 and 2).

The order of visual displays was randomly presented to each participant within each display type block. Within each unique force display condition, the participant performed three trials after one practice trial. Demand values in the displays were tracked and performance was measured by the total sum of the percentage value of differences between the demand value and grip exertion value. To minimize the effect of fatigue, a 1-minute rest period was provided after each trial and a 3-minute rest period was provided after each display condition. A total of six trials were performed: three sinusoidal waveform and bar chart trials at each frequency and one relative demand level. The sum of the percentage value of differences between the demand value and the grip strength was used to estimate controlled force exertion scores (Nagasawa and Demura, 2002), with smaller differences indicating a better ability to control force exertion. The duration of each trial was 40 seconds, and the controlled force exertion scores in each display condition were estimated from data from three trials, excluding the first 15 seconds of each trial, as in the previous study of Nagasawa et al. (2000). The mean of the second and third trials was used for the analysis (Nagasawa et al., 2004).

2. 5. *Statistical analysis*

Data were analyzed with SPSS Version 17.0 for Windows (SPSS Inc., Tokyo, Japan). The data are reported using ordinary statistical methods including mean (*M*) and standard deviation (±standard deviation, *SD*). A one-way analysis of variance on age, grip strength, and physical characteristics (height, body mass) was conducted to examine significant differences among age groups. When a significant effect was found, a multiple-comparison test was

conducted using Tukey's honestly significant difference (HSD) method for pair-wise comparisons. For each age group, correlation analyses were used to identify associations between the controlled force exerted in response to sinusoidal waveform and bar chart displays. In addition, coefficients of variance were calculated to examine individual differences between age groups. An alpha level of 0.05 was considered significant for all tests.

3. Results

There were significant differences among age groups in the means of age and grip strength. The young and middle-aged groups had significantly greater mean standing height and body mass than the elderly group. Table 2 shows the means of each age group for the sinusoidal waveform and the bar chart and correlations between the two displays. The coefficient of variance was in the same range in all age groups for both displays (CV_{SW} = 28.0–36.9, CV_{BC} = 29.1–32.6), but the elderly group showed a somewhat high value (36.9) for the sinusoidal waveform.

Table 2 near here

Figure 3 shows scatter plots for the controlled force exertion scores for the two displays. Significant correlations were observed between the sinusoidal waveform and bar chart in the young, middle-aged, and elderly groups. These correlations did not differ significantly between age groups.

Figure 3 near here

Table 3 shows the frequency and ratio of the controlled force exertion scores for the two displays. Scores over 1500% (Nagasawa and Demura, 2007) with the sinusoidal and bar chart displays were found in only one and two individuals, respectively, in the middle-aged group but in 12% and 16% of participants, respectively, in the elderly group. Among all participants, only 8% of participants in the elderly group scored over 1500% in both displays.

Table 3 near here

4. Discussion

The coefficient of variance for controlled force exertion with the sinusoidal waveform was somewhat higher in the elderly group than in the other two groups (36.90 vs 28.01 and 32.77). However, overall it was considered that participants in the present study formed a homogeneous group for controlled force exertion. Bemben et al. (1996) reported that the elderly show a noticeable decline in peripheral muscle activity when compared with young people based on the measurement of muscular endurance using intermittent grip strength. Voelcker-Rehage and Alberts (2005) reported that young participants are superior to elderly participants in the changing force tracking task. Compared to the young, the elderly are considered to have inferior controlled force exertion (i.e. peripheral muscular responses to the changing target and the exertion of neuromuscular function). Because the sinusoidal waveform signals are periodic and displayed as changes in the waveform from left to right visually and spatially with time, the sinusoidal waveform display is easy to anticipate after

the first period and requires participants to use more visual information concerning performance errors and more feed-forward (e.g. anticipatory) strategies than the bar chart display (Ofori et al., 2010). Also, with the sinusoidal demand, individuals must constantly change and regulate their force exertion. In contrast, with the bar chart, they exert a constant force level. This may explain why larger individual differences were found with the sinusoidal waveform display in the elderly group than in the other age groups.

On the basis of the above-mentioned differences between the two displays, it was hypothesized that the relationship between the controlled force exertion values in the two displays would decrease with age. However, contrary to the hypothesis, significant correlations were observed between the sinusoidal waveform and bar chart displays in all age groups, and no significant differences were found between age groups in correlations between the two displays. From these results, it is inferred that at all ages, participants can correctly regulate their controlled grip force exertion in a pursuit task, regardless of the difference in the displays. The functional role in movement performance may differ according to the region of the nervous system controlling each movement. The cerebellum is generally associated with skilled motor behaviors and the basal ganglia, particularly the striato-nigral system, is associated with actual motor behavior (Doyon and Benali, 2005). Reports by several researchers (Nagasawa and Demura, 2007; Nagasawa et al., 2009; Ofori et al., 2010) make it clear that aged-related differences are greater with pursuit movements and that controlled force exertion decreases with age. The present test was performed using submaximal muscular exertion with a moderate cycle (0.1 Hz and 0.3 Hz) of changing demand values. Success in this test strongly requires hand-eye

coordination and grip force that are controlled by feedback, such as the sense of force exertion and target matching. The magnitude and dynamic properties of force output are indicative of neuromuscular function (Ofori et al., 2010). Muscular strength decreases with changes of neuromuscular pathways and muscle fiber composition, spinal motor neuron apoptosis (Galganski et al., 1993), and muscle atrophy with age (Cauley et al., 1987). Although no participants scored over 1500% were found in the young group for either display, one (1%) and two (3%) individuals in the middle-aged group, and six (12%) and eight (16%) in the elderly group scored above 1500%. That is, the frequency of participants scoring over 1500% increased with age. Some of the elderly (about 8%) had scores over 1500% in both displays (see Figure 3 and Table 3). Nagasawa and Demura (2007) reported that, for controlled force exertion, the rate of decrease is remarkable after the age of 50 years, and scores over 1500% are most seen in the 5-point scale comprising this age group. To summarize, since participants scoring over 1500% in both displays were not found in the middle-aged group and were few in the elderly group, those scoring over 1500% in both displays were considered to be significantly inferior in controlled force exertion. Hence, it is necessary to take any appropriate measures to improve the controlled force exertion of people whose scores are greater than 1500% in both displays, and to intervene early if this problem is detected in middle-aged people. Therefore, it is necessary to pay attention to a score over a fixed value (1500%) or an abnormally large score in either of the displays because this suggests a marked decrease in controlled force exertion. Thus, individuals with poor controlled force exertion may also be identified on the basis of the relationship between scores achieved in both displays.

The participants in this study were healthy, active male adults aged 20–86 years with mean maximal grip strength of more than 27.7 kgf. A follow-up study is necessary to clarify the relationship between performances using the two displays and to compare the controlled force exertion in both displays between individuals with arm and muscular nervous dysfunction and healthy individuals.

5. Conclusions

In conclusion, measurements of controlled force exertion using the sinusoidal and bar chart displays show a significant relationship between relative grip exertion values. Furthermore, these relationships do not differ as a function of age. Individuals with scores over 1500% in both displays are considered considerably inferior in controlled force exertion. Those with poor controlled force exertion may also be identified on the basis of the relationship between scores achieved in both displays.

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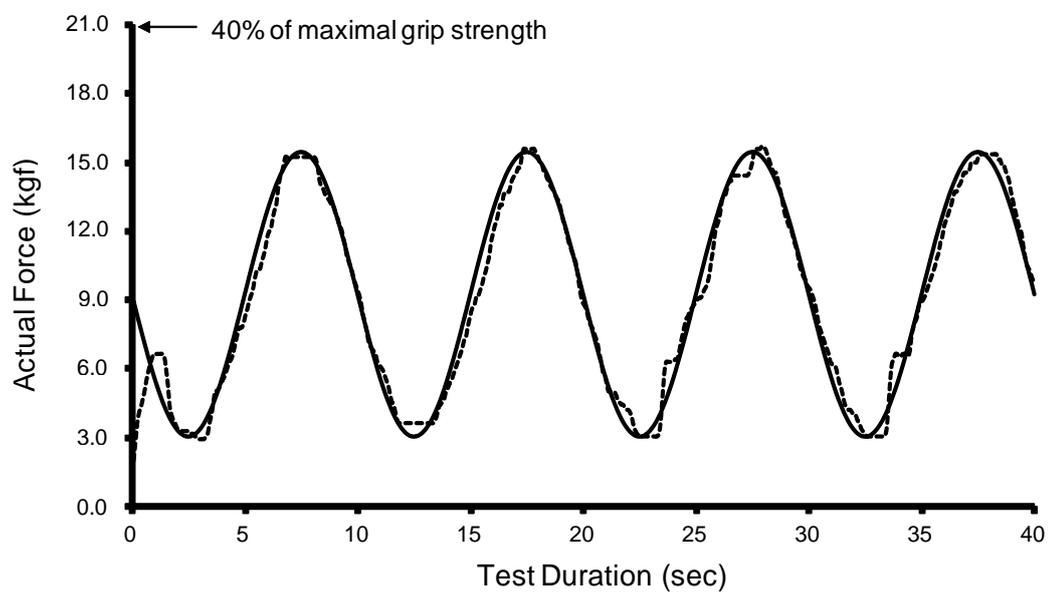
Figure 1. Sinusoidal waveform display (100 mm x 140 mm) of the demand value. The solid waveform (A) shows the demand value and the broken waveform (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in the range of 5-25% of maximal grip strength. 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.
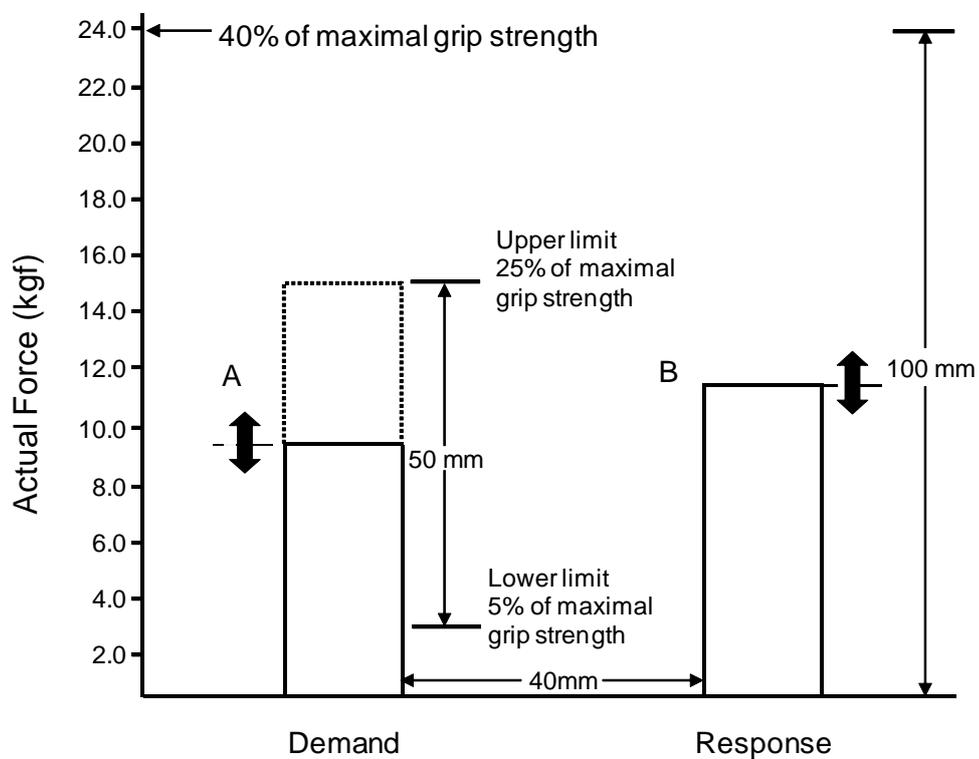
Figure. 2. Bar chart display (100 mm X 140 mm) of demand value. Bar chart display (100 mm X 140 mm) of demand value. Left bar (A) shows the demand value and right bar (B) is the exertion value of grip strength. The test was to fit line B (exertion value of grip strength) to line A (demand value), which varied in a span of 50 mm on the display. The test time was 40 sec for each trial. The controlled force exertion was calculated using the data from 25 sec of the trial following the initial 15 sec of the 40-sec period. Actual force was shown on the display, right.
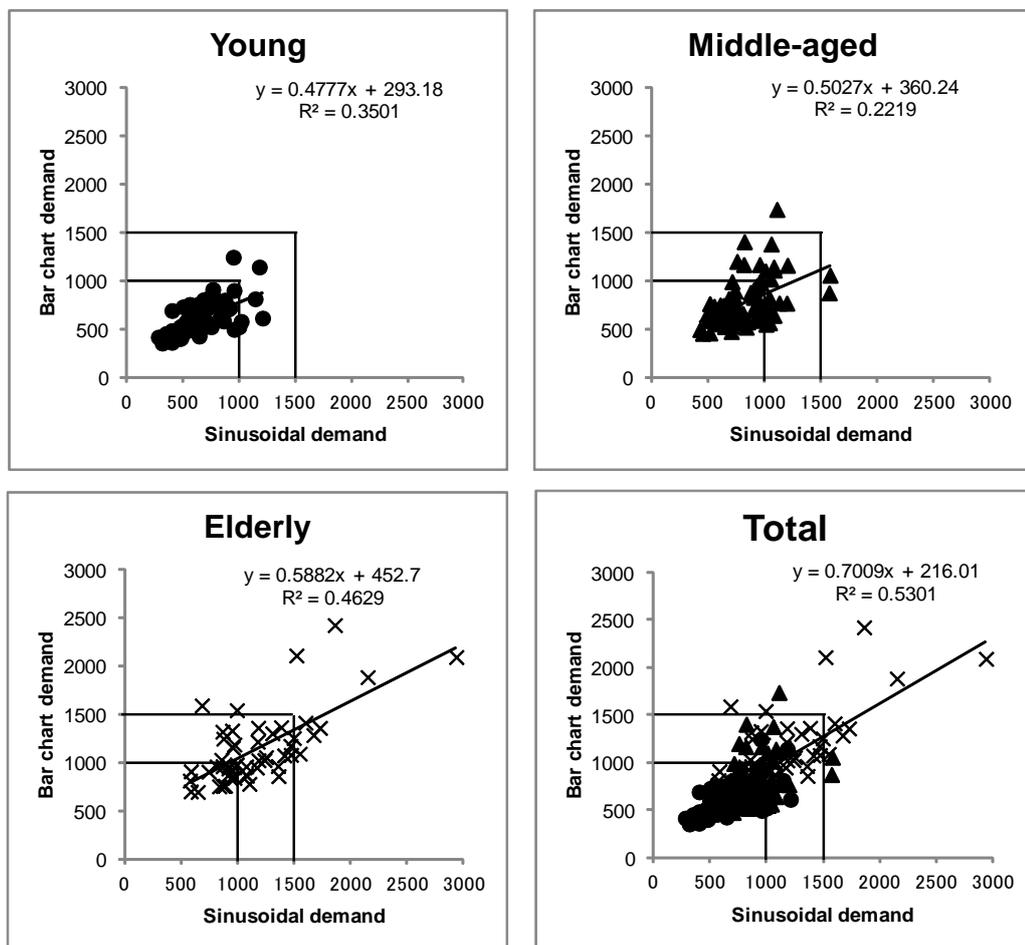
Fig. 3. Scatter plots by age group for the controlled force exertion score in the sinusoidal and bar chart demands.

Table 1. Physical characteristics of participants

Age group	Age (yr)		Height (cm)		Body mass (kg)		Grip strength (kgf)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Young (n=53)	24.6	3.25	172.0	4.84	68.7	7.62	50.1	7.26
Middle-aged (n=71)	44.3	8.70	169.4	6.85	68.4	9.27	45.1	8.06
Elderly (n=51)	69.3	6.40	162.7	6.86	60.8	9.90	32.5	9.19
Total (n=175)	45.6	18.58	168.3	7.29	66.2	9.62	43.0	10.76

Note: Age ranges of young, middle-aged, and elderly groups were 20–29, 30–59, and 60–86 years, respectively.

Table 2. Means, standard deviations, coefficient of variance and correlations by age group for the controlled force exertion test in the sinusoidal and bar-chart demands

Age group	Sinusoidal demand (%)			Bar-chart demand (%)			
	M	SD	CV	M	SD	CV	r
Young (n=53)	680.50	223.03	32.77	618.24	180.06	29.12	0.59 *
Middle-aged (n=71)	832.25	233.15	28.01	778.62	248.78	31.95	0.47 *
Elderly (n=51)	1155.47	426.36	36.90	1132.31	368.59	32.55	0.68 *
Total (n=175)	880.49	352.51	40.04	833.12	339.33	40.73	0.73 *

Note: Age ranges of young, middle-aged, and elderly groups were 20–29, 30–59, and 60–86 years, respectively. *p<0.05

Table 3. Frequency and ratio by age group for the controlled force exertion test in the sinusoidal and bar-chart demands

Age group	Sinusoidal demand score			Bar-chart demand score			Both Sinusoidal and Bar-chart demand score		
	under 1000	1000-1500	over 1500	under 1000	1000-1500	over 1500	under 1000	1000-1500	over 1500
Young (n=53)	48	5	0	51	2	0	52	1	0
	(90.6)	(9.4)	(0.0)	(96.2)	(3.8)	(0.0)	(98.1)	(1.9)	(0.0)
Middle-aged (n=71)	54	15	2	59	11	1	65	6	0
	(76.1)	(21.1)	(2.8)	(83.1)	(15.5)	(1.4)	(91.6)	(8.4)	(0.0)
Elderly (n=51)	25	18	8	24	21	6	36	11	4
	(49.0)	(35.3)	(15.7)	(47.1)	(41.2)	(11.7)	(70.6)	(21.6)	(7.8)

Note: Age ranges of young, middle-aged, and elderly groups were 20–29, 30–59, and 60–86 years, respectively.