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**The relative and absolute reliability of maximum phonation
time in community-dwelling Japanese people**

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Abstract

Background and aims The aim of the present study was to examine the approximate value of maximum phonation time (MPT) in community-dwelling Japanese people and to set the range of error after ascertaining relative and absolute reliability.

5 *Methods* Participants in the present study were adults living in Kobe and Himeji City, Hyogo Prefecture, Japan. Participants were seated in the upright sitting position and were asked to produce an /a/ sound at their normal speaking volume for as long as they possibly could. The examiner measured the time until the sound became inaudible. Two trials were performed.

10 *Results* The subjects in the final analysis comprised 380 adults (246 women, 134 men; age, 72.7 ± 5.9 years). The values of trial 1 and trial 2 were analyzed with intraclass correlation coefficient ($ICC_{(1,1)}$), and Bland-Altman plot. Average values of the women, men, and both sexes combined were 16.1, 18.7, and 17.0 sec, respectively. Average values of age groups 60-69, 70-79, and 80-89 years were 17.9, 16.8, and 15.9 sec, respectively. The $ICC_{(1,1)}$ was 0.87 ($P < 0.001$).

15 Both fixed bias and proportional bias existed. Limits of agreement (LOA) were -5.0 to 7.7 and % change ranged from -27.1% to 41.8%.

Conclusions These normative data indicated that sufficiently reliable values could be measured in two trials. LOA showed that the second value tended to be higher. In determining the effect of treatment, one must consider that the value will be slightly higher at re-test.

20

Key words: Maximum phonation time, Community-dwelling people, Relative reliability, Absolute reliability

Introduction

Speech-language-hearing therapists use maximum phonation time (MPT) to evaluate phonatory function. Because of its simplicity and ease of use, requiring only a stopwatch, MPT is a frequently used clinical tool for assessing phonatory mechanics [1]. MPT is widely used to evaluate maximum vocal capabilities because it is non-invasive, quick, and inexpensive [2,3]. MPT has been used in various situations in previous research. Solomon et al. reported that subjects used 90% of their vital capacity (VC) for their best MPT trial [4]. Another study reported that patients with myopathy showed a significant positive correlation between MPT and VC [5]. Izawa et al. reported that peak VO_2 [2,3], minute ventilation (VE)/ VCO_2 slope [6], body mass index (BMI) [7], and disease severity correlated positively with MPT in all patients with chronic heart failure [8]. Furthermore, in the case of vocal fold paralysis, MPT increased following surgery [9]. The MPT value was also lower in patients with cerebrovascular disease than in healthy people [10]. According to these previous studies [4-10], MPT appears to be affected by several kinds of disease, and therefore it may be a useful tool for the assessment of disease. However, the number of studies is small, and further research is needed to allow meaningful use of MPT in the future. Therefore, we first need to obtain sufficient normative data on MPT for both sexes and all age groups [1].

Cielo et al. previously reported that MPT in Brazilian children aged 4 ($n = 7$), 5 ($n = 11$), and 6 ($n = 5$) years was 5.77, 7.16, and 10.32 sec, respectively [11]. In another study comprising 1660 subjects, Mendes Tavares et al. also reported that the MPT for vocalizing the /a/ sound in age groups of 4-6, 7-9, and 10-12 years was 6.09, 7.94, and 8.98 sec, respectively. They further concluded that these values of MPT could be used as normative values in pediatric studies because of the large sample size of their study [12]. Maslan et al. reported that adults (34 men and 35 women) in the 61-70-, 71-80-, and 81-90-year age groups had average MPTs of 22.27, 22.97, and 21.14 sec, respectively [1]. Yanagihara et al. reported MPTs for Japanese adults with an average age of 28 years for women ($n = 11$) and 36 years for men ($n = 11$) of 22.5 sec and 30.2 sec, respectively [13]. Also, Hirano et al. reported MPTs in adults (25 women and 25 men, age unknown) to be 25.7 sec for women and 34.6 sec for men [14]. However, although the study by Maslan et al. was recent, the participants were American. They mentioned that MPT might be affected by differences in height, weight, and BMI in their participants. There was a fundamental difference in their subjects compared with Japanese subjects because the physique is different between Americans and Japanese. Furthermore, Yanagihara et al. [13] and Hirano et al. [14] reported their results in the 1960s, nearly 50 years ago. Compared to these previous reports, current characteristics in the Japanese may be significantly different. For example, average life span, BMI, diet, and other lifestyle aspects have changed [15,16], and thus, MPT also might have changed. There is little recent research to clarify the value of MPT in older adults and especially in community-dwelling Japanese people. Therefore, more detailed normative data on MPT obtained by measurement in a large sample size is required.

Because it is very important to measure MPT quickly and accurately in clinical situations, it is necessary to obtain a reliable measurement in as few times as possible. Few studies discuss how many times to measure MPT [17], and more trials are necessary to understand how to test children [18]. As in children, MPT in adults may improve with increasing numbers of trials.

However, it is not clear whether a reliable value can be measured in two trials. We hypothesized that a reliable value would be obtained by two trials because of well-controlled test conditions. Furthermore, it is necessary to understand the range of error caused by repeated measurements when determining the effect of treatment. We thus hypothesized that the second value of MPT would be higher than the first because of practice effects.

Thus, the aim of the present study was to clarify approximate MPT values in community-dwelling Japanese people and to set the range of error after ascertaining relative and absolute reliability between test and re-test results.

Methods

Study Design and Participants

This was a cross-sectional study for which we held four measurement meetings from August 2014 to May 2015. Participants in the present study included 495 adult volunteers (322 women and 173 men) who live in Kobe and Himeji City, Hyogo Prefecture, in Japan.

Participants with a history of cerebrovascular disease, chronic obstructive respiratory disease, and asthma, with depression of cognitive function (Mini Mental State Examination [MMSE] <24 points), who were older than 89 or younger than 60 years, and who had missing data were excluded. This study was approved by the Kobe University Graduate School of Health Science Institutional Committee on Human Research (approval no. 181-1). All subjects participating in the study provided informed consent according to the ethical standards set forth in the Declaration of Helsinki.

We asked all participants to complete a self-reported questionnaire that covered factors such as age, sex, and medical history. We measured their height, weight, cognitive function with the MMSE, and MPT.

Measurement of MPT was referred from previous research [1,17]. Participants were positioned upright in a seated position. They were instructed to produce an /a/ sound at their normal speaking volume for as long as they possibly could. Even if their voice started sounding strained and effortful, they continued until they could no longer hold the sound. The examiner used a stopwatch to measure the time until the sound became inaudible. The trial was performed twice, and the subjects were allowed to rest for 10–15 seconds between trials. The 10 examiners, who were Kobe University students, included graduate students who were registered physical therapists and undergraduate students of the physical therapy and occupational therapy departments. To determine intra-class reliability and exclude inter-rater

reliability, the same examiner performed both trials.

Statistical Analysis

5 Characteristics were calculated for each group separated by sex and age (60-69, 70-79, and 80-89 years). First, we calculated means $\pm$ standard deviation (SD) and min-max of the MPT value for trial 1, trial 2, and the average. Second, intraclass correlation coefficient ($ICC_{(1,1)}$) analyses of the values of trial 1 and trial 2 were performed to assess relative reliability. Relative reliability is a measure of the degree to which test results are maintained with repeated
10 measurements. The $ICC_{(1,1)}$ is regarded as “great” when higher than 0.9, as “good” when 0.8-0.9, as “fair” when 0.7-0.8, and as “possible” when 0.6-0.7 [19]. Third, we performed Bland-Altman analysis to assess absolute reliability [20] and calculated the limit of agreement (LOA) to estimate the range of error. Absolute reliability is used to evaluate the values of acceptable range of error for a test’s use in individuals. A Bland-Altman plot was constructed with the
15 difference between the trial 1 and trial 2 values (trial 2 value minus trial 1 value) on the vertical axis and the average of trial 1 and trial 2 values on the horizontal axis. Systematic error, which includes fixed and proportional bias, was also analyzed by Bland-Altman plot [21]. Fixed bias, which presents as a deviation with a specific direction regardless of the true value, was considered to be present when zero was not included in the 95% confidence interval (CI) of
20 the mean difference between the trial 1 and trial 2 values, calculated as follows:

$$[95\%CI = d \pm t \times \sqrt{(SD_d)^2/n}]$$

When fixed bias existed, we calculated the limit of agreement (LOA) as:

$$[LOA = (\bar{d} \mp 1.96 \times SD_d) \pm t \times \sqrt{(3(SD_d)^2/n)}]$$

Proportional bias, which presents as a deviation that changes in a specific direction in proportion
25 to the true value, was considered to be present when there was a significant correlation between the value in the vertical axis and that in the horizontal axis. When proportional bias existed, we calculated the LOA as:

$$[LOA = (\bar{\%d} \mp 1.96 \times SD_{\%d}) \pm t \times \sqrt{(3(SD_{\%d})^2/n)}]$$

When no systematic error was detected, the presence of only an accidental error was
30 considered. Accidental error, which is the change caused by an error of measurement or circadian variation, always exists. When only an accidental error was detected, we calculated the minimal detectable change (MDC_{95}) as:

$$[MDC_{95} = 1.96 \times SD_d]$$

35 n = the number of measured subjects
 d = difference between the trial 1 and trial 2 values (trial 2 value minus trial 1 value)
 $\bar{d}$ = the mean of “ d ” values
 SD_d = the standard deviation of “ d ” values
 $\%d$ = d / average of the trial 1 and trial 2 values $\times 100$
 $\bar{\%d}$ = the mean of “ $\%d$ ” values

$SD_{d\%}$ = the standard deviation of “%d” values

t = the point of the t distribution (degree of freedom is $n-1$ and $P < 0.05$)

All analyses were performed with IBM SPSS statistical software (version 23) and Microsoft Excel® for 2011 (version 14.5.7). A P value of <0.05 was considered significant.

5

Results

After applying the exclusion criteria, 380 adults (246 women and 134 men) remained as analysis subjects. The characteristics of the participants are presented in *Table 1*. There were no significant differences in age or BMI between the women and men in each age group. Means $\pm$ SD and min-max values of MPT for trial 1, trial 2, and the average are shown in *Table 2*. Average MPT values of all women, all men, and both sexes combined were 16.1, 18.7, and 17.0 sec, respectively. Average MPT values of the age groups of 60-69, 70-79, and 80-89 years were 17.9, 16.8, and 15.9 sec, respectively. Among all participants, the highest MPT value was 51.7 sec, and the lowest value was 4.0 sec. The $ICC_{(1,1)}$ result of relative reliability between trial 1 (16.3 ± 7.0 sec) and trial 2 (17.7 ± 7.8 sec) was 0.87 ($P < 0.001$).

The Bland-Altman plot is shown in *Figure 1*, and the results of absolute relative reliability between trial 1 and trial 2 are shown in *Table 3*. Both fixed bias and proportional bias were present. The LOA was -5.0 to 7.7, and the % change in LOA from trial 1 to trial 2 ranged from -27.1% to 41.8%.

Discussion

The purpose of the present study was to investigate normative data of MPT in Japanese community-dwelling adults and to clarify whether reliable values could be measured in two trials and the extent of the range of error. The present results show normative data for each group divided by sex and age, and they indicated that it was possible to obtain reliable values with two trials and that a range of error could be determined.

Average MPT values of all women and all men were 16.1 and 18.7 sec, respectively, and those of the three age groups (60-69, 70-79, and 80-89 years) were 17.9, 16.8, and 15.9 sec, respectively. Although we did not compare values between groups in the present study, the results show that the older the subjects were, the lower was their MPT value. As well, the MPT values were lower in women than in men. The data did not clearly indicate that the changes in MPT were due to aging.

There was little difference in MPT between the age groups of 61-70, 71-80, and 81-90 years in a study by Maslan et al. [1] Goy et al. also reported that overall age-related differences were limited [22]. Gender difference in the present study was similar to that reported in these two previous studies. Although it has not been clearly proven, there may be a sex-related difference in the MPT value in that the value is lower in women than in men in various studies. In the present

study, the respective MPT values for both women and men were lower by about 10 and 15 seconds, respectively, than those reported by Hirano et al. [14]. Because the patient demographic data (e.g., age and BMI) were not clearly shown in this previous study, the results were difficult to compare. However, in cases in which the demographic data is clearly shown, such as in the report of Maslan et al. [1], the values in the present study were similar and supported those of the previous studies.

Reproducibility is “good” if the $ICC_{(1,1)}$ is greater than 0.8 [19]. In a previous study, researchers indicated that it may be best to perform multiple MPT trials regardless of the initial results [17]. In the present study, the $ICC_{(1,1)}$ value was sufficiently high at 0.87. Our results indicated that sufficiently reliable values could be measured in two trials.

The LOA in the present study ranged from -5.0 to 7.7, suggesting a tendency for the second MPT value to be higher. During the MPT measurements, we did not necessarily give the participants any feedback after trial 1. We surmise that after the first trial, the participants understood the test, so they were trying to do better by themselves without any examiner feedback in the second trial. When determining treatment effect, it must be considered that the value at re-test may be slightly higher than the initial value. If the value is 7.7 seconds greater than that of the previous measurement, phonation time can be considered to be prolonged. Furthermore, because the % change in LOA from trial 1 to trial 2 ranged from -27.1% to 41.8%, the amount of change for trial 2 became a larger positive value because the MPT value in trial 2 was higher than that in trial 1.

Limitations

There are several limitations in the present study. We did not take into account various factors. The results indicated the possibility that there were sex- or age-related differences between the MPTs. It will be necessary to clarify this in the future. Personal factors such as physique, BMI, and exercise capacity might also influence the MPT value, and additional study is needed to determine their influence. We also need to determine why the MPT range (4-52 sec) was so large. We did not ask about diseases of the larynx or past voice training in the questionnaire. Furthermore, several examiners measured MPT, so there could be differences in the teaching method, and the feedback was not uniform after trial 1. Because the strength and pitch of the voice can be different in each participant, we need to consider a better way to standardize these two factors when measuring MPT in a future trial.

Conclusions

The results of the present study showed average MPT values of community-dwelling women, men, and both sexes combined (age, 72.7 ± 5.9 years) to be 16.1, 18.7, and 17.0 sec, respectively. Average MPT values of the three different age groups (60-69, 70-79, and 80-89 years) were 17.9, 16.8 and 15.9 sec, respectively. Because the sample size of the present study was large, and the participants were self-supporting, community-dwelling members, these data might be

considered normative data.

The results also indicated that sufficiently reliable MPT values could be measured in two trials. However, the LOA was -5.0 to 7.7 and the % change in LOA from trial 1 to trial 2 ranged from -27.1% to 41.8%, indicating a tendency for the second trial value to be higher. When
5 determining the effect of treatment, it must be considered that the re-test value will be slightly higher than the initial value.

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Figure Legend

Fig. 1. Bland-Altman plot with the difference between trial 1 and trial 2 values (trial 2 minus trial 1 value) on the vertical axis and the average of trial 1 and trial 2 values on the horizontal axis. Because the 95% confidence interval of the difference did not include zero and there was a positive correlation, both fixed and proportional bias existed, and there was a tendency for the trial 2 value to be higher than the trial 1 value.

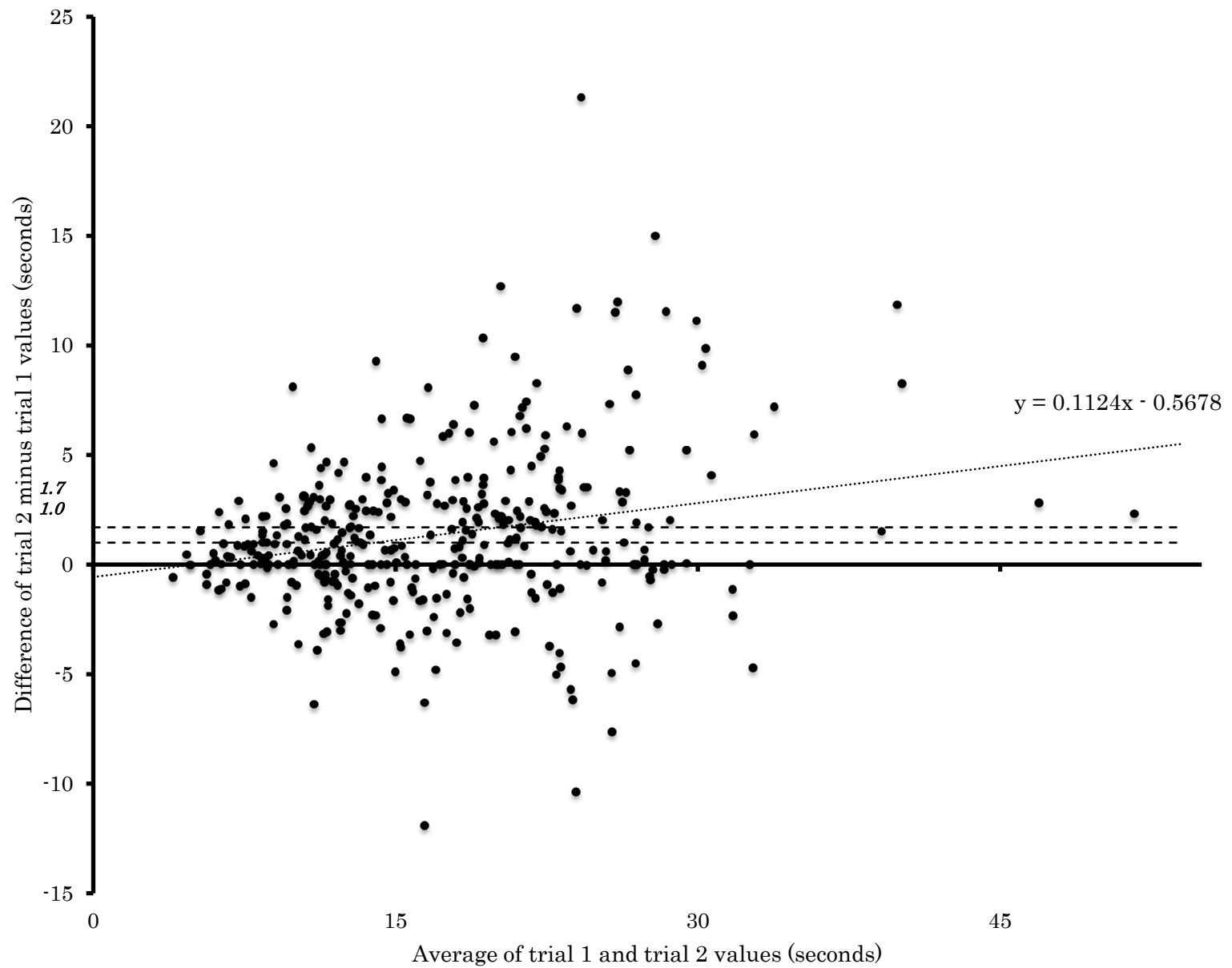


Figure 1. Bland-Altman plot with the difference between trial 1 and trial 2 values (trial 2 minus trial 1 value) as the vertical axis and the average of trial 1 and trial 2 values as the horizontal axis. Because the 95% confidence interval of the difference did not include zero and there was a positive correlation, both fixed and proportional bias existed, and there was a tendency for the second trial value to be higher than that of the first trial.

Table 1 Baseline characteristics of the analysis population

Group (age)	n	Age	BMI		Sex (women)
		M $\pm$ SD	M $\pm$ SD	Min-Max	%
Total	380	72.7 $\pm$ 5.9	22.8 $\pm$ 3.0	15.7-35.2	64.7
Men	134	73.0 $\pm$ 6.1	23.2 $\pm$ 2.9	15.7-31.6	
Women	246	72.6 $\pm$ 5.9	22.6 $\pm$ 3.1	15.9-35.2	
60-69 yrs.	115	65.9 $\pm$ 2.6	22.9 $\pm$ 3.0	16.4-31.6	64.3
Men	41	66.1 $\pm$ 2.6	23.2 $\pm$ 3.1	17.9-31.6	
Women	74	65.8 $\pm$ 2.7	22.7 $\pm$ 3.0	16.4-30.6	
70-79 yrs.	210	74.0 $\pm$ 2.7	22.7 $\pm$ 3.1	15.7-35.2	67.6
Men	68	73.9 $\pm$ 2.6	23.2 $\pm$ 2.8	15.7-30.7	
Women	142	74.0 $\pm$ 2.7	22.5 $\pm$ 3.3	15.9-35.2	
80-89 yrs.	55	82.4 $\pm$ 2.6	23.0 $\pm$ 2.8	17.5-28.9	54.5
Men	25	82.0 $\pm$ 2.8	23.3 $\pm$ 2.8	17.9-28.2	
Women	30	82.7 $\pm$ 2.4	22.9 $\pm$ 2.9	17.5-28.9	

M: mean; SD: standard deviation; BMI: body mass index.

Table 2 Fundamental statistics (means $\pm$ standard deviation) of maximum phonation time as a function of age, sex, and trial

	Age (yrs)	n	Trial 1		Trial 2		Average	
			M $\pm$ SD	Min-Max	M $\pm$ SD	Min-Max	M $\pm$ SD	Min-Max
M	60-69	41	18.7 $\pm$ 6.4	6.1-28.6	20.3 $\pm$ 7.6	5.2-35.4	19.5 $\pm$ 6.8	5.6-30.7
	70-79	68	18.0 $\pm$ 9.1	4.8-50.5	19.3 $\pm$ 9.4	4.8-52.8	18.7 $\pm$ 9.0	4.8-51.7
	80-89	25	17.0 $\pm$ 5.7	5.8-27.0	18.3 $\pm$ 6.5	5.8-29.3	17.7 $\pm$ 6.0	5.8-27.6
	Total	134	18.0 $\pm$ 7.8	4.8-50.5	19.4 $\pm$ 8.4	4.8-52.8	18.7 $\pm$ 7.9	4.8-51.7
W	60-69	74	16.0 $\pm$ 6.2	4.5-32.3	18.0 $\pm$ 7.1	5.4-35.5	17.0 $\pm$ 6.4	5.3-31.7
	70-79	142	15.5 $\pm$ 6.6	4.3-36.0	16.4 $\pm$ 7.7	3.7-45.8	15.9 $\pm$ 6.9	4.0-40.1
	80-89	30	13.7 $\pm$ 6.4	4.9-27.9	15.1 $\pm$ 6.4	4.9-27.7	14.4 $\pm$ 6.3	4.9-27.8
	Total	246	15.4 $\pm$ 6.5	4.3-36.0	16.7 $\pm$ 7.4	3.7-45.8	16.1 $\pm$ 6.7	4.0-40.1
B	60-69	115	17.0 $\pm$ 6.4	4.5-32.4	18.8 $\pm$ 7.3	5.2-35.5	17.9 $\pm$ 6.6	5.3-31.7
	70-79	210	16.3 $\pm$ 7.6	4.3-50.5	17.4 $\pm$ 8.4	3.7-52.8	16.8 $\pm$ 7.7	4.0-51.7
	80-89	55	15.2 $\pm$ 6.2	4.9-27.9	16.6 $\pm$ 6.6	4.9-29.3	15.9 $\pm$ 6.3	4.9-27.8
	Total	380	16.3 $\pm$ 7.0	4.3-50.5	17.7 $\pm$ 7.8	3.7-52.8	17.0 $\pm$ 7.2	4.0-51.7

M: men; W: women; B: both; M: mean; SD: standard deviation.

All units are in seconds.

Table 3 Absolute reliability between trial 1 and trial 2 (n = 380)

Bland-Altman analysis						
Fixed bias		Proportional bias			Acceptable range of error	
95% CI	Bias	B	r	Bias	LOA	
1.0 to 1.7	Exists	0.11**	0.23**	Exists	-5.0 to 7.7	-27.1% to 41.8%

95% CI: 95% confidence interval of the mean difference between trial 1 and trial 2;

B: standardizing coefficient; r: correlation coefficient; LOA: limit of agreement.

** Significance level <0.01.