HUMAN MOVEMENT (ISSN 1899-1955)
2023; 24(1): 140–148

Reliability and validity of a new measure of agility and equilibrium: the reaction balance test

original paper
DOI: https://doi.org/10.5114/hm.2023.120636

YUSUKE OYAMA[1], **TOSHIO MURAYAMA**[2]
[1] Faculty of Culture and Sport Policy, Toin University of Yokohama, Yokohama, Japan
[2] Faculty of Engineering, Niigata University, Niigata, Japan

ABSTRACT

Purpose. The evaluation has been limited to a single ability, such as agility or equilibrium, and has not been conducted in a series of movements. In addition, a measurement method that is less burdensome for the participants has not been established. In this study, we designed a new reaction balance test (RBT) that combines agility and equilibrium and examined its reliability and validity.

Methods. The participants were 49 young people (17 males, 32 females). Their whole-body reaction time (WRT) and center of pressure (COP) during a 30-second trial (COP30) of single-leg standing with open eyes were measured to determine their agility and equilibrium, respectively. Overall, 4 COP parameters were evaluated during COP30. For RBT, the participants were asked to quickly raise one leg after sensing a light stimulus and stand on the other leg for 10 seconds (COP10). The test evaluated their single-leg reaction time (SRT) and the same 4 parameters as those in COP30.

Results. The intraclass correlation coefficients between agility (WRT and SRT) and equilibrium (total length [TL] at COP30 and COP10) were all > 0.81. In addition, no proportional error was observed for COP30 or COP10, only for TL of the non-dominant leg. There were significant associations between WRT and SRT for agility and between COP30 and COP10 for equilibrium for TL.

Conclusions. It was suggested that the reliability and validity of RBT could be improved by evaluating TL by using the dominant leg for agility and the non-dominant leg for equilibrium.

Key words: fall avoidance ability, reaction time, center of pressure, postural control ability

Introduction

Falls occur when people exceed their postural control limits in response to disturbances that cause postural collapse [1]. This would explain why people recognize and react to disturbances before their posture collapses and use appropriate response strategies relevant to the situation [2]. Therefore, measuring and evaluating agility (i.e., quick reaction to disturbance) and equilibrium (i.e., postural control ability after the reaction) are essential because these 2 abilities construct fall avoidance movements.

Agility is ‘a rapid whole-body movement with change of velocity or direction in response to a stimulus’ [3]. It occurs when the body reacts to avoid a fall. Therefore, decreased agility may delay reaction time [4] and prevent appropriate response strategies for the situation. Agility has been evaluated by using whole-body reaction time (WRT), which is the time it takes to perform a jumping motion upon recognizing a light stimulus and then lift both feet off the measurement mat [5, 6]. In addition, Lajoie and Gallagher [7] reported that reaction times in fallers were slower than those in non-fallers. However, agility should be evaluated more safely because WRT with a jumping motion may impose a heavy physical load on certain participants, such as frail older adults and people with low physical fitness levels. The risk of injury during measurement is duly included in the evaluation. Although previous studies [8, 9] have examined reaction times with the participants in a sitting position, which is less burdensome for them, this method is impractical for fall avoidance movements.

Even if the body responds through agility and appropriate response strategies are used, falls may still occur if individuals cannot control their posture with

Correspondence address: Yusuke Oyama, Faculty of Culture and Sport Policy, Toin University of Yokohama, 1614 Kuroganecho, Aoba, Yokohama, Kanagawa 225-8503, Japan, e-mail: y.oyama@toin.ac.jp, https://orcid.org/0000-0002-6175-8603

Received: April 22, 2022
Accepted for publication: November 22, 2022

Citation: Oyama Y, Murayama T. Reliability and validity of a new measure of agility and equilibrium: the reaction balance test. Hum Mov. 2023;24(1):140–148; doi: https://doi.org/10.5114/hm.2023.120636.

their lower limbs. Equilibrium begins to decline in the late 40s and worsens rapidly between the ages of 70 and 80 [10]. Sturnieks et al. [11] reported that age-related changes in vestibular sensation, as well as in the somatosensory and visual systems were among the causes of equilibrium decline. Equilibrium is classified into static and dynamic postural control ability [12]. Since it is easier to identify age-related decline in the dynamic postural control ability than in the static postural control ability [13], disturbance stimulation methods using the EquiTest or a stimulated treadmill have been used [14, 15]. However, the disadvantages of these methods are that they can only be performed in a laboratory environment and are burdensome for the participants. On the other hand, measures of single-leg standing with the eyes open are applied to evaluate static postural control ability [16, 17]. Among them, the use of a stabilometer allows for a detailed evaluation of equilibrium, as well as discrimination between fall and non-fall groups by center of pressure (COP) velocity [18] and sway area [19]. On the other hand, the age-related decline is easier to identify in dynamic postural control ability than in static postural control ability, such as single-leg standing with the eyes open [13]. Therefore, evaluating dynamic movements by adding a task to single-leg standing with the eyes open may allow for the evaluation of equilibrium in conditions similar to actual fall situations.

Although previous studies reported that agility and equilibrium were associated with fall risk in each of the measures used, they only examined these 2 abilities in relation to another specific ability. Falls are common in situations involving such disturbances as stumbles and slips [20]. Evaluating fall avoidance ability in a sequence of movements is important because avoiding a fall involves a sequence of 2 phases, namely, rapid body reaction and postural control, using appropriate response strategies. Therefore, we have developed a new reaction balance test (RBT) that jointly assesses agility and equilibrium. The purpose of this study was to examine its reliability and validity.

Material and methods

Participants

A total of 49 healthy adults, of whom 17 were male (*M* [*SD*] age: 20.5 [1.3] years, *M* [*SD*] height: 171.9 [5.1] cm, *M* [*SD*] weight: 66.9 [6.1] kg) and 32 were female (*M* [*SD*] age: 20.2 [1.1] years, *M* [*SD*] height: 161.0 [5.9] cm, *M* [*SD*] weight: 54.7 [5.0] kg), were selected as participants for this pilot study. The inclusion criterion was the ability to perform the various measurements, and the exclusion criteria were inability to perform the various measurements owing to orthopaedic disease or pain, as well as potential abnormalities. The subjects received sufficient oral and written explanations of the purpose of the study and its measurements before it began.

Whole-body reaction time

Previous studies used WRT to measure agility [5, 6] by applying a pressure-detecting measurement mat (T.K.K. 5408; Takei Scientific Instruments, Niigata, Japan). The participants stood on the mat with their knees slightly bent. The examiner gave the subjects a red light signal from a light stimulus generator set up 2 m in front of them at the eye level and then instructed them to make a quick jumping motion once they sensed it. WRT was the time from the red light flashed to when both the participants' feet left the mat. A short WRT meant a superior degree of agility. A total of 5 measurement trials were performed, and the average of 3 (i.e., excluding the maximum and minimum data) was used as the representative value. Two practice trials were performed before the main trial to deepen the individual's comprehension of the methodology in advance. The same examiner performed all measurements.

Single-leg standing with the eyes open

The COP during the task of single-leg standing with the eyes open measured equilibrium with a stabilometer (T.K.K. 5810; Takei Scientific Instruments, Niigata, Japan), in accordance with a previous study [21]. The sampling rate was set at 100 Hz. The participants stood on one leg on the stabilometer for 35 seconds. They were instructed to look at a marker set up 2 m in front of them at the eye level and to place their hands on their waist. The COP during the first 5 seconds of the task is large [21]. Thus, we evaluated its parameters per second (total length [TL], outer peripheral area [OPA], rectangular area [RA], and standard deviation of the elliptical area [SDA]), using only the data for the subsequent 30 seconds (i.e., excluding the first 5 seconds; COP30). Two trials of measurement were performed for the dominant and non-dominant legs, and the average of the 2 was the representative value for each leg. The dominant and non-dominant legs were determined with the method by de Ruiter et al. [22]. The order of trials for the dominant and non-dominant legs was randomized. One trial for each leg was performed before the main trial to deepen the participant's comprehension of the methodology in advance. The same examiner performed all measurements.

Reaction balance test

The RBT's combined measurement of agility and equilibrium was performed by using a COP and reaction time measurement device (Takei Scientific Instruments, Niigata, Japan). We set up the measurement mat to determine the pressure on each side on top of the stabilometer and then asked the participant to stand on it. The examiner gave the subject a red light signal from a light stimulus generator set up 2 m in front of them at the eye level and instructed them to quickly raise one leg and stand on the other leg for 10 seconds (Figure 1).

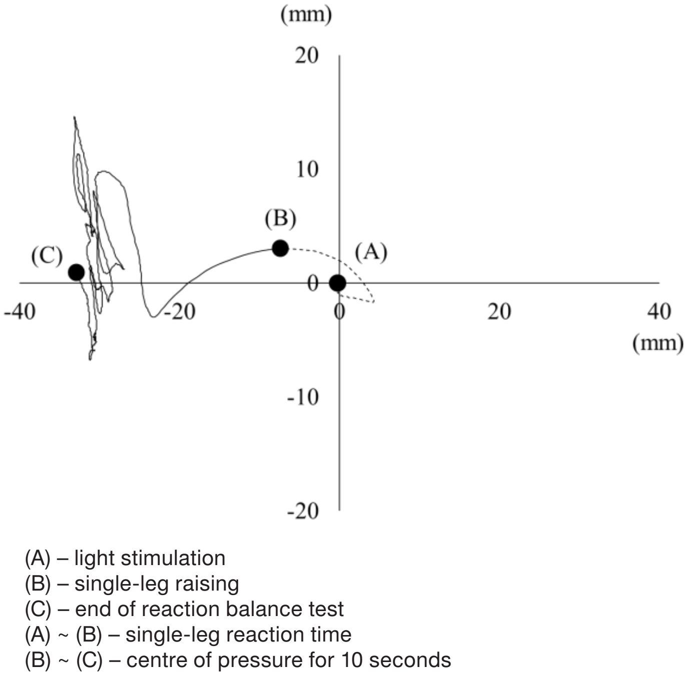
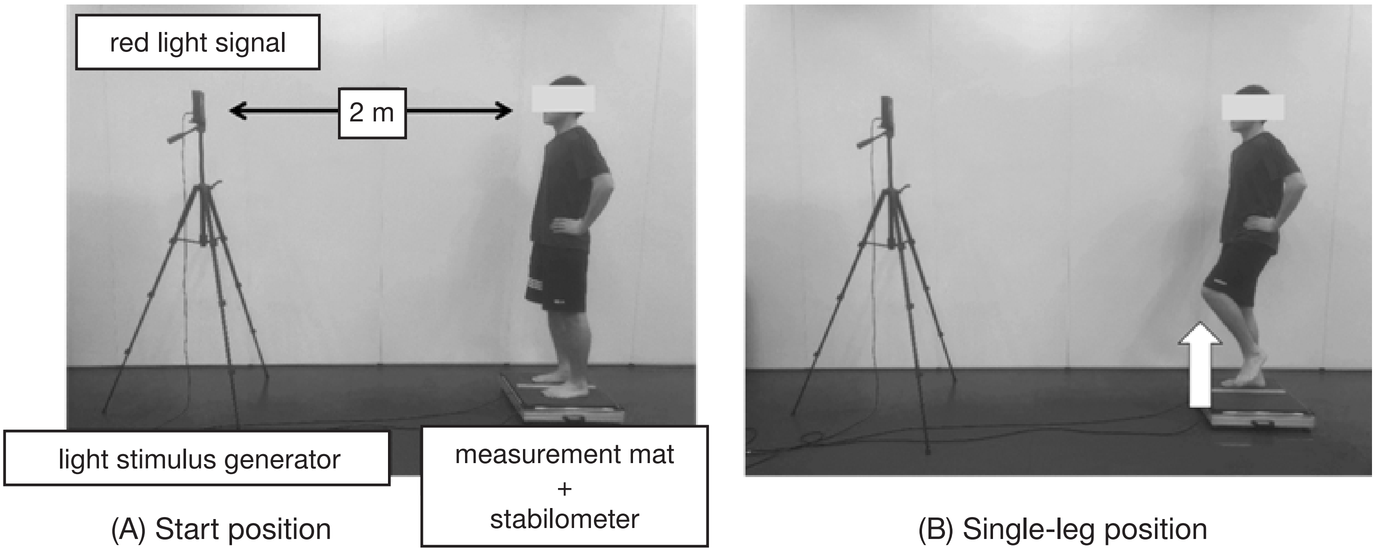


Figure 2. Example of centre of pressure data of the reaction balance test

RBT assessed agility from when the red light flashed to when one leg of the participant left the mat (single-leg reaction time [SRT]). It determined equilibrium by measuring COP during the 10 seconds of single-leg standing after the participant raised one leg (Figure 2). The sampling rate was 100 Hz. We evaluated the same 4 parameters per second as those in COP30 (TL, OPA, RA, and SDA), using the data for the entire duration of COP10. Overall, 5 trials of measurement were performed for the dominant and non-dominant legs, and the average of 3 (i.e., excluding the maximum and minimum data) was used as the representative value for SRT. The representative data of COP10 were the average values of the 3 trials used to calculate the representative SRT data. We calculated the representative data of the dominant and non-dominant legs for SRT and COP10. The order of trials for the dominant and non-dominant legs was randomized. One trial for each leg was performed before the main trial to deepen the participant's comprehension of the methodology in advance. The same examiner performed all measurements.



(A) Start position

(B) Single-leg position

Figure 1. Measurement method of the reaction balance test. (A) The participant is standing on the measurement mat on top of the stabilometer. (B) On perceiving the red light signal, the participant is raising one leg for 10 seconds

Data analysis

Intraclass correlation coefficients (ICCs) were calculated for each measurement parameter to examine intertrial reliability. The ICCs of 3 trials (1, 1) were calculated for WRT, SRT, and COP10, whereas those of 2 trials (1, 1) were calculated for COP30. ICCs ≥ 0.81 were defined as almost perfect [23]. Bland-Altman analysis was used to examine systematic error for WRT and SRT and that between COP30 and COP10. 1-way ANOVA was conducted for WRT to compare the number of trials completed for each parameter, while 2-way ANOVA (trials × legs) was performed for SRT, COP30, and COP10 to compare differences between the dominant and non-dominant legs. The effect size (η^2) was calculated to examine the magnitude of the differences. The Shapiro-Wilk test was applied to check the normality of the data. If normality was found, Pearson's correlation coefficient was calculated, and if normality was not found, Spearman's rank correlation coefficient was calculated. A correlation coefficient of less than 0.2 was defined as 'slight correlation,' between 0.2 and 0.4 as 'low correlation,' between 0.4 and 0.7 as 'moderate correlation,' between 0.7 and 0.9 as 'high correlation,' and of more than 0.9 as 'very high correlation' [24]. All analyses were conducted with the R 3.4.1 software (R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was set at $p < 0.05$ in all analyses.

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Toin University of Yokohama Ethics Committee (reference No.: I-50).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

Table 1 shows the mean and ICC values for 3 trials of WRT and SRT (dominant and non-dominant legs). All ICCs were > 0.81 (range: 0.830–0.920). Figure 2 presents the results of Bland-Altman analysis of agility. No proportional error was observed between WRT and SRT for either the dominant or the non-dominant leg. The 1-way ANOVA and 2-way ANOVA results did not reveal significant main effects or interactions.

Table 2 shows the mean and ICC values for 2 trials of COP30 and 3 trials of COP10. Although both the dominant and non-dominant legs presented ICCs > 0.81 for TL in COP30, the ICCs for the other parameters were low, especially for the dominant leg (ICC range: 0.117–0.306; non-dominant leg ICC range: 0.340–0.433). On the other hand, COP10 exhibited ICCs ≥ 0.81 for SDA of the non-dominant leg. The ICCs of the non-dominant leg tended to be higher, as in COP30, including those of the other parameters (ICC range: 0.611–0.802). Figures 3 and 4 show the results of Bland-Altman analysis of equilibrium. No proportional error was observed only for TL of the non-dominant leg. In addition, the results of 2-way ANOVA did not reveal significant main effects or interactions.

Table 3 shows the results of the analysis of the relationship between WRT and SRT and that between COP30 and COP10. Pearson's correlation coefficient was calculated since the data for both parameters were found to be normal for the association between WRT and the dominant leg. On the other hand, Spearman's rank correlation coefficient was calculated since the data were not found to be normal for both or either of the parameters. There was a significant correlation between WRT and SRT for both the dominant and non-

Table 1. Reliability of agility and 1-way ANOVA or 2-way ANOVA (trials × legs)

Parameter	Trial 1	Trial 2	Trial 3	ICC (1, 1) (95% CI)	Main effect (ES)		Interaction (ES)
					Trial	Leg	
WRT* (ms)	409.0 ± 73.5	402.9 ± 72.8	399.9 ± 74.5	0.920 (0.876–0.951)	0.748 (0.004)	–	–
SRT (dominant) (ms)	573.5 ± 89.0	568.2 ± 90.6	563.1 ± 90.2	0.830 (0.744–0.893)	0.774 (0.002)	0.592 (0.001)	0.774 (0.002)
SRT (non-dominant) (ms)	580.6 ± 99.0	586.8 ± 100.5	576.3 ± 99.1	0.854 (0.779–0.909)			

ICC – intraclass correlation coefficient, WRT – whole-body reaction time, SRT – single-leg reaction time
* 1-way ANOVA
Effect size (*ES*): $0.01 < \eta^2$: small, $0.06 < \eta^2$: medium, $0.14 < \eta^2$: large

Table 2. Reliability of postural control ability and 2-way ANOVA (trials × legs)

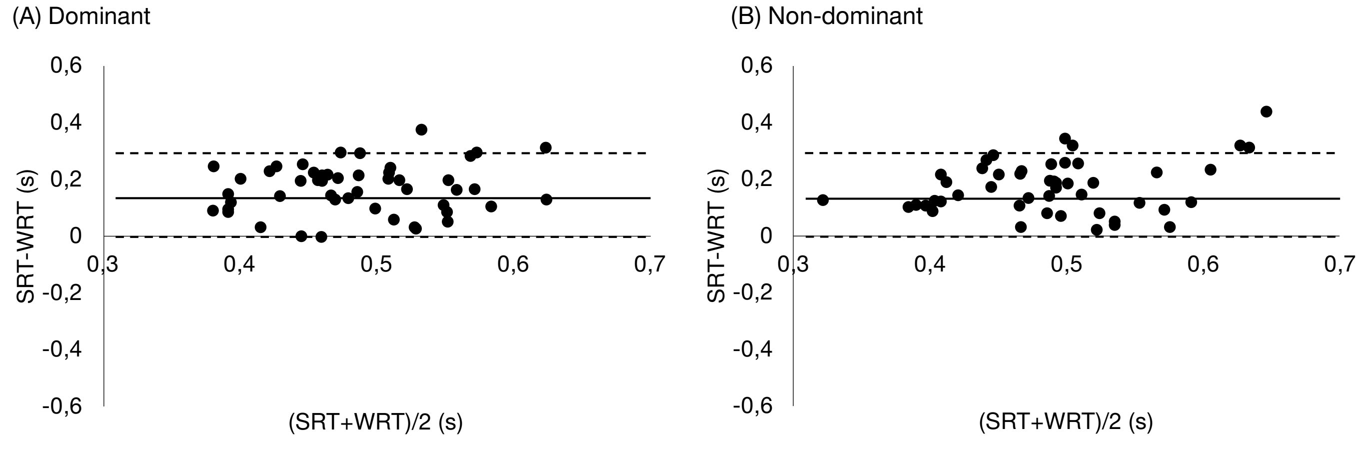
	Parameter	Trial 1	Trial 2	Trial 3	ICC(1, 1) (95% CI)	Main effect (*ES*)		Interaction (*ES*)
						Trial	Leg	
COP30 (dominant)	TL (mm/s)	22.2 ± 9.5	21.3 ± 8.1	–	0.909 (0.845–0.948)	0.599 (0.001)	0.750 (0.001)	0.865 (0.000)
	OPA (mm^2/s)	22.6 ± 9.3	25.1 ± 24.7		0.132 (–0.151 to 0.395)	0.730 (0.001)	0.554 (0.002)	0.357 (0.004)
	RA (mm^2/s)	33.4 ± 14.6	37.9 ± 42.5		0.117 (–0.165 to 0.382)	0.794 (0.000)	0.608 (0.001)	0.279 (0.006)
	SDA (mm^2/s)	4.1 ± 1.7	4.4 ± 3.4		0.306 (0.032–0.538)	0.778 (0.000)	0.870 (0.000)	0.354 (0.004)
COP30 (non-dominant)	TL (mm/s)	21.3 ± 7.9	20.9 ± 7.8	–	0.909 (0.844–0.947)			
	OPA (mm^2/s)	21.7 ± 9.1	21.9 ± 7.4		0.433 (0.178–0.634)			
	RA (mm^2/s)	32.7 ± 13.7	32.0 ± 11.1		0.400 (0.139–0.610)			
	SDA (mm^2/s)	4.1 ± 1.5	4.3 ± 1.6		0.340 (0.069–0.564)			
COP10 (dominant)	TL (mm/s)	33.6 ± 9.1	31.6 ± 6.4	31.9 ± 6.2	0.611 (0.460–0.740)	0.772 (0.002)	0.850 (0.000)	0.560 (0.004)
	OPA (mm^2/s)	188.8 ± 96.8	190.1 ± 114.3	188.8 ± 113.6	0.661 (0.521–0.777)	0.965 (0.000)	0.541 (0.001)	0.956 (0.000)
	RA (mm^2/s)	360.7 ± 200.0	386.4 ± 266.9	367.7 ± 232.1	0.741 (0.623–0.833)	0.874 (0.001)	0.588 (0.001)	0.857 (0.001)
	SDA (mm^2/s)	54.0 ± 39.8	57.2 ± 49.3	57.1 ± 47.4	0.802 (0.706–0.875)	0.833 (0.001)	0.472 (0.002)	0.869 (0.001)
COP10 (non-dominant)	TL (mm/s)	32.1 ± 7.5	32.0 ± 6.4	32.4 ± 8.2	0.661 (0.522–0.777)			
	OPA (mm^2/s)	182.3 ± 91.6	181.8 ± 104.2	179.6 ± 100.0	0.743 (0.627–0.835)			
	RA (mm^2/s)	356.4 ± 227.6	355.6 ± 238.7	352.8 ± 229.0	0.780 (0.675–0.860)			
	SDA (mm^2/s)	52.7 ± 42.4	54.0 ± 45.6	51.8 ± 43.4	0.826 (0.739–0.891)			

ICC – intraclass correlation coefficient, COP30 – centre of pressure for 30 seconds, COP10 – centre of pressure for 10 seconds, TL – total length, OPA – outer peripheral area, RA – rectangular area, SDA – standard deviation of the elliptical area
Effect size (*ES*): 0.01 < η^2: small, 0.06 < η^2: medium, 0.14 < η^2: large

Table 3. Validity of agility and postural control ability

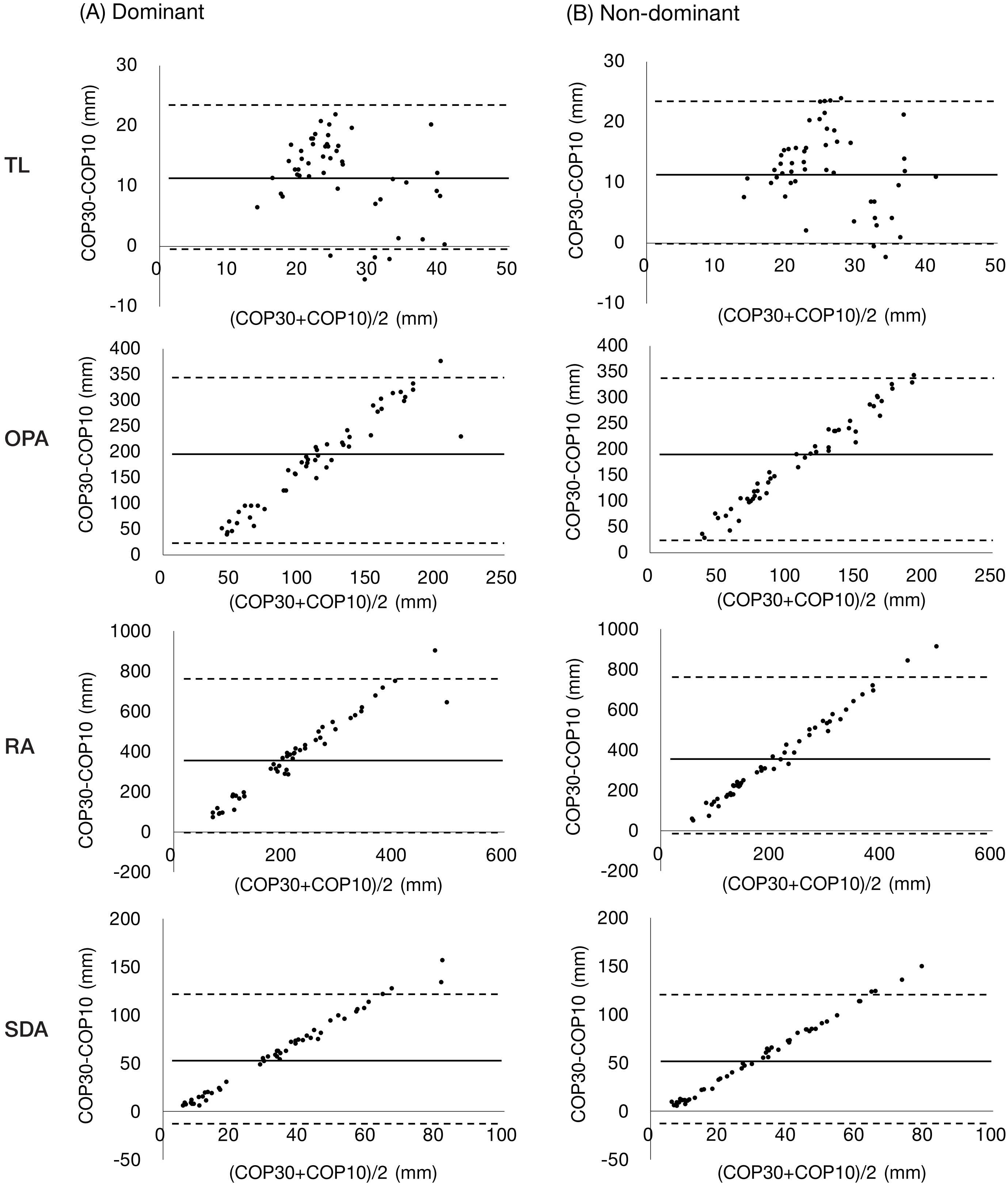
		Agility (WRT)	Postural control ability (COP30)			
			TL	OPA	RA	SDA
RBT (SRT, COP10)	Dominant	0.381* (0.007)	0.650* (< 0.001)	–0.139 (0.339)	–0.091 (0.531)	0.044 (0.763)
	Non-dominant	0.410* (0.004)	0.588* (< 0.001)	–0.008 (0.956)	–0.005 (0.975)	0.087 (0.555)

WRT – whole-body reaction time, TL – total length, OPA – outer peripheral area, RA – rectangular area, SDA – standard deviation of the elliptical area, COP30 – centre of pressure for 30 seconds, COP10 – centre of pressure for 10 seconds, RBT – reaction balance test, SRT – single-leg reaction time
Upper row – correlation coefficient, Lower row – *p* value, * $p < 0.05$



SRT – single-leg reaction time, WRT – whole-body reaction time

Figure 3. Bland-Altman plots for (A) dominant, (B) non-dominant leg measured with whole-body reaction time and single-leg reaction time. Solid lines indicate mean between-method differences (bias) and dashed lines indicate upper and lower 95% limits of agreement (± 1.96 standard deviation of the bias)



TL – total length, OPA – outer peripheral area, RA – rectangular area, SDA – standard deviation of the elliptical area,
COP30 – centre of pressure for 30 seconds, COP10 – centre of pressure for 10 seconds

Figure 4. Bland-Altman plots for (A) dominant, (B) non-dominant leg measured with centre of pressure for 30 seconds and centre of pressure for 10 seconds. Solid lines indicate mean between-method differences (bias) and dashed lines indicate upper and lower 95% limits of agreement (± 1.96 standard deviation of the bias)

dominant legs, with a low to moderate correlation (dominant leg: *r* = 0.381; non-dominant leg: *r* = 0.410). Moreover, the correlation between COP30 and COP10 was significant only for TL for both the dominant and non-dominant legs and both correlations were moderate (dominant leg: *r* = 0.650; non-dominant leg: *r* = 0.588).

Discussion

This study aimed to examine the reliability and validity of the RBT that jointly assesses agility and equilibrium. The investigation of RBT reliability revealed that SRT for agility had high ICCs for both the dominant and non-dominant legs. COP10 for equilibrium tended to have higher ICCs for the non-dominant leg. Although no proportional error was found between WRT and SRT for either the dominant or the non-dominant leg, no proportional error was reported between COP30 and COP10 only for TL of the non-dominant leg. In addition, there were no differences between trials or legs (dominant and non-dominant). The examination of RBT validity revealed that SRT for agility was significantly related to WRT for both the dominant and non-dominant legs. COP10 for equilibrium was significantly related only to TL for both the dominant and non-dominant legs. These results suggest that RBT is reliable and valid for both the dominant and non-dominant legs; it is recommended that SRT for agility is evaluated with the dominant leg and TL of COP for equilibrium is evaluated with the non-dominant leg.

The reliability of RBT was high for both agility and equilibrium. Although the degree of agility differs depending on the task, previous studies on agility and reaction time have reported relatively high ICCs, ranging from 0.71 to 0.90 [25, 26]. These outcomes are supported by this study results, which revealed high ICCs, ranging from 0.830 to 0.920, for WRT and SRT of the dominant and non-dominant legs through RBT.

Moreover, previous studies [27, 28] have reported that ICC decreases with test complexity. RBT is a test in which the participants raise one leg in reaction to a light stimulus and then perform single-leg standing with the eyes open for 10 seconds. Therefore, the lower ICCs for SRT relative to those for WRT in this study can be ascribed to the more complicated task involved in RBT. It requires the body to react with the consideration of single-leg standing after the reaction. On the other hand, the COP30 and COP10 for equilibrium presented high ICCs for each parameter. These results are consistent with those reported in previous studies [29, 30] that identified TL as the most reliable COP parameter. However, the ICC of TL during COP10 was lower than that for the same parameter during COP30. The measurement of COP may have influenced these results for 10 seconds immediately after single-leg standing in RBT.

COP is larger in the first 5 seconds after the start of single-leg standing [21]. Thus, only the data for the subsequent 30 seconds (i.e., excluding the first 5 seconds) were used in the analysis of COP30 in this study. Conversely, the use of the data for the entire duration of COP10 (i.e., including the first 5 seconds) possibly affected the ICCs. In addition, Le Clair and Riach [31] reported that the longer the measurement time, the higher the reliability of COP parameters, which may have been one of the reasons for the lower ICCs when the measurement time was 10 seconds in this study. Furthermore, the ICCs of the non-dominant leg tended to be higher for both COP30 and COP10. The dominant leg is ‘the leg used to manipulate an object or to lead out in movement,’ whereas the non-dominant leg is ‘the leg which performs the stabilizing or supporting role’ [32, p. 181]. In this study, the non-dominant leg was considered more stable and presented higher ICCs for COP parameters.

As for RBT validity, agility and equilibrium showed a significant association. The fact that WRT with the jumping motion and SRT with the single-leg raising motion exhibited a relationship suggests that agility can be assessed regardless of the task difficulty or the movement posture. Simple reaction time is generally accepted to depend on perception (hearing, seeing, and feeling stimuli), processing (focusing and understanding information), and reaction (motor agility) [33]. The WRT and SRT measured in this study share many common processes, and they only differ in the reaction (jumping and single-leg raising) in these processes. Blomkvist et al. [34] measured upper and lower extremity reaction times in 354 participants aged 20–99 years and reported the same age and sex effect trend for both measurements. These results suggest that differences in the movements and postures used to measure reaction time in this study had minimal effects and that WRT and SRT were associated.

Equilibrium was related to both the dominant and non-dominant leg in terms of TL in COP30 and COP10. Thus, equilibrium could be evaluated by single-leg standing for 10 seconds in RBT. The 10-second single-leg standing task has been used in studies of patients with knee osteoarthritis. It is associated with lower extremity alignment, knee pain, and quadriceps strength [35]; it has also been applied in comparative studies with healthy adults [36]. As mentioned, TL is a highly reliable parameter [29, 30], which substantiates the association that we found between TL of COP30 and COP10. Therefore, evaluating TL by measuring COP for 10 seconds in RBT is useful.

This study has several limitations. First, we were not able to establish the evaluation parameters of RBT. Although RBT aimed to evaluate agility and equilibrium with single-leg raising and single-leg standing, our study did not determine these comprehensive parameters as specific parameters for the test. In the future, studies should examine the relationship between agility and equilibrium in RBT and identify parameters for it. Second, we were not able to examine the parameters by gender. Although there are many physical factors that differ by gender, and agility and equilibrium are considered to be among them, the sample size was too small to examine the values by gender. In the future, the sample size should be increased and a detailed analysis should be conducted by gender.

Conclusions

We tested and confirmed the reliability and validity of RBT for the combined assessment of agility and equilibrium. RBT was found to be reliable and valid for both the dominant and non-dominant leg. In addition, the reliability and validity of RBT may be improved by using the dominant leg for SRT for agility and the non-dominant leg for COP for equilibrium to evaluate TL.

Acknowledgements

We would like to express our gratitude to the participants and to our staff for their help with data collection. This research was funded with a grant from the Japan Society for the Promotion of Science KAKENHI (grant number: JP20K19522).

Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

References

1. Oliver D. Older people who fall: why they matter and what you can do. Br J Community Nurs. 2007;12(11): 500–507; doi: 10.12968/bjcn.2007.12.11.27481.
2. Horak FB, Nashner LM. Central programming of postural movements: adaptation to altered support-surface configurations. J Neurophysiol. 1986;55(6):1369–1381; doi: 10.1152/jn.1986.55.6.1369.
3. Sheppard JM, Young WB. Agility literature review: classifications, training and testing. J Sports Sci. 2006; 24(9):919–932; doi: 10.1080/02640410500457109.
4. Schmidt RA, Lee TD, Winstein CJ, Wulf G, Zelaznik HN. Motor control and learning: a behavioral emphasis. Champaign: Human Kinetics; 2017.
5. Cao Z-B, Maeda A, Shima N, Kurata H, Nishizono H. The effect of a 12-week combined exercise intervention program on physical performance and gait kinematics in community-dwelling elderly women. J Physiol Anthropol. 2007;26(3):325–332; doi: 10.2114/jpa2.26.325.
6. Momma H, Kato K, Sawada SS, Gando Y, Kawakami R, Miyachi M, et al. Physical fitness and dyslipidemia among Japanese: a cohort study from the Niigata Wellness Study. J Epidemiol. 2021;31(4):287–296; doi: 10.2188/jea.JE20200034.
7. Lajoie Y, Gallagher SP. Predicting falls within the elderly community: comparison of postural sway, reaction time, the Berg balance scale and the Activities-specific Balance Confidence (ABC) scale for comparing fallers and non-fallers. Arch Gerontol Geriatr. 2004;38(1):11–26; doi: 10.1016/s0167-4943(03)00082-7.
8. Cai Y, Leveille SG, Hausdorff JM, Bean JF, Manor B, McLean RR, et al. Chronic musculoskeletal pain and foot reaction time in older adults. J Pain. 2021;22(1): 76–85; doi: 10.1016/j.jpain.2020.05.003.
9. Morozumi K, Yamamoto I, Fujiwara T, Nishiya T, Takeuchi Y, Umeki C, et al. Effect of dentures wearing on motor reaction time and balance function in elderly people. J Physiol Anthropol Appl Human Sci. 2004; 23(4):129–137; doi: 10.2114/jpa.23.129.
10. Patti A, Bianco A, Şahin N, Sekulic D, Paoli A, Iovane A, et al. Postural control and balance in a cohort of healthy people living in Europe: an observational study. Medicine. 2018;97(52):e13835; doi: 10.1097/MD.0000000000013835.
11. Sturnieks DL, St George R, Lord SR. Balance disorders in the elderly. Neurophysiol Clin. 2008;38(6):467–478; doi: 10.1016/j.neucli.2008.09.001.
12. Brown CN, Mynark R. Balance deficits in recreational athletes with chronic ankle instability. J Athl Train. 2007;42(3):367–373.
13. Baloh RW, Fife TD, Zwerling L, Socotch T, Jacobson K, Bell T, et al. Comparison of static and dynamic posturography in young and older normal people. J Am Geriatr Soc. 1994;42(4):405–412; doi: 10.1111/j.1532-5415.1994.tb07489.x.
14. Whipple R, Wolfson L, Derby C, Singh D, Tobin J. Altered sensory function and balance in older persons. J Gerontol. 1993;48(Spec No):71–76; doi: 10.1093/geronj/48.special_issue.71.
15. Liu X, Bhatt T, Wang Y, Wang S, Lee A, Pai Y-C. The retention of fall-resisting behavior derived from treadmill slip-perturbation training in community-dwelling older adults. Geroscience. 2021;43(2):913–926; doi: 10.1007/s11357-020-00270-5.

16. De Rekeneire N, Visser M, Peila R, Nevitt MC, Cauley JA, Tylavsky FA, et al. Is a fall just a fall: correlates of falling in healthy older persons. The Health, Aging and Body Composition Study. J Am Geriatr Soc. 2003;51(6):841–846; doi: 10.1046/j.1365-2389.2003.51267.x.
17. Vellas BJ, Rubenstein LZ, Ousset PJ, Faisant C, Kostek V, Nourhashemi F, et al. One-leg standing balance and functional status in a population of 512 community-living elderly persons. Aging. 1997;9(1–2):95–98; doi: 10.1007/BF03340133.
18. Kwok B-C, Clark RA, Pua Y-H. Novel use of the Wii Balance Board to prospectively predict falls in community-dwelling older adults. Clin Biomech. 2015;30(5):481–484; doi: 10.1016/j.clinbiomech.2015.03.006.
19. Maranesi E, Merlo A, Fioretti S, Zemp DD, Campanini I, Quadri P. A statistical approach to discriminate between non-fallers, rare fallers and frequent fallers in older adults based on posturographic data. Clin Biomech. 2016;32:8–13; doi: 10.1016/j.clinbiomech.2015.12.009.
20. Gabell A, Simons MA, Nayak US. Falls in the healthy elderly: predisposing causes. Ergonomics. 1985;28(7):965–975; doi: 10.1080/00140138508963219.
21. Jonsson E, Seiger A, Hirschfeld H. One-leg stance in healthy young and elderly adults: a measure of postural steadiness? Clin Biomech. 2004;19(7):688–694; doi: 10.1016/j.clinbiomech.2004.04.002.
22. De Ruiter CJ, de Korte A, Schreven S, de Haan A. Leg dominancy in relation to fast isometric torque production and squat jump height. Eur J Appl Physiol. 2010;108(2):247–255; doi: 10.1007/s00421-009-1209-0.
23. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics. 1977;33(1):159–174; doi: 10.2307/2529310.
24. Guilford JP. Fundamental statistics in psychology and education. New York: McGraw-Hill Book Company; 1956.
25. Spiteri T, Cochrane JL, Nimphius S. The evaluation of a new lower-body reaction time test. J Strength Cond Res. 2013;27(1):174–180; doi: 10.1519/JSC.0b013e318250381f.
26. Zouhal H, Abderrahman AB, Dupont G, Truptin P, Le Bris R, Le Postec E, et al. Laterality influences agility performance in elite soccer players. Front Physiol. 2018;9:807; doi: 10.3389/fphys.2018.00807.
27. Pojskic H, Åslin E, Krolo A, Jukic I, Uljevic O, Spasic M, et al. Importance of reactive agility and change of direction speed in differentiating performance levels in junior soccer players: reliability and validity of newly developed soccer-specific tests. Front Physiol. 2018;9:506; doi: 10.3389/fphys.2018.00506.
28. Pojskic H, Pagaduan J, Uzicanin E, Separovic V, Spasic M, Foretic N, et al. Reliability, validity and usefulness of a new response time test for agility-based sports: a simple vs. complex motor task. J Sports Sci Med. 2019;18(4):623–635.
29. Nagymáté G, Orlovits Z, Kiss RM. Reliability analysis of a sensitive and independent stabilometry parameter set. PLoS One. 2018;13(4):e0195995; doi: 10.1371/journal.pone.0195995.
30. Takacs J, Carpenter MG, Garland SJ, Hunt MA. Test re-test reliability of centre of pressure measures during standing balance in individuals with knee osteoarthritis. Gait Posture. 2014;40(1):270–273; doi: 10.1016/j.gaitpost.2014.03.016.
31. Le Clair K, Riach C. Postural stability measures: what to measure and for how long. Clin Biomech. 1996;11(3):176–178; doi: 10.1016/0268-0033(95)00027-5.
32. Peters M. Footedness: asymmetries in foot preference and skill and neuropsychological assessment of foot movement. Psychol Bull. 1988;103(2):179–192; doi: 10.1037/0033-2909.103.2.179.
33. Kanai R, Dalmaijer ES, Sherman MT, Kawakita G, Paffen CLE. Larger stimuli require longer processing time for perception. Perception. 2017;46(5):605–623; doi: 10.1177/0301006617695573.
34. Blomkvist AW, Eika F, Rahbek MT, Eikhof KD, Hansen MD, Sondergaard M, et al. Reference data on reaction time and aging using the Nintendo Wii Balance Board: a cross-sectional study of 354 subjects from 20 to 99 years of age. PLoS One. 2017;12(12):e0189598; doi: 10.1371/journal.pone.0189598.
35. Hunt MA, McManus FJ, Hinman RS, Bennell KL. Predictors of single-leg standing balance in individuals with medial knee osteoarthritis. Arthritis Care Res. 2010;62(4):496–500; doi: 10.1002/acr.20046.
36. Hurley MV, Scott DL, Rees J, Newham DJ. Sensorimotor changes and functional performance in patients with knee osteoarthritis. Ann Rheum Dis. 1997;56(11):641–648; doi: 10.1136/ard.56.11.641.