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Research Paper

Validation of the Wii Balance Board to assess static balance during dual-task activity in healthy subjects

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ABSTRACT

Objective: Although dual-task paradigm is commonly used in rehabilitation there is, currently, a lack of information about quantitative balance assessment performed in dual-task conditions. The aim of this study is to validate the use of the Nintendo Wii Balance Board (WBB) to assess balance modifications induced by dual-task activity in healthy subjects.
Material and methods: Seventy-five healthy participants (37 ± 14 years old, 173 ± 8 cm, 73 ± 16 kg, 35 women) participated in this study. Balance was recorded in control situation (baseline) and under two different cognitive tasks (verbal fluency and calculation). Each trial lasted for 60 s and were performed with eyes open and closed. Nine parameters were extracted based on center of pressure displacement based on a previously-validated method. ANOVA tests were used to compare the different conditions followed by Bonferroni's corrections. Protocol was repeated one week after to assess the reproducibility.
Results: Statistically significant differences were found comparing eyes open and closed situation. Concerning the influence of dual-tasks statistically significant decrease of the balance was observed for both eyes open and closed conditions (increase of the total sway and the speed of displacement). Concerning the reproducibility all parameters shows good to excellent ICC values for the different conditions.
Conclusion: In this study, we demonstrated the validity of the WBB to detect the effect of the dual-task on balance in healthy subjects. Further studies are needed to determine if such a kind of evaluation can be used in clinics with subjects at risk of falling.

1. Introduction

While the automatic nature of postural control has long suggested a unique contribution of spinal circuits [1], it now appears that supraspinal structures can play at least as important a role [2]. Understanding the nature of the relationship between cognitive mechanisms and postural control has interested several researchers [3], whereas until then equilibration was considered automatic and governed only by subcortical processes. In 1985, a pilot study was conducted on the interrelationship between cognition and postural control and it was shown that they used identical neural mechanisms [4]. Bipedal standing requires attention [5] and the attention resources mobilized are more important than sitting [6]. This relation between balance and cognition has been demonstrated through the dual-task paradigm in which subjects perform a postural task and a cognitive task simultaneously [7].

Most studies have focused on the relationship between posture and cognition in the elderly: visual, proprioceptive, vestibular or cognitive disorders increase the risk of falling [8].

The most well-known dual-task test is the "Stops walking when talking" whose name comes from the observation that the elderly person who talks while walking must stop one or other of his activity because of his attention cost too high [9].

Dual task tests have been shown to be useful in identifying elderly people at high risk of falling, actually it is the difference in performance between dual-task and single-task gait trials that is essential for discriminating fallers and superior to other measures [10].

These alterations in balance by adding an attentional load are all the more important because the elderly person has low scores on

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conventional balance tests such as the Berg scale [11]; the demented subject, who has significantly greater cognitive impairment than the elderly subject, has greater difficulty performing dual task tests and falls more frequently [12].

Despite the fact that dual-task paradigm provide important clinical information (e.g. to identify subjects most at risk of falling) there is currently a lack of quantitative information about the influence of dual-task on static balance. Due to the lack of study, the link between static standing balance under dual-task conditions and the risk of fall is not clear yet in older people [13] or in patients with neurologic diseases [14]. Furthermore, the few studies performed in this field only analysis the total displacement of center of pressure while other relevant parameters can be obtained: therefore an important question is to determine which parameters could be the more suitable to assess risk of fall or predict the evolution of patients.

The Nintendo Wii Balance Board™ (WBB) has been extensively studied in recent years for research purposes, i.e. balance assessment during static conditions [15,16], and for clinical applications, i.e., assessment of elderly patients [17] or of patients suffering from various diseases. A recent systematic review summarized all the studies about the validation of the WBB, the authors concluded that evidence suggests that the WBB can be used as a reliable and valid tool for assessing standing balance [18].

Therefore, the WBB appears suitable to assess the balance of patients suffering from various clinical conditions. The main advantage of the WBB compared to laboratory force plate is that the WBB is transportable, therefore assessment can be done in the hospital or directly at the patients' homes which makes assessments easier and can be done more regularly. We also showed that there is, currently, a lack of information about the best parameters to select to identify patient at risk of falling. Large scale study are needed to determine those parameters, in this context WBB can be used in a context of multicentric studies since it is reproducible [19] and affordable.

However, to the authors' best knowledge, there is currently no study focusing on the use of WBB to assess balance under various cognitive loads. The aim of this study is, therefore, to validate the use of the WBB to assess balance modifications induced by dual-task activities in healthy subjects.

2. Material and Methods

2.1. Participants

Seventy-five healthy participants (37 ± 14 years old [range 18–68], 173 ± 8 cm, 73 ± 16 kg, 35 women) participated in this study. This study was approved by the Ethical Committee of Erasme Hospital (B406201733610) and written informed consent was obtained from all subjects prior to their participation. Exclusion criteria included neurological conditions, balance deficits, or orthopedic disorders in the last six months.

2.2. Procedure

Subjects were asked to stand on the middle of the WBB (45 × 26.5 cm) as quiet as possible arms relaxed along the body without moving their feet during the protocol and fix a target located on a wall at 2 m.

A control situation and two different cognitive tasks were tested: a calculation task (*"Numbers"*) where the subjects had to count back from 3 to 3 (starting from a number randomly selected between 120 and 130) and a verbal fluency task (*"Words"*) where the participants have to name as many animals as possible [20].

Those two tasks have been performed eyes open and closed. The order of the six trials was randomly determined. Subjects were asked to stand on the WBB during the protocol to maintain a constant width between the feet.

The protocol was repeated one week after to test de reproducibility of measurements.

2.3. Data processing

The WBB was connected to a laptop (Intel Core I5, Windows 7, 6 GB RAM) through a Bluetooth connection; data were retrieved using custom-written software based on the WiimoteLib software. The data collection frequency was 100 Hz. Data were analysed during the 5th and the 55th seconds of each trials.

Previous works have shown that the time interval between samples of WBB was inconsistent [16], therefore, linear interpolation of the raw signals of WBB sensors was applied to obtain a regular sample rate. Based on center of pressure (CP) displacements in the antero-posterior (AP) and mediolateral (ML) directions recorded during the different conditions using Eq. 1. and 2.

$$CPap = (FL + FR) - (PL + PR) \tag{1}$$

$$CPml = (FR + PR) - (FL + PL) \tag{2}$$

where PL, PR, FL, and FR are the displacement values from the posterior left, posterior right, front left, and front right WBB sensors, respectively.

Nine variables were then processed using custom-made MATLAB code (The Mathworks, Natick, RI) based on a previously-validated method [21] using Eqs. (3)–(11): the total displacement of sway (DOT); the area of the 95% prediction ellipse (often referred to as the 95% confidence ellipse) (area); the distance between the maximum and minimum COP displacement (RoM AP and RoM ML); the dispersion of COP displacement from the mean position (SD AP and SD ML); the mean velocity of COP displacement (MV AP and MV ML); and the AP and ML displacements of the total COP sway divided by the total duration of the trial (TMV).

$$DOT = \sum_{i=1}^{N} \sqrt{CPap(i)^2 + CPml(i)^2} \tag{3}$$

$$Area = \pi \times prod\left(2.4478 \times \sqrt{svd(eig(cov(CPap, CPml)))}\right) \tag{4}$$

$$AP\ RoM = \max(CPap) - \min(CPap) \tag{5}$$

$$ML\ RoM = \max(CPml) - \min(CPml) \tag{6}$$

$$AP\ SD = \frac{1}{N}\sqrt{\sum_{i=1}^{N} CPap(i)^2} \tag{7}$$

$$ML\ SD = \frac{1}{N}\sqrt{\sum_{i=1}^{N} CPml(i)^2} \tag{8}$$

$$AP\ velocity = \frac{f}{N}\sum_{i=1}^{N-1} |CPap(i+1) - CPap(i)| \tag{9}$$

$$ML\ velocity = \frac{f}{N}\sum_{i=1}^{N-1} |CPml(i+1) - CPml(i)| \tag{10}$$

$$TMV = \frac{f}{N}\sum_{i=1}^{N-1} \sqrt{(CPap(i+1) - CPap(i))^2 + (CPml(i+1) - CPml(i))^2} \tag{11}$$

2.4. Statistical analysis

The normality of each parameter was checked using graphical methods (boxplots, histograms, and QQ-plots) and homogeneity of variances using the Levene test. One-way repeated measures ANOVA tests were applied to compare the six conditions. Omega-squared were computed to estimate the effect size [22]. Bonferroni tests were used to correct for multiple comparisons in our post-hoc analysis. Reproducibility of measurement were analysed using Intraclass Correlation Coefficient (ICC). Pearson's correlation coefficients were computed to study the relation between the age and the cognitive function as well as the relation between the cognitive level and the balance.

Statistical analyses were performed at an overall significance level of 0.05. Statistics have been conducted in RStudio (version 1.1.442) with R version 3.4.4.

3. Results

Mean results of the six modalities and statistics are presented in Table 1. Statistically significant differences were found for all parameters between situation Eyes Open and Closed (p-value < 0.00.001 for all variables except for AP RoM [p = 0.002] and AP SD [p = 0.038] for the ANOVA). The addition of a cognitive task induces a significant increase of the postural sway (DOT) only for eyes open: increase of 41% and 33% for the numbers and words respectively for the eyes open. On the other hand concerning the speed related parameters statistically significant differences were found for both eyes open and closed: increase of 43% and 52% of the TMV for the numbers and words respectively for the eyes open and of 31% and 42% for the numbers and words respectively for the eyes closed (the results of the post-hoc tests are presented in Table 1). No statistically significant difference were found between the two different type of cognitive tasks.

We compared the results of the cognitive tasks according to the age of the participants using Pearson's correlation coefficients, results are presented in Fig. 1: for the Words there is no influence, for the Numbers there is a downward trend although it is not significant.

In order to represent a possible influence of age on the phenomenon, the normalized results (expressed in percent to control situation) have been presented according to the age of the participants in Fig. 2.

Finally, to assess a potential relation between the cognition and the balance we also presented the normalized results of the DOT according to the cognitive levels in Fig. 3 and computed Pearson's correlation coefficients.

Results of the ICC are presented in Table 2, all parameters shows good to excellent reproducibility for the different conditions (mean ICC for eyes open: 0.86 for control situation, 0.81 for numbers and 0.74 for words, for eyes closed: 0.93 for control situation, 0.87 for numbers and 0.81 for words).

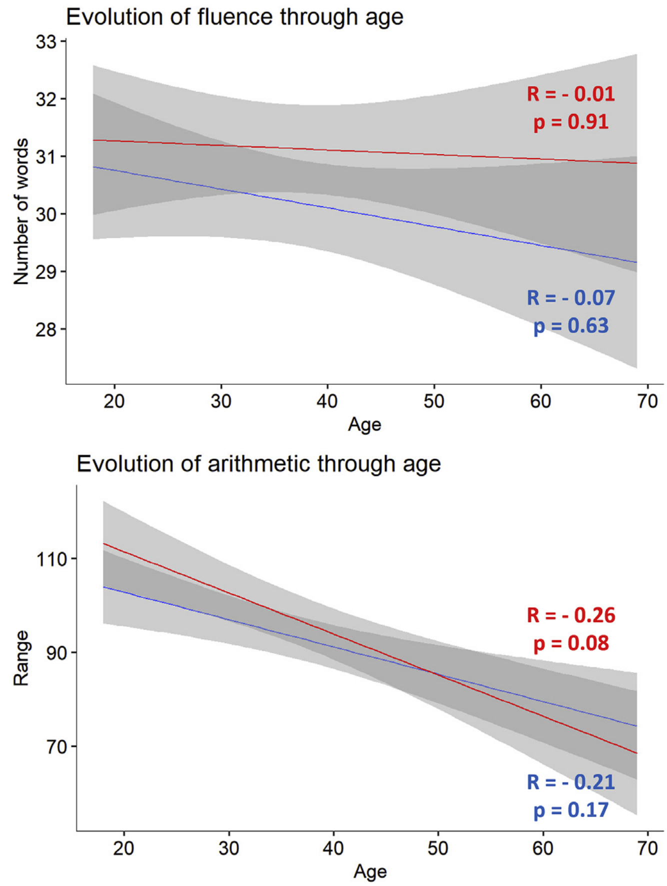

Fig. 1. Results of the cognitive tasks according to the age of the participants during dual-task activities (blue color represents eyes open, red eyes closed). R indicated the Pearson's correlation coefficients and p the p-value. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

4. Discussion

To the authors best knowledge this study is the first one to use the WBB to assess the evolution of balance across the age of the participants during two different kind of dual-task activities.

Regarding the effect of the dual on the balance of healthy subjects, our results are in agreement with a previous study on the addition of cognitive task on balance: the DOT increases as well as the antero-posterior and medio-lateral oscillations with the addition of a cognitive task of the audio-verbal type in subjects aged between 18 and 30 years [23].

Table 1
Mean (std) results for the studied parameters under the five different conditions. *p*-values are the results of the ANOVA, and ω^2 is the measure of the effect size ($\omega2 < 0.01$ = small, between 0.01 and 0.06 = medium, $\omega2 > 0.14$ = large).

Variable	Eyes Open			Eyes Closed			p-value	ω^2
	Control	Numbers	Words	Control	Number	Words		
DOT (mm)	955 (244)	1350 (673) $^{\$\$}$	1268 (471) $^{\$\$\$}$	1224 (312)***	1381 (488)	1394 (443)	<0.001	0.04
Area (mm^2)	2748 (1811)	7213 (5390) $^{\$\$\$}$	8446 (6837) $^{\$\$\$}$	3574 (1856)**	7165 (5924) $^{\$\$\$}$	8157 (7860) $^{\$\$\$}$	<0.001	0.09
ML RoM (mm)	35 (14)	64 (51) $^{\$\$\$}$	78 (61) $^{\$\$\$}$	36 (13)	59 (33) $^{\$\$\$}$	75 (61) $^{\$\$\$}$	<0.001	0.11
AP RoM (mm)	142 (32)	190 (81) $^{\$\$\$}$	186 (75) $^{\$\$\$}$	186 (50)***	212 (74)	214 (67) $^{\$}$	0.002	0.02
ML SD (mm)	5.3 (1.9)	9.2 (6.8) $^{\$\$\$}$	11.3 (8.5) $^{\$\$\$}$	5.7 (2.1)	9.1 (4.6) $^{\$\$\$}$	10.3 (6.2) $^{\$\$\$}$	<0.001	0.12
AP SD (mm)	25.8 (5.8)	32.5 (14.3) $^{\$}$	31.9 (11.0) $^{\$\$}$	33.1 (8.4)***	31.0 (13.7)	35.4 (9.8)	0.038	0.01
ML Speed (mm/s)	26 (4)	32 (11) $^{\$\$\$}$	37 (13) $^{\$\$\$}$	27 (5)	34 (10) $^{\$\$\$}$	37 (14) $^{\$\$\$}$	<0.001	0.11
AP Speed (mm/s)	57 (13)	82 (24) $^{\$\$\$}$	87 (27) $^{\$\$\$}$	82 (28)***	104 (33) $^{\$\$}$	111 (39) $^{\$\$\$}$	<0.001	0.05
TMV (mm/s)	67 (14)	96 (30) $^{\$\$\$}$	102 (33) $^{\$\$\$}$	91 (27)***	119 (40) $^{\$\$\$}$	129 (47) $^{\$\$\$}$	<0.001	0.06

*p < 0.05 **p < 0.01 ***p < 0.001 comparison Eyes Open and Closed (after Bonferroni' corrections)$^{\$}$ p < 0.05 $^{\$\$}$ p < 0.01 $^{\$\$\$}$ p < 0.001 comparison to control situation (after Bonferroni' corrections) No statistically significant difference for the two different tasks (Eyes Open or Closed).

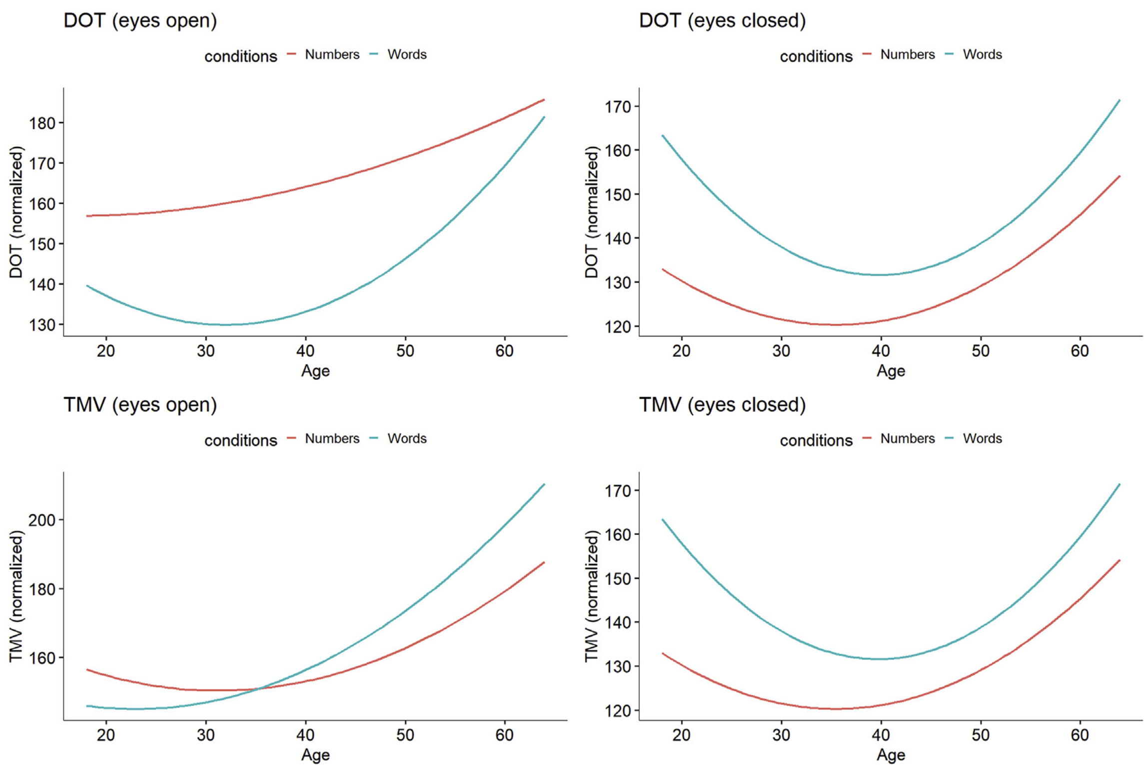

Fig. 2. Results of normalized (expressed in percentage of the control situation for eyes open and closed) CP displacement (DOT) and TMV for eyes open (left) and eyes closed (right).

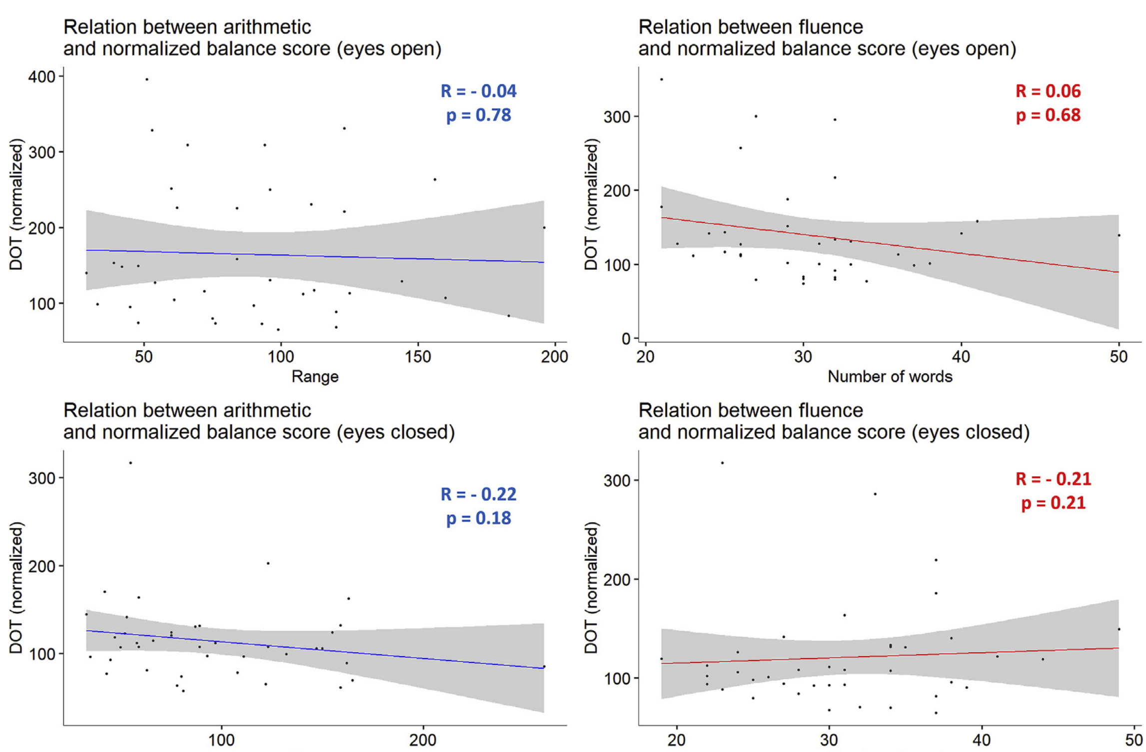

Fig. 3. Relation between cognitive performance and the total displacement of CP (DOT) during dual-task activities. R indicated the Pearson's correlation coefficients and p the p-value.

Our observations are also consistent with another study who found that subjects oscillated more in subjects with an average age of 45 years when they had to perform a complementary mental task, as significantly as they had their eyes open or closed [5].

On the other hand, some author showed that there was an improvement and not a deterioration in postural control when adding a visuo-

Table 2
Intraclass Correlation Coefficient (ICC) [95% CI] between results of the two sessions for the different conditions.

Variable	Eyes Open			Eyes Closed		
	Control	Numbers	Words	Control	Numbers	Words
DOT (mm)	0.87 [0.83–0.91]	0.84 [0.80–0.88]	0.74 [0.64–0.84]	0.93 [0.90–0.96]	0.89 [0.85–0.93]	0.86 [0.82–0.90]
Area (mm^2)	0.87 [0.81–0.93]	0.88 [0.82–0.94]	0.73 [0.66–0.80]	0.94 [0.91–0.97]	0.88 [0.84–0.92]	0.84 [0.80–0.88]
ML RoM (mm)	0.76 [0.70–0.82]	0.67 [0.59–0.75]	0.67 [0.60–0.74]	0.89 [0.94–0.93]	0.81 [0.75–0.87]	0.70 [0.63–0.77]
AP RoM (mm)	0.85 [0.80–0.90]	0.66 [0.58–0.74]	0.72 [0.64–0.80]	0.93 [0.90–0.96]	0.88 [0.85–0.91]	0.76 [0.69–0.83]
ML SD (mm)	0.82 [0.78–0.86]	0.85 [0.80–0.90]	0.73 [0.66–0.80]	0.94 [0.90–0.98]	0.84 [0.80–0.88]	0.78 [0.70–0.86]
AP SD (mm)	0.87 [0.81–0.93]	0.78 [0.70–0.86]	0.74 [0.68–0.80]	0.93 [0.89–0.97]	0.87 [0.82–0.93]	0.81 [0.75–0.87]
ML Speed (mm/s)	0.86 [0.80–0.92]	0.87 [0.82–0.93]	0.68 [0.61–0.75]	0.96 [0.93–0.99]	0.90 [0.86–0.94]	0.82 [0.78–0.86]
AP Speed (mm/s)	0.94 [0.90–0.98]	0.88 [0.82–0.94]	0.83 [0.79–0.87]	0.96 [0.93–0.99]	0.88 [0.85–0.91]	0.88 [0.82–0.94]
TMV (mm/s)	0.93 [0.89–0.97]	0.87 [0.81–0.93]	0.81 [0.77–0.85]	0.94 [0.91–0.97]	0.91 [0.88–0.94]	0.86 [0.80–0.92]

verbal cognitive task with a decrease in the total displacement of the pressure center [24]. There is a greater shift in the pressure center if the subject is asked to prioritize the postural task over the cognitive task.

Differences exist in methodology, the average age of the selected sample was 21.6 ± 2.3 years while for our study it is 36.9 ± 14.4 years, moreover in this study it was asked the subject to focus on one task as a priority to the detriment of the other.

Same conclusion were found in another study: there is a decrease in the total area swept by the CP and reduced antero-posterior and lateral oscillations in young subjects (22 ± 2 years) while there is no change for middle-aged subjects (43 ± 8 years) [25].

The difficulty of the cognitive task should also be taking into consideration [23]: the more complicated the task, the greater the instability. In our study, we did not observe any significant difference in the balance perturbation induced by the arithmetic task or verbal fluence task (enumeration of animal names). We observed in Fig. 1 that the Words task is not influenced by the age of the participants which is coherent with previous studies on cognition that showed that Not all cognitive functions are affected by age in the same way [26]: a decline across the adult lifespan in the ability to rapidly process information is observed and to invoke executive processes, although longitudinal studies indicate that this decline might occur primarily after the age of 60 [27]. In contrast, semantic memory and short-term memory show remarkable preservation across most of the adult lifespan, with declines occurring only very late, and not systematically, in life [28]. On the other hand, some functions seem to improve with normal aging, such as semantic memory and the richness of vocabulary [29].

One of the difficulties often found when assessing balance in clinics or in research in the big variability between the trials inducing low reproducibility of the measurement [30]. In this study we found good to excellent results reproducibility for all the conditions: mean ICC for the nine parameters are for the eyes open 0.86 for the control situation, 0.81 for the numbers condition, 0.74 for the words condition and for the eyes closed 0.94 for the control situation, 0.87 for the numbers condition, 0.81 for the words condition. Regardless the conditions better results were obtained with eyes closed. The control and maintenance of balance is ensured by three systems: the vestibular system, the vision and the proprioception. When visual information is deleted, not only are the results more reproducible but also more discriminating in terms of pathologies (e.g. fall risk prediction in the elderly [31], patients suffering from Mid Cognitive Impairment [32]).

One of the limitation of this study is that we performed measurements on healthy subjects while in clinics balance evaluation is most of the time done with patients suffering from various neurologic (e.g. stroke, multiple sclerosis, Parkinson's disease) or orthopedic (e.g. low back pain) or to assess risk of fall among elderly subjects. Further studies will focus on those groups of patients.

5. Conclusion

In this study we demonstrated the validity of the WBB to detect the effect of dual-task activities on the balance of healthy subjects. We did not find statistically significant difference between the two cognitive activities (Numbers or Words) indicating that both tasks can be used depending on the abilities of the participants. It is known that fluency tasks (i.e. Words) are more influenced by education and cultural background of the subjects. We found good to excellent reproducibility for the different studied parameters regardless the tasks. These results indicate that the WBB could be used as a fast, affordable and easy-to-use tool to assess balance on a regular basis during patients' follow-up. Further studies are needed to determine if such a kind of evaluation can be used in clinics with patients suffering from various pathologies.

List of abbreviations

AP	antero-posterior
CP	Center of Pressure
DOT	Total displacement of sway
ML	Medio-lateral
MV	Mean velocity
RoM	Range of Motion
SD	Dispersion of COP from the mean position
TMV	Total Mean Velocity
WBB	Wii Balance Board

Conflict of interest

None.

References

[1] Stuart DG. Integration of posture and movement: contribution of Sheerington, Hess, and Bernstein. Hum Mov Sci 2005;24(5–6):621–43.
[2] Peterson DS, Gera G, Horak FB, Fling BW. Supraspinal control of automatic postural responses in people with multiple sclerosis. Gait Posture 2016;47:92–5.
[3] Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 2002;16:1–14.
[4] Kerr B, Condon SM, McDonald LA. Cognitive spatial processing and the regulation of posture. J Exp Psychol Hum Percept Perform 1985;11(5):617–22.
[5] Andersson G, Yardley L, Luxon LA. Dual task study of interference between mental activity and control of balance. Am J Otol 1998;19(5):632–7.
[6] Lajoie Y, Teasdale N, Bard C, Fleury M. Attentional demands for static and dynamic equilibrium. Exp Brain Res 1993;97(1):139–44.
[7] Dault MC, Frank JS, Allard F. Influence of a visuo-spatial, verbal and central executive working memory task on postural control. Gait Posture 2001;14(2):110–6.
[8] Montero-Odasso M, Verghese J, Beauchet O, Hausdorff JM. Gait and cognition: a complementary approach to understanding brain function and the risk of falling. J Am Geriatr Soc 2012;60(11):2127–36.
[9] Hyndman D, Ashburn A. "Stops walking when talking" as a predictor of falls in people with stroke living in the community. J Neurol Neurosurg Psychiatry 2004;75(7):994–7.
[10] Commandeur D, Klimstra MD, MacDonald S, Inouye K, Cox M, Chan D, Hundza SR. Difference scores between single-task and dual-task gait measures are better than clinical measures for detection of fall-risk in community-dwelling older adults. Gait Posture 2018;66:155–9.
[11] Brauer SG, Woollacott M, Shumway-Cook A. The interacting effects of cognitive demand and recovery of postural stability in balance-impaired elderly persons. J Gerontol A Biol Sci Med Sci 2001;56(8):489–96.

[12] Naidu AS, Vasudev A, Burhan AM, Ionson E, Montero-Odasso M. Does dual-task gait differ in those with late-life depression versus mild cognitive impairment? Am J Geriatr Psychiatry 2018;(18):30532–3. pii: S1064-7481.
[13] Yang L, Liao LR, Lam FMH, He CQ, Pang MYC. Psychometric properties of dual-task balances assessments for older adults: a systematic review. Maturitas 2015;80: 359–69.
[14] Yang L, Lam FMH, Liao LR, Huang MZ, He CQ, Pang MYC. Psychometric properties of dual-task balances and walking assessments for individuals with neurological conditions: a systematic review. Gait Posture 2017;52:110–23.
[15] Clark RA, Bryant AL, Pua Y, McCrory P, Bennell K, Hunt M. Validity and reliability of the Nintendo Wii balance board for assessment of standing balance. Gait Posture 2010;31:307–10.
[16] Huurnink A, Fransz DP, Kingma I, van Dieën JH. Comparison of a laboratory grade force platform with a Nintendo Wii Balance Board on measurement of postural control in single-leg stance balance tasks. J Biomech 2013;46:1392–5.
[17] Koslucher F, Wade MG, Nelson B, Lim K, Chen FC, Stoffregen TA. Nintendo Wii Balance Board is sensitive to effects of visual tasks on standing sway in healthy elderly adults. Gait Posture 2012;36:605–8.
[18] Clark RA, Mentiplay BF, Pua YU, Bower KJ. Reliability and validity of the Wii Balance Board for assessment of standing balance: a systematic review. Gait Posture 2018;61:40–54.
[19] Bonnechère B, Jansen B, Omelina L, Rooze M, Van Sint Jan S. Intechangeability of the Wii balance board for bipedal balance assessment. JMIR Rehabil Assist Technol 2015;2:e8.
[20] Ghai S, Ghai I, Effenberg AO. Effects of dual tasks and dual-task training on postural stability: a systematic review and meta-analysis. Clin Interv Aging 2017;12:557–77.
[21] Bonnechère B, Jansen B, Omelina L, Sholukha V, Van Sint Jan S. Validation of the Balance Board for clinical evaluation of balance during serious gaming rehabilitation exercises. Telemd J E Health 2016;22(9):709–17.
[22] Albers C, Lakens D. When power analyses based on pilot data are biased: inaccurate effect size estimators and follow-up bias. J Exp Soc Psychol 2018;74:187–95.
[23] G.L. Pellecchia. Postural sway increases with attentional demands of concurrent cognitive task. Gait Posture. 18, 29–34
[24] Jehu DA, Desponts A, Paquet N, Lajoie Y. Prioritizing attention on a reaction time task improves postural control and reaction time. Int J Neurosci 2015;125(2): 100–6.
[25] Jamet M, Deviterne D, Gauchard GC, Vançon G, Perrin PP. Age-related part taken by attentional cognitive processes in standing postural control in a dual-task context. Gait Posture 2007;25(2):179–84.
[26] Tedden T, Gabrieli JD. Insights into the ageing mind: a view from cognitive neuroscience. Nat Rev Neurosci 2004;5(2):87–96 [Review].
[27] Ofen N, Shing YL. From perception to memory: change in memory systems across the lifespan. Neurosci Biobehav Rev 2013;37(9 Pt B):2258–67.
[28] Hertzog C, Kramer AF, Wilson RS, Lindenberger U. Enrichment effects on adult cognitive development: can the functional capacity of older adults Be preserved and enhanced? Psychol Sci Public Interest 2008;9(1):1–65.
[29] Verhaeghen P. Aging and vocabulary scores: a meta-analysis. Psychol Aging 2003; 18(2):332–9.
[30] Dewar R, Claus AP, Tucker K, Ware R, Johnston LM. Reproducibility of the balance evaluation systems test (BESTest) and the mini-BESTest in school-aged children. Gait Posture 2017;55:68–74.
[31] Howcroft J, Lemaire ED, Kofman J, McIlroy WE. Elderly fall risk prediction using static posturography. PLoS One 2017;12(2):e0172398.
[32] Bahureksa L, Najafi B, Saleh A, Sabbagh M, Coon D, Mohler MJ, Schwenk M. The impact of mild cognitive impairment on gait and balance: a systematic review and meta-analysis of studies using instrumented assessment. Gerontology 2017;63(1): 67–83.