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Nintendo Wii Balance Board is sensitive to effects of visual tasks on standing sway in healthy elderly adults

Frank Koslucher [a], Michael G. Wade [a], Brent Nelson [b], Kelvin Lim [b], Fu-Chen Chen [c], Thomas A. Stoffregen [a,*]

[a] School of Kinesiology, University of Minnesota, United States
[b] Department of Psychiatry, University of Minnesota, United States
[c] Department of Recreation Sport & Health Promotion, National Pingtung University of Science and Technology, Taiwan

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ABSTRACT

Research has shown that the Nintendo Wii Balance Board (WBB) can reliably detect the quantitative kinematics of the center of pressure in stance. Previous studies used relatively coarse manipulations (1- vs. 2-leg stance, and eyes open vs. closed). We sought to determine whether the WBB could reliably detect postural changes associated with subtle variations in visual tasks. Healthy elderly adults stood on a WBB while performing one of two visual tasks. In the Inspection task, they maintained their gaze within the boundaries of a featureless target. In the Search task, they counted the occurrence of designated target letters within a block of text. Consistent with previous studies using traditional force plates, the positional variability of the center of pressure was reduced during performance of the Search task, relative to movement during performance of the Inspection task. Using detrended fluctuation analysis, a measure of movement dynamics, we found that COP trajectories were more predictable during performance of the Search task than during performance of the Inspection task. The results indicate that the WBB is sensitive to subtle variations in both the magnitude and dynamics of body sway that are related to variations in visual tasks engaged in during stance. The WBB is an inexpensive, reliable technology that can be used to evaluate subtle characteristics of body sway in large or widely dispersed samples.

1. Introduction

In upright stance, movement of the body is subtle but continuous. The quantitative kinematics of standing body sway are influenced by a wide variety of factors, including clinical conditions such as chronic lead poisoning [1] pregnancy [2], and autism [3]. For this reason, measures of standing body sway are increasingly attractive as non-invasive metrics that may be used to differentiate clinical populations. One area of special interest is relations between postural sway and aging [4].

Classically, measurement of the quantitative kinematics of standing body sway has required the use of highly specialized equipment. Examples include moving platform posturography [5], laboratory force plates [6], video digitizing systems [7,8], electrogoniometers [9], magnetic tracking systems [10], and electromyography [11]. Generally, these technologies were developed specifically for basic research and/or clinical applications. They tend to be expensive, which makes it difficult to collect data at multiple sites or in a dedicated fashion over long periods of time. In addition, these technologies can be cumbersome to use, often requiring the attachment of markers, sensors and/or cables to the skin or clothing, or (in the case of moving platform posturography) the use of safety harnesses. These factors make it difficult to conduct rapid, non-invasive assessments of standing body sway in large groups of subjects.

Advances in technology now offer lower cost systems that might make it possible to obtain non-invasive data on large groups of subjects. One of these is the Wii Balance Board, or WBB, a peripheral of the Wii gaming system (Nintendo, Inc.). The WBB is about 0.5 m wide, 0.2 m long, and 0.05 m thick. Four piezoelectric strain gauges are built into the corners of the device and the outputs of these gauges are available through a Bluetooth wireless connection. The WBB operates on AA batteries and weighs about 3.5 kg. The WBB was designed to permit dynamic body position to be used as a control input for video games and exercise routines. The WBB is widely available and has a dramatically reduced cost relative to technologies that have traditionally been used to measure the kinematics of standing body sway.

* Corresponding author at: 224 Cooke Hall, 1900 University Ave. SE, Minneapolis, MN 55455, United States. Tel.: +1 612 626 1056; fax: +1 612 626 7700.
E-mail address: tas@umn.edu (T.A. Stoffregen).

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Clark et al. [12] compared standing body sway obtained from the WBB and from a standard laboratory-grade force plate. They used a custom software application to access data from the WBB strain gauges through the Bluetooth connection. They evaluated total COP path length during one-leg and two-leg stance, and with eyes open and closed. They concluded that the WBB "provides comparable data to a [force plate] when assessing COP path length during standing balance trials" (p. 310). In part due to the results of Clark et al., the WBB is being used in the development of a variety of clinical interventions [13,14].

Relative to the current study, the experiment of Clark et al. [12] was limited in three important respects. First, Clark et al. used as participants only healthy young adults (mean age = 23.7 $\pm$ 5.6 - years). Healthy elderly adults typically exhibit greater overall body sway [15], which might mask the effects of more subtle manipulations that can influence stance across age groups. In the present study our participants were healthy elderly adults.

Second, the experimental manipulations employed by Clark et al. (one-leg vs. two-leg stance and eyes closed vs. eyes open) while widely used were relatively coarse. Young et al. [14] also compared stance on a WBB with the eyes open versus closed. The use of such manipulations in initial validations of the WBB was appropriate, but raises the question of whether the WBB can be used to assess more subtle manipulations of postural sway. Standing body sway is influenced by non-postural tasks that are engaged in during stance [for reviews, see 4,16]. Examples include auditory reaction time [17], visual search [10], visual vigilance [18], and focused auditory attention [19]. These effects have been observed in multiple age groups, including children [3], young adults [10], and healthy elderly [8]. In the present study, we asked whether the WBB would be sensitive to effects of visual tasks on the standing postural sway of healthy elderly adults.

Finally, in Clark et al. [12] the evaluation of data on body sway was limited to the measurement of COP path length. Path length is a common metric for postural sway but there are many others, and it cannot be assumed that validation of the WBB for measures of path length will extend to other balance measures [20]. Following Young et al. [14], we used the WBB to determine the positional variability of the COP. Positional variability provides a measure of the overall magnitude of postural activity, and is sensitive to the effects of variations in visual tasks performed during stance [21]. We asked whether subtle variations in visual tasks would influence the positional variability of the COP, as measured using the WBB.

We also evaluated the utility of the WBB for assessment of the temporal dynamics of body sway. Magnitude measures, such as positional variability, path length, and range, provide information about the size or spatial extent of movement (e.g., "by how many centimeters do COP data points tend to differ from each other?"). Magnitude measures, by their nature, tend to eliminate or discard the temporal structure of movement data, that is, how the measured quantity varies in time (e.g., "to what extent does COP displacement at time A resemble displacement at time B?"). Analyses that preserve information about the temporal structure of data on human movement (that is, analyses of the temporal dynamics of movement) are increasingly common [20,22,23]. In particular, previous research has revealed changes in the temporal structure of postural activity in response to variations in visual tasks [24,25].

Clark et al. [12] focused on comparison of the WBB with a laboratory grade force plate. Following Young et al. [14], we used only the WBB. We asked whether the WBB would be sensitive to subtle variations in the postural activity of healthy elderly adults resulting from variations in visual tasks that have been observed in previous studies using laboratory grade force plates [8,24,28], and magnetic tracking systems [3,10,25].

2. Methods

2.1. Participants

There were ten participants aged 64–85 years (mean 72.6 years, SD = 7.1 years) recruited from the University of Minnesota Retirees volunteer list. They ranged in height from 1.50 to 1.90 m (mean = 1.70 m, SD = .14 m) and in weight from 56.8 to 105.5 kg (mean = 74.8 kg, SD = 14.4 kg). Foot length ranged from 21.0 to 29.0 cm (mean = 26.2 cm, SD = 2.37 cm). None of the participants used a cane or other walking aid, and each reported being in good health.

2.2. Apparatus

We used a standard WBB. The WBB was interfaced with a laptop computer using a custom Microsoft Windows application written in C# using the open source library WiiMoteLib running under Windows 7 to access the Wii through the Bluetooth connection. Data was stored on a disk for later analysis. The sampling rate was 30 Hz. We did not filter data from the WBB. Nintendo does not report precision measures for the WBB. We evaluated precision empirically. We placed an 18 kg lead brick on the WBB in known positions as marked out on a grid. For each position of the brick we recorded 5 s of COP data and computed the mean position over that period. This process was repeated 4 times and the means across these are reported here. In the mediolateral axis (i.e., the long axis of the WBB), movement of the brick 1 cm in either direction yielded a change in measured position of 0.5. In the anterior–posterior axis (i.e., the short axis of the WBB), movement of the brick 1 cm in either direction yielded a change in measured position of 1.7. In all analyses we used these values to scale the data in cm.

2.3. Procedure

Participants completed the informed consent procedure and were asked to remove their shoes. The WBB was placed 1.0 m from a wall. Using lines marked on the surface of the WBB, stance width was fixed at 15 cm between the midline of the heels, and the angle between the feet was fixed at 17 degrees. Targets for the visual tasks were affixed to the wall at each participant's eye height. For the Inspection task, a blank piece of white cardstock was used. For the Search task, the target was a block (paragraph) of English text printed in sans seriff 12 point Avante Garde font. There were three targets, each with a different block of text. All targets were 13.5 cm $\times$ 17 cm.

The WBB was calibrated before each trial. With the participant standing off the board we collected data from each of the board's sensors for 10 s. We computed the mean reading for each sensor over the 10-s period, and used that mean as the zero point for that sensor for that trial. For each trial, the computed zero point for each sensor was subtracted from each data point for that sensor before combining the calibrated values to compute the COP.

For each trial the participant was asked to stand with their heels and great toes on designated marks on the WBB. Participants were instructed to stand comfortably with their arms at their sides. There was a total of six trials for each subject, each lasting 30 s, with postural data being collected continuously. On three trials the participant performed the Inspection task, and on three trials they performed the Inspection task. The order in which the tasks were performed was randomized using a Latin Square.

Participants were instructed to stand comfortably, without moving their feet or arms. For the Search task, the participant was instructed to read the text on the card and to count the number of a target letters in the text. The target letters were A, R, N, and S, with one used as the target letter for a given trial. At the end of the trial, they were asked to indicate their position in the text at the end of the trial as well as how many target letters they counted. For the Inspection task, the participants were asked to maintain their gaze within the borders of the blank target.

After postural testing, each participant completed the Mini Mental State Exam, version 1 (MMSE) to screen for individuals with dementia [27]. The maximum possible score on the MMSE was 30. On the MMSE, a score of 27 or greater indicates normal cognition.

2.4. Analysis of postural data

We assessed the magnitude of postural activity in terms of the positional variability of the COP, which we defined operationally as the standard deviation of COP position. We assessed movement dynamics using detrended fluctuation analysis, or DFA. DFA describes the relation between the magnitude of fluctuations in postural motion and the time scale over which those fluctuations are measured [26]. DFA has been used in several studies of the control of stance [23], and in our own research at sea [18,25]. We conducted inferential tests on α, the scaling exponent of DFA, as derived from the COP data [23]. The scaling exponent is an index of long-range autocorrelation in the data, that is, the extent to which the data are self-similar over different time-scales. When $\alpha < 0.5$ or $1 < \alpha < 1.5$, the signal is anti-persistent (smaller α = more anti-persistence). When $0.5 < \alpha < 1$ or $1.5 < \alpha < 2$, the signal is persistent (larger α = more persistence [23]). In conducting detrended fluctuation analysis we did not integrate the time series.

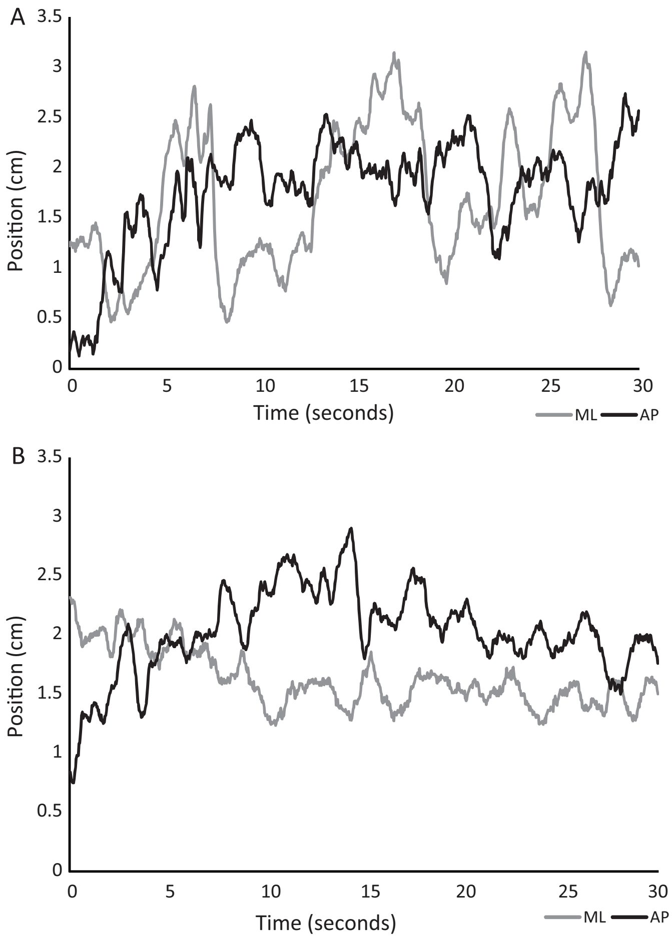

Fig. 1. Representative raw COP data from the WBB from two trials for a single participant. (A) COP during performance of the Inspection task. (B) COP during performance of the Search task. ML: COP in the mediolateral axis. AP: COP in the anterior–posterior axis.

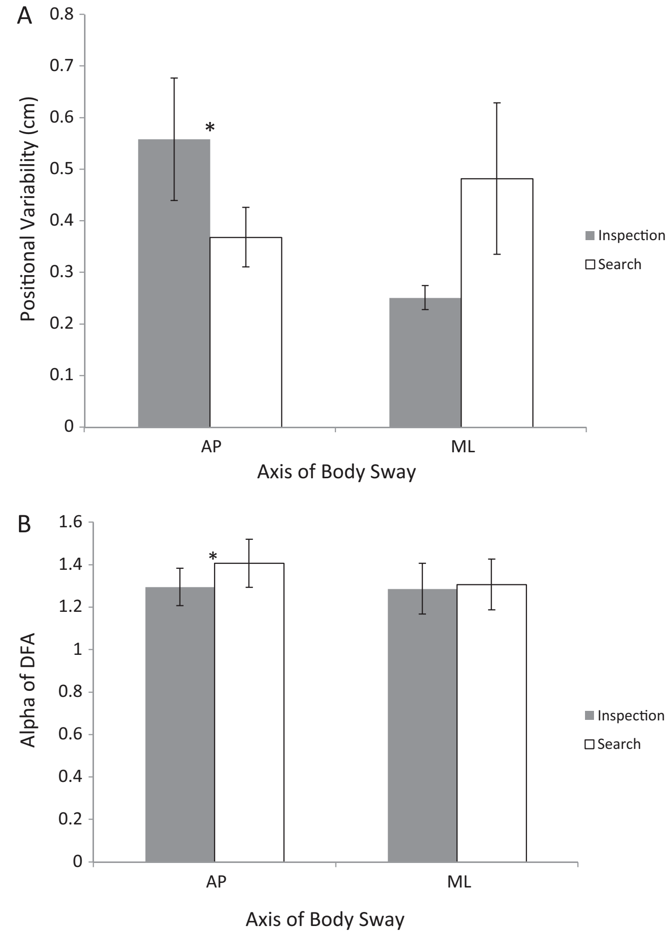

Fig. 2. Postural sway as a function of visual task condition for the anterior–posterior (AP) and mediolateral (ML) axes. (A) Positional variability. (B) α of detrended fluctuation analysis (DFA). The error bars represent the standard error of the mean.

3. Results

One participant struggled to read the cards during the search task. For this participant, the WBB was moved 24 cm closer to the wall.

3.1. Mini Mental State exam

The mean score on the Mini Mental State exam was 29.30 (SD = 0.675). The minimum score was 28, indicating that all of the participants were functioning without dementia.

3.2. Visual performance

There was no measure of visual performance for the Inspection task. Following previous studies, we took for granted that participants were able to maintain their gaze within the boundaries of the blank target [10,28]. For the Search task, the overall mean proportion correct was 73.2 and the mean number of errors per trial was 4.13.

3.3. Postural activity

For each dependent variable we conducted separate repeated measures analyses of variance for movement in the anterior–posterior (AP) and mediolateral (ML) axes with factors Task (Inspection, Search) and Trials (1–3). We estimated the effect size using the partial η^2 statistic. Cohen [29] has argued that values of partial $\eta^2 > 0.14$ indicate a large effect.

Representative data from sample trials are shown in Fig. 1. The results are illustrated in Fig. 2. For positional variability of the COP in the AP axis, we found a significant effect of conditions, $F(1, 9) = 7.61$, $p = .022$, partial $\eta^2 = 0.458$, with positional variability being reduced during performance of the Search task, relative to the Inspection task. For DFA we also found a significant effect of conditions for movement in the AP axis, $F(1, 9) = 6.97$, $p = .027$, partial $\eta^2 = 0.436$, with greater predictability or self-similarity during performance of the Search task, relative to the Inspection task. There were no other significant effects.

4. Discussion

Visual performance data were similar to previous studies using the same task. Stoffregen et al. [10] used the same search task with young adults (university students) and obtained values were 90.1 and 6.13. Stoffregen et al. [28], also using the same search task, obtained values of 84.3 and 8.60 for a group of mixed-age adults (25–54 years old). These similarities suggest that our sample was representative of those used in earlier studies.

Analysis of postural activity revealed reduced positional variability of sway in the AP axis during performance of the Search task, relative to sway during performance of the Inspection task. Previous studies have found reduction in the positional variability of sway in the AP axis during performance of more demanding visual tasks in the elderly [8] in healthy young adults [10], and in 9-year old children with and without autism spectrum disorder [3]. The present results confirm that the WBB can be used to detect similar effects in the unperturbed body sway of healthy elderly adults.

Our analysis of movement dynamics revealed increased predictability or self-similarity of sway in the AP axis during performance of the Search task, relative to sway during performance of the Inspection task. Previous studies of the dynamics of sway in elderly samples have not evaluated the effects of visual tasks on unperturbed standing sway [23]; thus, the present study is the first demonstration of an effect of visual tasks on the dynamics of postural sway in this age group. Studies of younger adults have identified effects of variations in the difficulty of visual tasks on the self-similarity of postural activity in the AP axis [24] and across both AP and ML axes [25]. Overall, our results suggest that the WBB can be a simple, inexpensive tool for evaluating the dynamics of unperturbed standing body sway in the elderly.

The results of the present study confirm the findings of Clark et al. [12] and extend these to effects of visual tasks on both the magnitude and the dynamics of standing body sway in healthy elderly participants. The results suggest that the WBB can be used to evaluate subtler, more fine-grained aspects of postural control. The results of the present study indicate that clinicians can use the WBB for assessment of standing balance. One possible application concerns relations between postural sway and clinical movement disorders in children. Developmental research has shown that the influence of visual tasks on standing body sway occurs in typically developing children and also in children with autism spectrum disorder [3]. By contrast, variations in visual tasks have different effects on typically developing children than among children with developmental coordination disorder [30]. These studies suggest that the influence of visual task on standing body sway may be specific to particular clinical conditions. If so, then it may be possible to use the WBB as a low-cost, non-invasive part of diagnostic test batteries for some clinical conditions.

The results of the present study, combined with the low cost and easy availability of the WBB suggest new opportunities for large-scale data collection and screening. The WBB might be obtained in quantity and used to assess relatively large numbers of individuals in a wide variety of settings.

Conflict of interest statement

None of the authors have any potential conflicts of interest in this study.

References

[1] Bhattacharya A, Shukla R, Bornschein R, Dietrich K, Kopke JE. Postural disequilibrium quantification in children with chronic lead exposure: a pilot study. Neurotoxicology 1988;9:327–40.
[2] Jang J, Hsiao KT, Hsiao-Wecksler ET. Balance (perceived and actual) and preferred stance width during pregnancy. Clinical Biochemistry 2008;23: 468–76.
[3] Chang C-H, Wade MG, Stoffregen TA, Hsu C-Y, Pan C-Y. Visual tasks and postural sway in children with and without Autism Spectrum Disorder. Research in Developmental Disabilities 2010;31:1536–42.
[4] Woollacott M, Shumway-Cook A. Attention and the control of posture and gait: a review of an emerging area of research. Gait and Posture 2002;16:1–14.
[5] Henry SM, Fung J, Horak FB. Effect of stance width on multidirectional postural responses. Journal of Physiology 2001;85:559–70.
[6] Balasubramaniam R, Riley MA, Turvey MT. Specificity of postural sway to the demands of a precision task. Gait and Posture 2000;11:12–24.
[7] Dijkstra TMH, Schoner G, Gielen CCAM. Temporal stability of the action–perception cycles for postural control in a moving visual environment. Experimental Brain Research 1994;97:477–86.
[8] Prado JM, Stoffregen TA, Duarte M. Postural sway during dual tasks in young and elderly adults. Gerontologist 2007;53:274–81.
[9] Oullier O, Bardy BG, Stoffregen TA, Bootsma RJ. Postural coordination in looking and tracking tasks. Human Movement Science 2002;21:147–67.
[10] Stoffregen TA, Pagulayan RJ, Bardy BG, Hettinger LJ. Modulating postural control to facilitate visual performance. Human Movement Science 2000;19:203–20.
[11] Melzer I, Benjuya N, Kaplanski J. Age-related changes of postural control: effect of cognitive tasks. Gerontologist 2001;47:189–94.
[12] Clark RA, Bryant AL, Eua Y, McCrory P, Bennell K, Hunt M. Validity and reliability of the Nintendo Wii Balance Board for assessment of standing balance. Gait and Posture 2010;31:307–10.
[13] Gil-Gomez J-A, Llorens R, Alcaniz M, Colomer C. Effectiveness of a Wii balance board-based system (eBaViR) for balance rehabilitation: a pilot randomized clinical trial in patients with acquired brain injury. Journal of NeuroEngineering and Rehabilitation 2011;8:30–8.
[14] Young W, Ferguson S, Brault S, Craig C. Assessing and training standing balance in older adults: a novel approach using the 'Nintendo Wii' balance board. Gait and Posture 2011;33:303–5.
[15] Alexander NB. Postural control in older adults. Journal of the American Geriatrics Society 1994;42:93–108.
[16] Stoffregen TA, Hove P, Bardy BG, Riley MA, Bonnet CT. Postural stabilization of perceptual but not cognitive performance. Journal of Motor Behavior 2007;39:126–38.
[17] Marsh AP, Geel SE. The effect of age on the attentional demands of postural control. Gait and Posture 2000;12:105–13.
[18] Yu Y, Yank JR, Katsumata Y, Villard S, Kennedy RS, Stoffregen TA. Visual vigilance performance and standing posture at sea. Aviation Space and Environmental Medicine 2010;81:375–82.
[19] Fearing FS. Factors influencing static equilibrium: an experimental study of the effect of controlled and uncontrolled attention upon sway. Journal of Comparative Psychology 1925;5:1–24.
[20] Cavanaugh JT, Guskiewicz KM, Stergiou N. A nonlinear dynamic approach for evaluating postural control: new directions for the management of sport-related cerebral concussion. Sports Medicine 2005;35:935–50.
[21] Kapoula Z, Lê TT. Effects of distance and gaze position on postural stability in young and old subjects. Experimental Brain Research 2006;173:438–45.
[22] Kinsella-Shaw JM, Harrison SJ, Colon-Semenza C, Turvey MT. Effects of visual environment on quiet standing by young and old adults. Journal of Motor Behaviour 2006;38:251–64.
[23] Lin D, Seol H, Nussbaum MA, Madigan ML. Reliability of COP-based postural sway measures and age-related differences. Gait and Posture 2008;28: 337–42.
[24] Yu Y, Chung H-C, Hemingway L, Stoffregen TA. Standing body sway in women with and without morning sickness in pregnancy. Gait and Posture, http://dx.doi.org/10.1016/j.gaitpost.2012.06.021, in press.
[25] Chen F-C, Stoffregen TA. Specificity of postural sway to the demands of a precision task at sea. Journal of Experimental Psychology: Application, http://dx.doi.org/10.1037/a0026661, in press.
[26] Chen Z, Ivanov PCh, Hu K, Stanley HE. Effect of nonstationarities on detrended fluctuation analysis. Physical Review E Statistical Nonlinear and Soft Matter Physics 2002;65(4 (Pt. 1)). 041107-1–15.
[27] Espino DV, Lichtenstein MJ, Palmer RF, Hazuda HP. Evaluation of the Mini-Mental State Examination's internal consistency in a community-based sample of Mexican-American and European-American elders: results from the San Antonio longitudinal study of aging. Journal of the American Geriatrics Society 2004;52:822–7.
[28] Stoffregen TA, Villard S, Chen F-C, Yu Y. Standing body sway on land and at sea. Ecological Psychology 2011;23:19–36.
[29] Cohen J. Statistical power analysis for the behavioral sciences, 2nd ed., NJ, Erlbaum: Hillsdale; 1988.
[30] Chen F-C, Tsai CL, Stoffregen TA, Wade MG. Postural responses to a supra-postural visual task among children with and without developmental coordination disorder. Research in Developmental Disabilities 2011;32:1948–56.