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Evaluation of Anticipatory Postural Adjustment before Quantified Weight Shifting—System Development and Reliability Test

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Featured Application: Measuring APA via proactive balance paradigm might be optimal since the APA components can be consistently induced with adequate to good reliability.

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Abstract: Anticipatory postural adjustment (APA) existed before a self-induced perturbation is an important motor control skill for balance and gait initiation, but cannot be easily monitored. During proactive balance test, a self-initiated weight shifting is produced. This might be an optimal paradigm for APA measurement. The purpose of this study was to investigate if APAs existed in the proactive balance test which consists of quantifiable weight shifting. The feature and reliability of the APAs were also evaluated. We firstly built a proactive balance test program on the commercially available Wii balance board. The program could generate adjustable target direction and distance for guiding subjects performing quantifiable weight shifting. The center of pressure (COP) was recorded and analyzed for balance-related variables (path length, path time, and direction error) and APA-related variables (APA time, APA distance, and APA correction). The results showed that APAs could be detected in every testing trial. Adequate to good reliability in both balance and APA-related variables were found. This study proved the feasibility of quantifying APA during proactive balance tests and its feasibility for clinical- and home-based measurements.

Keywords: balance; anticipatory postural adjustment (APA); center of pressure (COP); Wii balance board; home-based system

1. Introduction

Falls and fall-related injuries among elders are the most common causes for admission to hospital care and are major concerns of health and social care providers [1–3]. Balance and gait disorders have been suggested to be the most significant risk factors of the falls [4–6], and proper balance training had been reported to reduce such risk factors [7,8]. Observational scales, such as the Tinetti [9–11] or Berg balance scales [9,11,12] are being used in clinical practice for balance evaluation. However, these scales require professionally trained personnel to perform the tests and are limited by floor/ceiling effects [9,12,13].

The proactive balance tests measure self-initiated weight shifting abilities in various directions [14,15] and are commonly used as an option for clinical balance measurement. This has been implemented by using a stabilometric platform or force plate to quantitatively measure center of pressure (COP) during weight shifting [9,16–24] and has been reported to be able to distinguish fallers from non-fallers [25,26]. Recently, there have been some studies using Wii balance to develop proactive balance measure/training system at home. A review study showed that custom applications using the Wii Balance Board as a proxy for scientific force platforms have great promise as a low cost and portable way to assess balance [27].

In addition to proactive balance ability, the anticipatory postural adjustments (APAs) had been suggested to be important motor control strategy for dynamic balance abilities in daily life activities. Studies showed that during a self-initiated arm forward reaching task, the COP moved backward before the actual arm movement. This COP movement was defined as APA that was used to overcome the foreseeing COP perturbation generated by the arm movement [28–30]. APA is not only for maintaining postural stability during such self-induced perturbations, but also for moving the COM to the new target [31].

Notwithstanding the fact that APA measurements have been suggested to be important for patients with gait initiation difficulties, e.g., those who suffer from Parkinson's disease [32–34], there are currently no home and/or institute-based systems available to quantify APA measurements. Conventional measurements of APA usually use the fast arm-raise task to create a self-induced perturbation [28–30,35]. However, this testing paradigm is not feasible in all clinical conditions. For example, a patient might not be able to generate fast arm movements due to bradykinesia. Therefore, designing a paradigm to measure APA with low physical demand is important.

Researchers showed that an APA-related COP shifting could be detected before the subjects raise one leg from two-legs standing posture [31]. The APA was to overcome the expected postural perturbation generated by weight shifting. In proactive balance tests, subjects are asked to produce quantifiable weight shifting movements. It is plausible to hypothesize that the APA of COP shifting could be detectable in proactive balance tests. This paradigm to measure APA might be optimal since it does not require subjects to generate fast movement. Therefore, the purpose of this study is to investigate if APAs could be detected in proactive balancing task. The reliability and modulation of APAs according to the amount and directions of weight shifting were also evaluated. This study also develops a testing system to prove the concepts.

2. Materials and Methods

2.1. Platform and Software Development

A Wii balance board (Nintendo Co., Ltd., Kyoto, Japan) was used to develop a testing platform. The advantages of using the Wii balance board include low cost, light weight, and good precision (total errors were acceptable in single device comparison [36]. The signals of the four force transducers (F1, F2, F3, and F4) at the four corners are transmitted by Bluetooth and received by an Acer V3-772G laptop computer (Acer Inc., New Taipei City, Taiwan) (Figure 1).

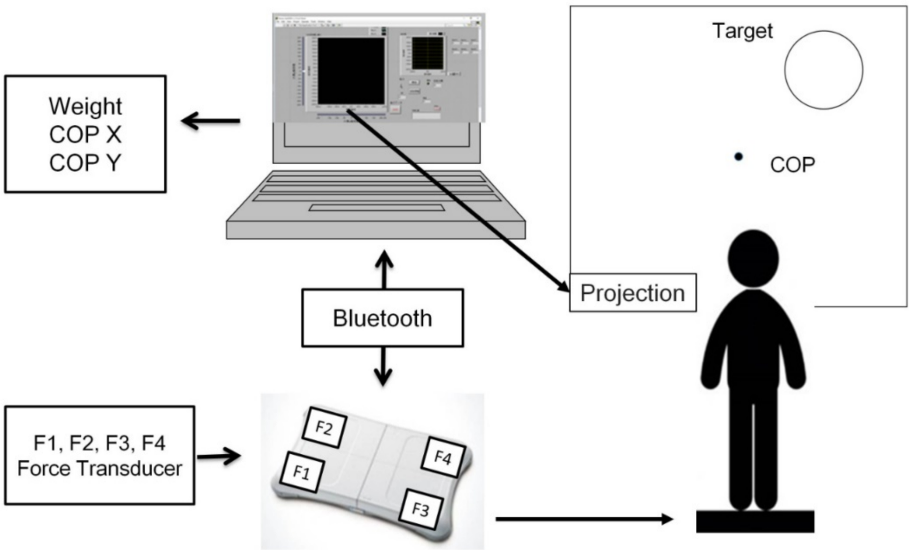


Figure 1. The testing platform setup. The Wii balance board is wirelessly connected to the laptop via Bluetooth. The LabVIEW graphical user interface includes multiple control panels for program adjustment and data management. The screen displays the circular target and trajectory of the subject's center of pressure (COP).

2.2. *Proactive Balance Testing Program*

A guiding program was developed using Labview10.0 (National Instruments Corp., Austin, TX, USA). The forces from four load cells were used to calculate weight and COP in real time by the following equations. The weight is the sum of four forces (F_i, i = 1, 2, 3, 4) measured by four load cells in Wii balance board. These load cells are installed beneath the plate; they are numbered as shown in Figure 1. According to their positions, the position (x, y) of COP, which is the COM, can be calculated by the following equations, where L_x is the horizontal distance between F_1 and F_3 and L_y the vertical distance between F_1 and F_2.

$$Weight = \sum_{i=1}^{4} F_i \quad (1)$$

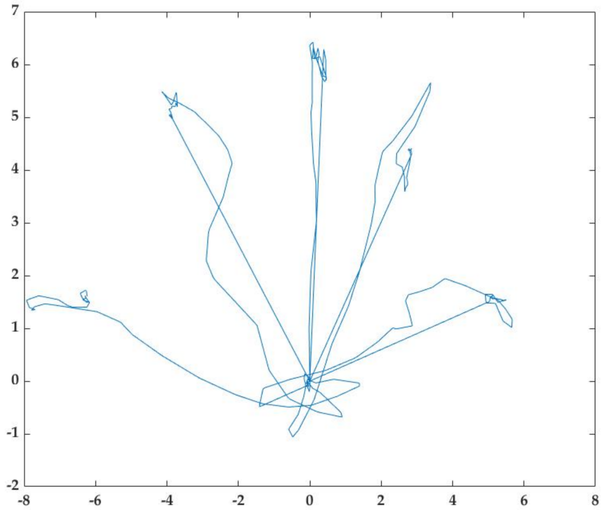
$$COP_x = \frac{(F_3 + F_4)L_x}{Weight} \quad (2)$$

$$COP_y = \frac{(F_2 + F_4)L_y}{Weight} \quad (3)$$

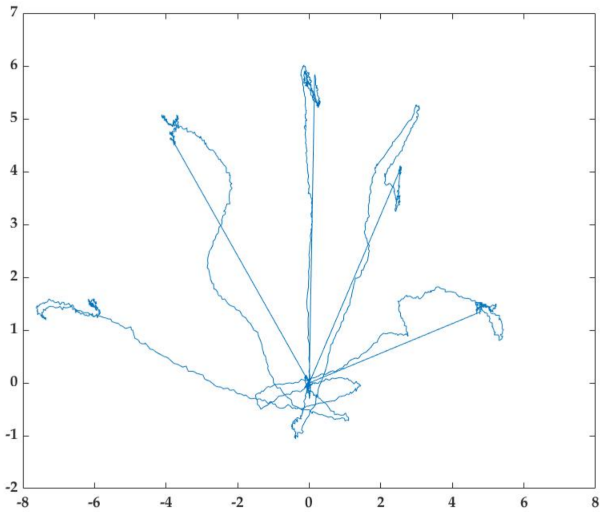
Here, the position of the first load cell is assumed to be at the origin of x-y coordinates.

The initial COP can be reset to zero for those who have asymmetric balance and cannot move their COP to the origin (geometric center). The target distance is adjustable by changing the diameter of a circle. The direction of movements and number of trials are also adjustable.

In order to test the validity of using the Wii balance board to detect APAs in proactive balancing task, a pilot test was performed. In this test, the Wii balance board was placed above a force plate (Kistler, 9260AA). A subject stood on the Wii balance board and initiated weight shifting guided by the proactive balance test program. The COP calculated from the Wii balance board and the force plate were recorded. The correlations between the two devices were evaluated by Pearson correlation coefficient. High correlations between these two devices were shown on COP trajectories in both X (r > 0.99) and Y (r > 0.99) directions (Figure 2).



(**a**)



(**b**)

Figure 2. The COP trajectories measured by a Wii balance board (**a**) and a Kistler force plate (**b**). The Wii balance board which was placed over the Kistler force plate so that the COP from both devices could be measured simultaneously. A subject stood on the Wii balance board and performed weight shifting guided by proactive balance test program.

2.3. Subjects

Ten healthy volunteers were recruited (Table 1). The subjects have no previous history of neuromuscular disorders or lower extremity injuries within six months before testing. Written informed consent was obtained prior to participation. This protocol has been approved by the Institutional Review Board of Chang Gung Medical Foundation.

Table 1. Descriptive data on subjects.

	Gender (Female: Male)	Age (yr)	Height (cm)	Weight (kg)
N = 10	3:7	24.80 ± 1.69	167.10 ± 6.24	64.20 ± 9.19

All values except gender ratios are means ± standard deviations.

After explanation of the procedures, the subject stood on the platform with both arms crossed in front of the chest. The COP was projected in front of the subject in a big screen. Before tests, several practices of weight shifting were performed with the projected COP moving corresponding to the subject's weight shifting. During the maximum forward weight shifting test, the subject performed forward weight shifting to move the projected COP forward (corresponding to the 90-degree target direction) as far as possible. This test was repeated three times. After that, two target distances were set up, in which 60% of the maximal forward weight shifting distance is the short target distance and 80% of the maximal forward weight shifting distance is the long target distance. The target directions were set at 0, 45, 90, 135, and 180 degrees to guide subjects to move their COP to the left, front left, forward, front right, and right, respectively.

During the proactive balance tests, the computer program detects the initial COP, awaits the COP to stabilize after a pre-set time (3 s), and determines the target that will appear on the screen. After the subject moves his/her COP to the target and stays in the target for a pre-set time, the target disappears and a new circle is displayed on the screen to guide the subject to move the COP back to the origin. In order to be fluid during the tests, a trial will be skipped if the subject fails to move and/or maintain their COP for a certain amount of time. The COP trajectory will then not be shown on the screen. Each targeted direction (five directions) and distance (two distances) was randomly tested and repeated again in the same order (Figure 3).

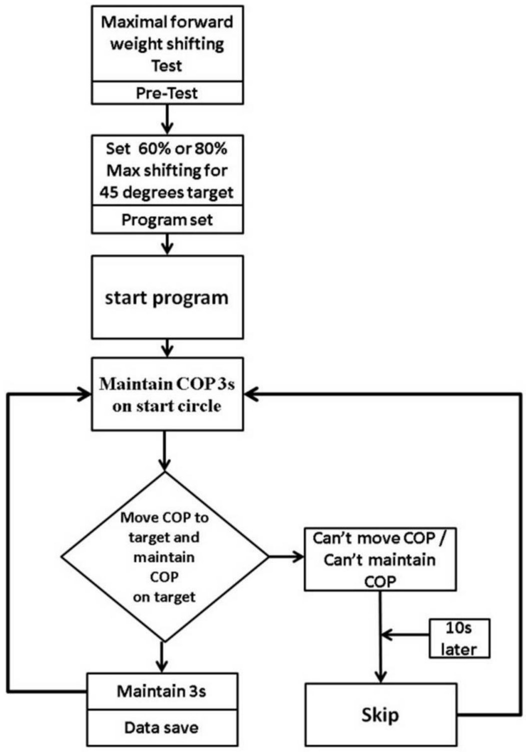


Figure 3. The flowchart to illustrate the algorism of the testing program.

2.4. Data Analysis

The data collected include proactive balance and APA variables. The proactive balance was evaluated by three variables, including direction error, path length, and path time. The APA was also evaluated by three variables, including APA distance, APA correction, and APA time.

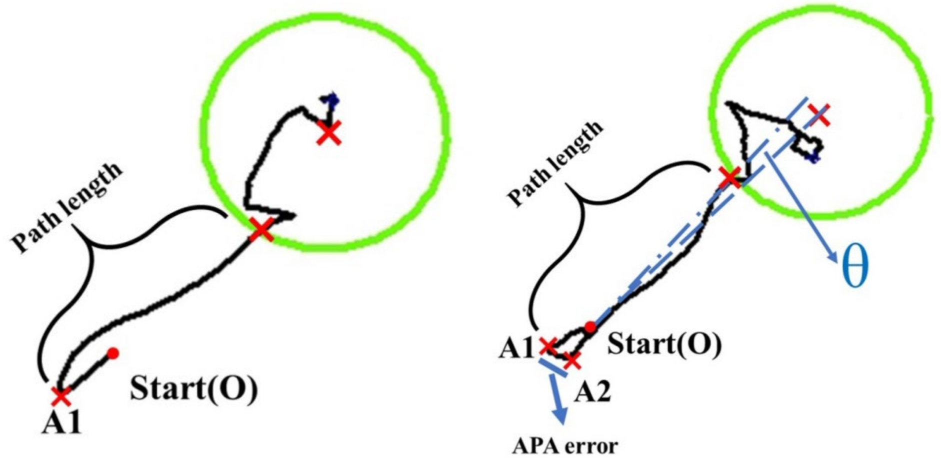
2.4.1. Definition of the Proactive Balance Variables

The direction error is the angle between the ideal path (a straight line from the origin to the target center) and the actual path (a straight line from origin to the point that the

COP first touches the target area). The path length is the total path length for COP moving from the origin to the point entering the target area. The path time is the total duration for COP moving from the origin to the target area.

2.4.2. Definition of the APA Variables

The APA is identified if the COP initially moves toward the opposite direction of the target. It is then defined as the farthest point in the quadrant opposite to the target. The APA distance is the maximum displacement on the x and y axis of APA. In cases when the maximum displacements on the x and y axes occur at the same point, the APA has only one phase (Figure 4a). If the maximum displacements on the x and y axes occur in different points, the APA has two phases (Figure 4b). In such two-phase conditions, the APA distance will correspond to the point that occurs first. The distance between these two points is defined as the APA correction (Figure 4b). The APA time refers to the duration of COP moving from the origin to the APA point.



(**a**) (**b**)

Figure 4. Representative data from two trials with illustration of variables. The black lines are discursion of COP and the green circles are targets. The red "x"s are the center of the targets which are not displayed for subjects. When the COP successfully touch the edge of the target and stay in target for 4 s, the trial is completed and the "path length" is calculated from the total COP discursion from the start point "O" to the point at which the COP touches the edge of the target. θ refers to direction error. The anticipatory postural adjustment (APA) is defined as the farthest point in the quadrant opposite to the target. (**a**) An example shows only one phase in APA. (**b**) An example shows two phases in APA. The distance between A1 and A2 is defined as "APA correction".

2.5. Statistical Analysis

Intraclass correlation (ICC) is used to analyze test-retest reliability because it takes into account systematic errors between repeated measurements [37]. The ICC form was used by following Shrout and Fleiss reliability coefficients guidelines [38]. Excellent reliability was determined if ICC > 0.75; Adequate reliability was determined if ICC was between 0.40 and 0.74; Poor reliability was determined if ICC < 0.40 [39–41]. Two-way (direction vs. distance) repeated measures ANOVA was used to analyze the response of proactive balance variables and APA variables in different target directions (0, 45, 90, 135, and 180 degrees) and target distances (60% and 80%). Data were analyzed in the SAS software version 9.4 (SAS Institute Inc., Cary, NC, USA).

$$ICC(3,1) = \frac{\text{BMS} - \text{EMS}}{\text{BMS} + (k-1)\text{EMS}} \quad (4)$$

k: number of raters.

3. Results

3.1. Proactive Balancing

The path length and path time showed adequate (>0.40) to excellent reliability (>0.75) in most of the directions (Table 2). For direction error, the ICC was generally low. Due to the low ICC, the direction error was not analyzed (Table 3).

Table 2. The test-retest reliability of Proactive Balance and APA.

	Target Distance	Target Direction				
		0° (Left)	**45° (Front Left)**	**90° (Forward)**	**135° (Front Right)**	**180° (Right)**
Path Time	60%	0.76 *	0.71	0.73	0.44	0.88 *
	80%	0.63	0.72	-	0.52	0.64
Path Length	60%	0.78 *	0.78 *	0.44	0.49	0.78 *
	80%	0.75 *	0.95 *	0.75 *	-	0.50
Direction Error	60%	-	-	-	-	-
	80%	0.95 *	0.74	-	-	0.72
APA Time	60%	0.69	0.74	0.67	0.60	0.72
	80%	0.83 *	0.69	0.82 *	0.78 *	-
APA Distance	60%	0.82 *	0.69	-	0.50	0.62
	80%	0.41	0.93	-	-	0.61
APA correction	60%	-	0.49	-	-	-
	80%	-	0.63	-	0.80 *	-

* ICC > 0.75.

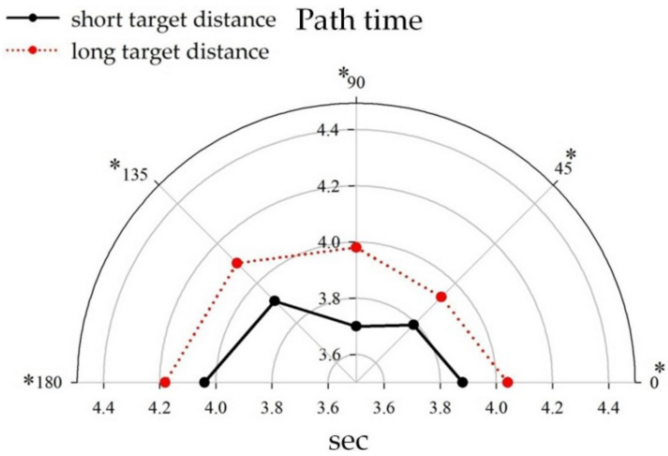
Table 3. The mean, standard deviation, and results of ANOVA of the proactive balance variables (path time, path length, direction error) and APA variables (APA time, APA distance, APA correction) in different target directions and target distances. The main effect is not shown if the interaction is significant ($p < 0.05$).

Variables	Target Distance	Target Direction					2 Way ANOVA (p)		
		0° (Left)	**45° (Front Left)**	**90° (Forward)**	**135° (Front Right)**	**180° (Right)**	**Interaction**	**Main Effect Distance**	**Main Effect Direction**
Path Time (s)	60%	3.88 ± 0.78	3.79 ± 0.64	3.70 ± 0.63	3.91 ± 0.91	4.04 ± 0.99	0.93	0.03 *	0.15
	80%	4.04 ± 0.95 [a]	3.93 ± 0.69 [a]	3.98 ± 0.57 [a]	4.10 ± 0.89 [a]	4.18 ± 1.08 [a]			
Path Length (mm)	60%	88.78 ± 24.62	89.00 ± 45.22	70.11 ± 19.01	72.62 ± 28.81	75.56 ± 23.22	0.02 **	-	-
	80%	99.10 ± 43.40	101.58 ± 21.76	104.29 ± 41.87 [a]	105.24 ± 36.96 [a]	116.64 ± 50.82 [a]			
Direction Error (deg)	60%	8.28 ± 5.27	11.22 ± 8.33	7.00 ± 5.06	13.79 ± 8.32	6.49 ± 5.80	NA		
	80%	6.77 ± 4.81	8.41 ± 6.35	5.18 ± 4.62	8.78 ± 6.33	6.08 ± 3.90			
APA Time (s)	60%	0.58 ± 0.15	0.59 ± 0.19	0.64 ± 0.14	0.56 ± 0.12	0.55 ± 0.15	0.27	0.45	<0.01 *
	80%	0.57 ± 0.15	0.57 ± 0.12	0.66 ± 0.14	0.55 ± 0.14	0.61 ± 0.15			
APA Distance (mm)	60%	28.04 ± 12.81	26.56 ± 17.67	20.71 ± 7.97	16.35 ± 6.61	20.76 ± 10.49	0.01 **	-	-
	80%	26.84 ± 13.92	21.40 ± 7.51	25.39 ± 13.85	20.52 ± 11.17	28.73 ± 20.52			
APA correction (mm)	60%	-	3.26 ± 2.78	-	2.70 ± 4.00	-	0.59	0.54	<0.01 *
	80%	-	3.09 ± 3.04	-	3.41 ± 3.78	-			

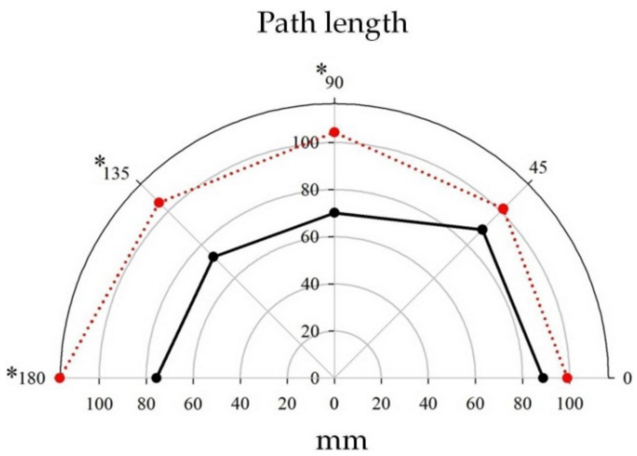
**: Significant interaction ($p < 0.05$) between target direction and target distance *: significant main effect ($p < 0.05$). [a]: significantly different from short target distance.

3.1.1. Path Time

The path time was affected by target distance but not target direction. The path time was less in short target distance trials ($p = 0.03$) in all movement directions and irrelevant to movement directions ($p = 0.15$) (Figure 5a).



(**a**)



(**b**)

Figure 5. The mean values of path time (**a**) and path length (**b**) for short (60%, black line) and long (80%, red line) target distances in all movement directions. * Statistical significance between short and long target distances.

3.1.2. Path Length

Unlike the path time, a significant interaction between target distance and direction ($p = 0.02$) was observed in the path length results. This suggested that the response of path length to target distance was not identical in different target directions. The path lengths were significantly ($p < 0.01$) shorter in shorter target distances only at 90, 135, and 180 degrees although the trend was seen in all directions (Figure 5b).

3.2. APA

The results showed that the APAs were successfully detected in 100% of proactive balancing trials. The APA time and distance demonstrated adequate to excellent ICC in all directions and target distances except for the APA distance at 90 degrees (Table 2).

3.2.1. APA Time

The APA time was affected by target direction ($p < 0.01$) but not by target distance. The APA time was longer in the 90 degrees direction (forward leaning direction) as compared to the other directions (0, 45, 135, and 180 degrees) (Figure 6a).

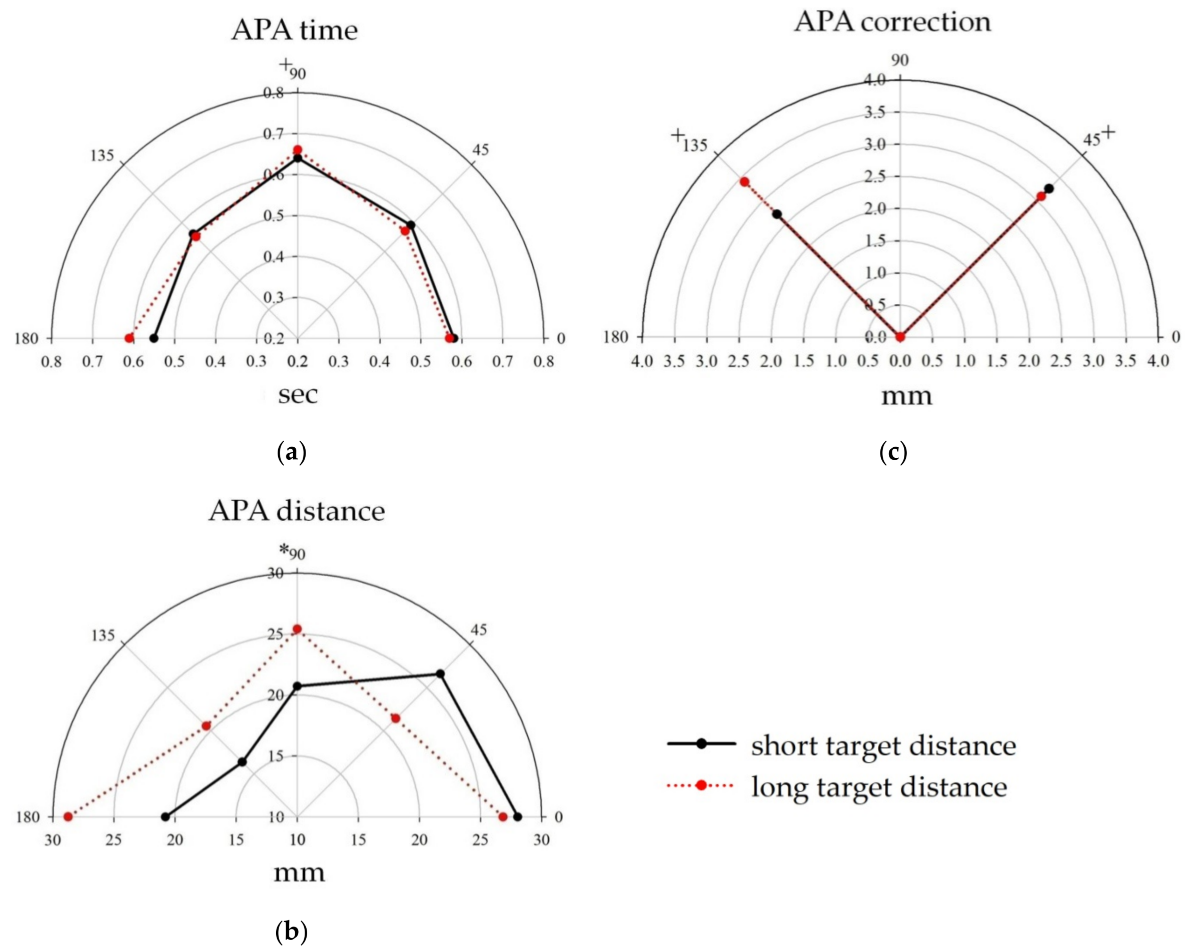


Figure 6. The APA time (**a**), APA distance (**b**), and APA correction (**c**) in short (60%, black line) and long (80%, red line) target distances in all movement directions. * Statistical significance between short and long target distance ($p < 0.05$) +Statistical significance between a specific target direction and 0 degree target direction ($p < 0.05$).

3.2.2. APA Distance

Unlike the APA time, a significant interaction between target distance and direction ($p = 0.01$) was observed in the APA distance results. The APA distance of the different target distances was only significantly different ($p < 0.05$) in the forward leaning 90 degrees direction (Figure 6b).

3.2.3. APA Correction

The APA correction only existed in the 45- and 135-degrees target directions, suggesting that the APA may have more than one phase in these two target directions (Figure 6c). The APA correction was affected by target direction ($p < 00.01$) but not by target distance.

4. Discussion

In this study, we have successfully detected APA in self-initiated weight shifting during proactive balance tests. The reliability of proactive balance and APA variables were also established. To our knowledge, this is the first study to quantify APA during proactive balance tests.

4.1. APA

Our study successfully detected APA in 100% of proactive balancing trials in all target directions. To our knowledge, this is the first study to successfully quantify APA components during proactive balance tests. This success rate is higher than those reported in previous studies which used fast arm-raise tasks to detect APA [31,42]. Kaminski and Simpkins (2001) reported that APA could not be detected in some arm-raise tasks, which caused little perturbation of equilibrium [31,42]. The high APA detecting rate during proactive balance test was possibly due to the reason that the proactive balance test produced higher amplitude of perturbation of equilibrium than the arm raising movements did.

Although the generation of APA requires substantial amount of equilibrium perturbation, our results showed that the APA time was invariant to target distances. This suggested that the APA time might be pre-programmed and the modulation of APA time was independent of external biomechanical challenge. Previous studies suggested that, during gait initiation, the first APA was pre-programmed and requires the bilateral inhibition of soleus and activation of tibialis anterior [43–45]. Although the pattern of APA during proactive balance test was not identical to the APA during gait initiation, our study supported the invariant pre-programmed feature of APA modulation during proactive balance test.

There are two types of APA patterns detected in our study, one phase or plural phases. The APA had only one phase in 0-(left), 90-(forward), or 180-(right) degree target directions which were all orthogonal directions. The APA had more than one phases in 45 (front-left) and 135 (front-right) degree target directions which were diagonal directions. In the biomechanical point of view, the diagonal movement directions were more complicated than orthogonal movement directions. The orthogonal movement direction required the control of simple anterior-posterior or medio-lateral shifts of COP. However, the diagonal movement directions required simultaneously controlling of anterior-posterior and medio-lateral shifting of COP in a proportional manner. Remelius et al. [44] proposed a postural model control in the shift of COP. The ankle strategy which was dominated by ankle muscles operated the anterior-posterior (90 degrees) direction; whereas the hip strategy dominated by hip abductor/adductor muscles [46] operated the medio-lateral (0 and 180 degrees) direction. The 45 and 135 degrees direction of COP might need coordination of both ankle and hip strategies and, thus, generate more than one phases in the APA.

Weight shifting to diagonal directions might me more related to gait initiation. Previous studies showed that, during gait initiation, there are also two phases of APA. The COP transit in lateral and posterior directions toward the swing foot heel to form the first phase of APA, and then shift laterally toward the stance foot to form the second phase of APA [43–45]. Researchers suggested that the second phase of APA could increase the efficiency for gait initiation which reduced the load on the swing leg and are necessary for forward progression [45,47,48]. Whether the APAs detected in the diagonal weight shifting directions correlates with gait initiation in patients is suggested to be studied in the future.

Clinically, forward reaching task is commonly used in evaluating the balance ability in health and diseases [49,50]. However, Behrman et al. reported that, for PD patients, the forward reaching did not identify every person at risk of fall and suggested other evaluations should be added to increase the sensitivity [49]. Our results showed the APA time was longer in the forward direction (90 degree) than in other directions. This result suggests that forward reaching might use a different motor strategy from other directions. It is essential to add multiple directions, especial diagonal directions, of weight shifting in clinical evaluation.

Different from the APA time, our study showed that the APA distance was varied according to different target directions. This suggested that the APA distance might be influenced by biomechanical constraint. Other factors, such as the subjects' dominant side and initial standing position, could not be excluded.

4.2. Reliability of the Measurmet

The APA time and distance demonstrated adequate to excellent ICC in all directions and target distances except for the APA distance at 90 degrees. Since this is a novel paradigm to evaluate APA, there were no previous systems to compare with. The good reliability the APA measurement was possibly due to the reliable perturbation generated by the current testing paradigm. For the proactive balance variables, our study also showed the adequate to excellent reliability on both path length and path time measurements. The ICC values of proactive balance variables were comparable with previous studies that utilized a stabilometric platform [9,41]. The studies reported the ICC of COP parameters to be between 0.54 and 0.92 for incomplete SCI [9] and multiple sclerosis individuals [41], in which COP was tested during steady standing.

There are also several other studies that use the Wii balance board as a clinical device for measuring balance and COP. For example, Clark et al. [51] used a custom-design software and found that the Wii balance board for COP path length had good test-retest reliability within-device (ICC = 0.66–0.94) and between-devices (ICC = 0.77–0.89). High concurrent validity with gold standard force plate was also reported [51]. The variability possibly stemmed from the tested subjects' variability rather than the device itself.

There are several concerns while interpreting the results of this study. First, our results showed the path time and path length were consistent in all directions. This should be due to the fact that the participants are healthy and are able to perform weight shifting symmetrically toward all directions. The testing direction could still be crucial for patients needed to be studied. Second, although the system was developed on Wii balance board, this does not exclude other COP measurement devices' probable feasibility. Any force plate system that could measure COP with adequate reliability and accuracy could be used. Third, whether the APAs measured in this paradigm could predict falls in patient population is suggested in future studies.

5. Conclusions

In conclusion, this study successfully developed a novel paradigm to measure APA via a proactive balance test paradigm. Quantifiable and consistent self-initiated weight shifting could be produced by integrating the Wii balance board with a custom-design proactive balance test program. This might be an optimal testing paradigm since APA can be detected in every trial with adequate to good reliability. As the capability of balance and APA can be monitored simultaneously in the home-based setting system and, thus, made feasible for remote healthcare, e.g., telerehabilitation. Future studies for testing APAs using this novel paradigm in patient groups and establishing the correlations with gait initiation difficulties are suggested.

Author Contributions: J.-W.L., R.-S.C., V.C.-F.C., Y.-R.W., H.-L.C., and Y.-J.C. conceived, designed, and coordinated the study. J.-W.L., Y.-R.W., and Y.-J.C. acquired data. J.-W.L., V.C.-F.C., H.-L.C., and Y.-J.C. analyzed and interpreted the data, and were a major contributor in writing the manuscript. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Institutional Review Board of Chang Gung Medical Foundation (protocol code 103-5361B, 10 November 2014).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Tinetti, M.E. Clinical practice. Preventing falls in elderly persons. *N. Engl. J. Med.* **2003**, *348*, 42–49. [CrossRef] [PubMed]
2. American Geriatrics Society; British Geriatrics Society; American Academy of Orthopaedic Surgeons Panel on Falls Prevention. Guideline for the prevention of falls in older persons. *J. Am. Geriatr. Soc.* **2001**, *49*, 664–672. [CrossRef]
3. Craig, J.; Murray, A.; Mitchell, S.; Clark, S.; Saunders, L.; Burleigh, L. The high cost to health and social care of managing falls in older adults living in the community in Scotland. *Scott. Med. J.* **2013**, *58*, 198–203. [CrossRef] [PubMed]
4. Cho, S.I.; An, D.H. Effects of a Fall Prevention Exercise Program on Muscle Strength and Balance of the Old-old Elderly. *J. Phys. Ther. Sci.* **2014**, *26*, 1771–1774. [CrossRef] [PubMed]
5. Najafi, D.A.; Dahlberg, L.E.; Hansson, E.E. A combination of clinical balance measures and FRAX(R) to improve identification of high-risk fallers. *BMC Geriatr.* **2016**, *16*, 94. [CrossRef]
6. Mohler, M.J.; Wendel, C.S.; Taylor-Piliae, R.E.; Toosizadeh, N.; Najafi, B. Motor Performance and Physical Activity as Predictors of Prospective Falls in Community-Dwelling Older Adults by Frailty Level: Application of Wearable Technology. *Gerontology* **2016**, *62*, 654–664. [CrossRef]
7. Donath, L.; Rossler, R.; Faude, O. Effects of Virtual Reality Training (Exergaming) Compared to Alternative Exercise Training and Passive Control on Standing Balance and Functional Mobility in Healthy Community-Dwelling Seniors: A Meta-Analytical Review. *Sports Med.* **2016**, *46*, 1293–1309. [CrossRef]
8. Laufer, Y.; Dar, G.; Kodesh, E. Does a Wii-based exercise program enhance balance control of independently functioning older adults? A systematic review. *Clin. Interv. Aging* **2014**, *9*, 1803–1813. [CrossRef]
9. Tamburella, F.; Scivoletto, G.; Iosa, M.; Molinari, M. Reliability, validity, and effectiveness of center of pressure parameters in assessing stabilometric platform in subjects with incomplete spinal cord injury: A serial cross-sectional study. *J. Neuroeng. Rehabil.* **2014**, *11*, 86. [CrossRef]
10. Tinetti, M.E.; Williams, T.F.; Mayewski, R. Fall risk index for elderly patients based on number of chronic disabilities. *Am. J. Med.* **1986**, *80*, 429–434. [CrossRef]
11. Park, J.; Koh, S.B.; Kim, H.J.; Oh, E.; Kim, J.S.; Yun, J.Y.; Kwon, D.Y.; Kim, Y.; Kwon, K.Y.; Park, J.H.; et al. Validity and Reliability Study of the Korean Tinetti Mobility Test for Parkinson's Disease. *J. Mov. Disord.* **2018**, *11*, 24–29. [CrossRef]
12. Lemay, J.F.; Nadeau, S. Standing balance assessment in ASIA D paraplegic and tetraplegic participants: Concurrent validity of the Berg Balance Scale. *Spinal Cord* **2010**, *48*, 245–250. [CrossRef] [PubMed]
13. Rosenfeld, J.; Jackson, C. Quantitative Assessment and Outcome Measures in Neuromuscular Disease. In *Neuromuscular Disorders in Clinical Practice*; Springer: Berlin/Heidelberg, Germany, 2002; pp. 309–343.
14. Muehlbauer, T.; Besemer, C.; Wehrle, A.; Gollhofer, A.; Granacher, U. Relationship between strength, power and balance performance in seniors. *Gerontology* **2012**, *58*, 504–512. [CrossRef]
15. Sturnieks, D.L.; Menant, J.; Vanrenterghem, J.; Delbaere, K.; Fitzpatrick, R.C.; Lord, S.R. Sensorimotor and neuropsychological correlates of force perturbations that induce stepping in older adults. *Gait Posture* **2012**, *36*, 356–360. [CrossRef] [PubMed]
16. Raymakers, J.A.; Samson, M.M.; Verhaar, H.J. The assessment of body sway and the choice of the stability parameter(s). *Gait Posture* **2005**, *21*, 48–58. [CrossRef] [PubMed]
17. Bove, M.; Marinelli, L.; Avanzino, L.; Marchese, R.; Abbruzzese, G. Posturographic analysis of balance control in patients with essential tremor. *Mov. Disord.* **2006**, *21*, 192–198. [CrossRef]
18. Aprile, I.; Padua, L.; Iosa, M.; Gilardi, A.; Bordieri, C.; Frusciante, R.; Russo, G.; Erra, C.; De Santis, F.; Ricci, E. Balance and walking in facioscapulohumeral muscular dystrophy: Multiperspective assessment. *Eur. J. Phys. Rehabil. Med.* **2012**, *48*, 393–402. [PubMed]
19. Donker, S.F.; Ledebt, A.; Roerdink, M.; Savelsbergh, G.J.; Beek, P.J. Children with cerebral palsy exhibit greater and more regular postural sway than typically developing children. *Exp. Brain Res.* **2008**, *184*, 363–370. [CrossRef] [PubMed]
20. Ruhe, A.; Fejer, R.; Walker, B. The test-retest reliability of centre of pressure measures in bipedal static task conditions–a systematic review of the literature. *Gait Posture* **2010**, *32*, 436–445. [CrossRef]
21. Yang, T.H.; Huang, C.F. The effect on center of mass control during stair-to-floor transition in Tai Chi elderly. *Phys. Educ. J.* **2018**, *51*, 307–319.
22. Corsi, C.; Cimolin, V.; Capodaglio, P.; Condoluci, C.; Galli, M. A biomechanical study of gait initiation in Down syndrome. *BMC Neurol.* **2019**, *19*, 66. [CrossRef] [PubMed]
23. Rasouli, O.; Stensdotter, A.K.; Van der Meer, A.L.H. TauG-guidance of dynamic balance control during gait initiation in patients with chronic fatigue syndrome and fibromyalgia. *Clin. Biomech.* **2016**, *37*, 147–152. [CrossRef]
24. Chen, V.C.; Chen, S.-W. Establishing the waist as the better location for attaching a single accelerometer to estimate center of pressure trajectories. *Clin. Biomech.* **2018**, *60*, 30–38. [CrossRef] [PubMed]
25. Prosperini, L.; Fortuna, D.; Gianni, C.; Leonardi, L.; Pozzilli, C. The diagnostic accuracy of static posturography in predicting accidental falls in people with multiple sclerosis. *Neurorehabil. Neural Repair* **2013**, *27*, 45–52. [CrossRef] [PubMed]
26. Gianni, C.; Prosperini, L.; Jonsdottir, J.; Cattaneo, D. A systematic review of factors associated with accidental falls in people with multiple sclerosis: A meta-analytic approach. *Clin. Rehabil.* **2014**, *28*, 704–716. [CrossRef] [PubMed]
27. Goble, D.J.; Cone, B.L.; Fling, B.W. Using the Wii Fit as a tool for balance assessment and neurorehabilitation: The first half decade of "Wii-search". *J. Neuroeng. Rehabil.* **2014**, *11*, 12. [CrossRef]

28. Vedula, S.; Kearney, R.E.; Wagner, R.; Stapley, P.J. Decoupling of stretch reflex and background muscle activity during anticipatory postural adjustments in humans. *Exp. Brain Res.* **2010**, *205*, 205–213. [CrossRef]
29. Pozzo, T.; Ouamer, M.; Gentil, C. Simulating mechanical consequences of voluntary movement upon whole-body equilibrium: The arm-raising paradigm revisited. *Biol. Cybern.* **2001**, *85*, 39–49. [CrossRef]
30. Cordo, P.J.; Nashner, L.M. Properties of postural adjustments associated with rapid arm movements. *J. Neurophysiol.* **1982**, *47*, 287–302. [CrossRef]
31. Kaminski, T.R.; Simpkins, S. The effects of stance configuration and target distance on reaching. I. Movement preparation. *Exp. Brain Res.* **2001**, *136*, 439–446. [CrossRef]
32. Jacobs, J.V.; Nutt, J.G.; Carlson-Kuhta, P.; Stephens, M.; Horak, F.B. Knee trembling during freezing of gait represents multiple anticipatory postural adjustments. *Exp. Neurol.* **2009**, *215*, 334–341. [CrossRef] [PubMed]
33. Burleigh-Jacobs, A.; Horak, F.B.; Nutt, J.G.; Obeso, J.A. Step initiation in Parkinson's disease: Influence of levodopa and external sensory triggers. *Mov. Disord.* **1997**, *12*, 206–215. [CrossRef] [PubMed]
34. Lin, C.C.; Creath, R.A.; Rogers, M.W. Variability of Anticipatory Postural Adjustments During Gait Initiation in Individuals With Parkinson Disease. *J. Neurol. Phys. Ther.* **2016**, *40*, 40–46. [CrossRef] [PubMed]
35. Mezaour, M.; Yiou, E.; Le Bozec, S. Effect of lower limb muscle fatigue on anticipatory postural adjustments associated with bilateral-forward reach in the unipedal dominant and non-dominant stance. *Eur. J. Appl. Physiol.* **2010**, *110*, 1187–1197. [CrossRef] [PubMed]
36. Bartlett, H.L.; Ting, L.H.; Bingham, J.T. Accuracy of force and center of pressure measures of the Wii Balance Board. *Gait Posture* **2014**, *39*, 224–228. [CrossRef] [PubMed]
37. Scholtes, V.A.; Terwee, C.B.; Poolman, R.W. What makes a measurement instrument valid and reliable? *Injury* **2011**, *42*, 236–240. [CrossRef]
38. Shrout, P.E.; Fleiss, J.L. Intraclass correlations: Uses in assessing rater reliability. *Psychol. Bull.* **1979**, *86*, 420–428. [CrossRef]
39. Andresen, E.M. Criteria for assessing the tools of disability outcomes research. *Arch. Phys. Med. Rehabil.* **2000**, *81*, S15–S20. [CrossRef]
40. Cicchetti, D.V. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychol. Assess.* **1994**, *6*, 284–290. [CrossRef]
41. Wajda, D.A.; Motl, R.W.; Sosnoff, J.J. Three-Month Test-Retest Reliability of Center of Pressure Motion During Standing Balance in Individuals with Multiple Sclerosis. *Int. J. MS Care* **2016**, *18*, 59–62. [CrossRef]
42. Latash, M.L.; Aruin, A.S.; Neyman, I.; Nicholas, J.J. Anticipatory postural adjustments during self inflicted and predictable perturbations in Parkinson's disease. *J. Neurol. Neurosurg. Psychiatry* **1995**, *58*, 326–334. [CrossRef] [PubMed]
43. Halliday, S.E.; Winter, D.A.; Frank, J.S.; Patla, A.E.; Prince, F. The initiation of gait in young, elderly, and Parkinson's disease subjects. *Gait Posture* **1998**, *8*, 8–14. [CrossRef]
44. Remelius, J.G.; Hamill, J.; Kent-Braun, J.; Van Emmerik, R.E. Gait initiation in multiple sclerosis. *Mot. Control* **2008**, *12*, 93–108. [CrossRef] [PubMed]
45. Cau, N.; Cimolin, V.; Galli, M.; Precilios, H.; Tacchini, E.; Santovito, C.; Capodaglio, P. Center of pressure displacements during gait initiation in individuals with obesity. *J. Neuroeng. Rehabil.* **2014**, *11*, 82. [CrossRef]
46. Delval, A.; Dujardin, K.; Tard, C.; Devanne, H.; Willart, S.; Bourriez, J.L.; Derambure, P.; Defebvre, L. Anticipatory postural adjustments during step initiation: Elicitation by auditory stimulation of differing intensities. *Neuroscience* **2012**, *219*, 166–174. [CrossRef]
47. Breniere, Y.; Cuong Do, M.; Bouisset, S. Are dynamic phenomena prior to stepping essential to walking? *J. Mot. Behav.* **1987**, *19*, 62–76. [CrossRef]
48. Breniere, Y.; Do, M.C. Control of gait initiation. *J. Mot. Behav.* **1991**, *23*, 235–240. [CrossRef]
49. Behrman, A.L.; Light, K.E.; Flynn, S.M.; Thigpen, M.T. Is the functional reach test useful for identifying falls risk among individuals with Parkinson's disease? *Arch. Phys. Med. Rehabil.* **2002**, *83*, 538–542. [CrossRef]
50. Bohannon, R.W.; Wolfson, L.I.; White, W.B. Functional reach of older adults: Normative reference values based on new and published data. *Physiotherapy* **2017**. [CrossRef]
51. Clark, R.A.; Bryant, A.L.; 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*, 307–310. [CrossRef]