Application of Real-Time Visual Feedback System in Balance Training of the Center of Pressure with Smart Wearable Devices

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Research Article

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Abstract

**Background:** Visual feedback from the center of pressure (COP) on the benefits of standing quietly remains controversial. The study was to investigate the adaptive effect of COP real-time visual feedback training provided by smart wearable devices on standing in silence.

**Methods:** Thirty healthy female college students were randomly divided into three groups (visual feedback balance training group (VFT), non-visual feedback balance training group (NVFT) and control group (CG)). Two force plates were used to calculate the coordinates of COP anteroposterior (COP\textsubscript{AP}) and COP mediolateral (COP\textsubscript{ML}). The motion analysis system is used to calculate the coordinates of the center of mass in two directions. Enhanced visual feedback on the screen in the form of fluctuating in different directions, VFT received real-time visual feedback from Podoon APP for training, the NVFT only performs open eye balance without receiving real-time visual feedback. The CG group did not receive any visual feedback. The training lasted 4 weeks, the training lasts 30 minutes at an interval of 1 days.

**Results:** After four weeks of balance training, the results showed that visual feedback training can improve the stability of human posture control by one leg stance and tandem stance static balance training on VFT intelligent App. The parameters of COP\textsubscript{ML}/AP max displacement, COP\textsubscript{ML}/AP velocity and COP radius and COP area in the VFT were significantly increased (p<0.05).

**Conclusion:** The conclusion shows that COP real-time visual feedback training provided by smart wearable devices can reduce postural sway better and improve body balance ability than general training when standing quietly.

**Background**

Balance ability refers to the human body to adjust automatically to maintain postural stability when it moves or is subjected to external forces [1]. Balance control is usually affected by joint range of motion and muscle strength, which can be used to monitor the sensory information of the mechanism [2]. Therefore, good balance must be regulated by the sensory system and neuromuscular system. During upright posture control, people are clearly aware of their position changes in space when they are given VF based on the displacement of the center of pressure (COP) or body center of mass (COM) [3]. The visual system can provide the human body with information about the surrounding environment, location, direction, and speed during movement. When the visual information is removed or altered, the action system must rely on proprioceptive feedback and sensory information from the vestibular system in order to maintain balance [4]. Therefore, VF can help increase the body’s stability and balance ability while controlling the posture of the human body. In recent years, sensorimotor integration technology has been used to provide VF to improve the balance ability of people with disabilities and high-risk falls. Previous studies have indicated that internal feedback on one’s own posture sway can be obtained through VF so that the body can control its posture changes more autonomously [5]. In a study detailing the effect of VF from COP on balance posture control of adolescents and the elderly, it was found that the use of VF for
COP in the standing task is a common method for evaluating and training posture control [6]. Therefore, VF can improve the upright posture control and change postural sway in the anterior–posterior and medial–lateral directions to maintain balance. In addition, further findings on ankle movement can clarify different types of VF on body sway and ankle joint mechanisms that contribute to postural sway control [7]. The comparison between the traditional body training and computer vision feedback training indicated that the computer vision feedback group had a better effect on the balance posture control of the human body [8]. Therefore, providing VF in balance training can effectively improve the balancing ability of participants.

VF training to control body posture helps improve the body's ability to maintain balance and achieve a stable standing effect. It can stabilize the body posture and significantly improve static and dynamic balance ability [9]. Previous studies have found that COP displacement and mean velocity of patients with spinal cord injury decreased after VF standing balance training, indicating that the ability of static and dynamic stability improved significantly after training [9]. After applying wearable devices to balance training for the elderly, the COP area and COP parameters displayed a significantly decrease, indicating that balance training is effective for improving postural control and functional performance in older adults [10]. These studies used screen COP displacement projection onto the screen as balance training to maintain stability. Therefore, appropriate external real-time VF information (the position of the real-time COP) should be provided during balance training to improve the control ability of posture balance and increase the benefit of training. In summary, effectively using the real-time VF information of COP provided by smart wearable devices for balance control and training can benefit technology-assisted balance training at home, thereby aiding sports training and physical rehabilitation.

This study aims to enhance the benefit of balance training effectively by using the real-time VF information of COP provided by smart insoles in the One Leg Stance (OLS) or Tandem Stance (TS) posture. This study demonstrates the effect of a simple technology-assisted VF system on body balance.

**Methods**

**Participants**

Thirty healthy female college students were recruited and randomly assigned to the VFT, NVFT, and CG with 10 persons in each group. The height (167.59 ± 4.68 cm), weight (57.10 ± 7.15 kg), and age (20.12 ± 1.13) of each participant were recorded. Exclusion criteria: Any past history of injury or treatment of the lower limb, Any neurological or vascular deficit affecting balance, Pain and swelling near ankle and foot, Visual or vestibular impairment [11]. The participants were informed of the content, process, and precautions for the study group. The test instructions were read out to them and they understood and were willing to cooperate fully with the experimenter and signed the consent form. The study was approved by the Research Ethics Committee of Hualien Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation (IRB109-053-B) and was conducted in accordance with the Declaration of Helsinki.
Equipment

A force plate (BTS P6000, BTS Bioengineering, Italy) was used to calculate the coordinates of the COP displacement in the ML and AP directions and the COP velocity. Force plate signals were collected at a sampling frequency of 300 Hz and synchronized with the motion analysis system. In order to avoid the impact of different wear and tear during the test and training, all participants wore the same experimental tights and uniform sports shoes. The running shoe incorporates a smart insole that acts as a smart wearable device to record COP changes. For the VF training groups, iPad Pro with Podoon APP was used as an additional visual supplement to help participants enhance the application of visual feedback in this study.

Experimental protocol

Participants were recruited prior to the experiment and their foot length was measured. Then, the smart foot pad matching their foot length was selected and cut. The participants would have a five-minute warm-up run and one minute of rest. After this preparation, thirty female college students were randomly assigned to the VFT, NVFT, and CG for the first balance training as a pre-test. The experiment consisted of 6 items, including the One Leg Stance Non-Visual Feedback (OLS-NF), One Leg Stance-Visual Feedback (OLS-VF), Tandem Stance (dominant leg in back)-Non visual feedback (TSDL-NF), Tandem Stance (dominant leg in back)-visual feedback (TSDL-VF), Tandem Stance (non-dominant leg in back)-Non visual feedback (TSNDL-NF), Tandem Stance (non-dominant leg in back)-visual feedback (TSNDL-VF) [12, 13]. After that, the participants completed balance training three times a week lasted four weeks, with 30 minutes of balance training every 1–2 days. Training included the VFT using Podoon APP to perform OLS/TS-VF balance training. The NVFT was given an open-eye balance training without Podoon APP participation on OLS/TS-NF. The control group did not do any balance training. In OLS, participants were instructed to stand on their dominant leg, while the non-supported leg was flexed at the knee with the plantar surface of the foot stabilized on the knee of the supporting leg [14]. In TS, the participants’ feet (on a line, heel-toe position) were placed on the center of the force plate [15]. They were asked to keep the dynamic point in the central circle as much as possible. The iPad Pro was located at an eye-level height, 1 m apart from the participants. After 4 weeks, the participants again performed six balance movements during the pretest to measure the effect of visual feedback on improving balance.

Statistical analysis

In this study, the average values of three test results in each subject's test action were calculated and used for statistical analysis. MATLAB (R2014a, The MathWorks, USA) was used for statistical analysis. The experiment used mixed design two-way analysis of variance (ANOVA) (Group × Times) to compare the differences in pretest and post-test among the VFT, NVFT, and CG. For each measurement, post hoc least significant difference comparisons were performed on the significant effects. The level of significance was set at $\alpha < 0.05$.

Results
After four weeks of balance training with different interventions, balance postures were assessed immediately after the training was completed. The position balance of VFT and NVFT was significantly improved (P < 0.05). In addition, COP value after intervention was significantly lower than that before intervention, except CG group. The effect from these interventions for the COP parameter varied from weak to moderate across the balance conditions.

**Analysis of COP parameters in the OLS**

For OLS, analysis of the COP parameters was a significant difference in the interaction effect between Groups*Times (p < 0.05).

**Effect of the time (pre- and post-test)**

Analysis of the COPML max displacement or COPAP max displacement (Figure 1). For the OLS-NF, the COPML max displacement of the VFT,NVFT was ▽18.37, ▽15.65 (p ≤ 0.001). The COPAP max displacement of the VFT was and NVFT was ▽31.94 (p = 0.018). For OLS-VF, the COPML max displacement of the VFT was ▽21.78 (p = 0.005) and the COPAP max displacement of the VFT was ▽54.21 (p = 0.008). Analysis of the COPML velocity or COPAP velocity (Figure 2). For OLS-NF, the COPML velocity of the VFT was ▽6.28 (p = 0.003) and the COPAP velocity of the VFT was ▽7.26 (p = 0.009). For OLS-VF, the COPML velocity of the VFT was ▽19.93 and NVFT ▽17.92 (p = 0.001, p = 0.003), the COPAP velocity of the VFT was ▽17.09 and NVFT was ▽8.43 (p = 0.001, p = 0.031). Analysis of the COP radius and COP area (Figure 3). For OLS-NF, the COP radius of the VFT was ▽28.67 (p = 0.001) and the COP area of the VFT was ▽42.84 (p < 0.001). For OLS-VF, the COP radius of the VFT was ▽44.44 (p < 0.001) and the COP area of the VFT was ▽47.16 (p < 0.001).

**Comparison between groups (VFT, NVFT and CG)**

Analysis of the COPML max displacement or COPAP max displacement (Figure 1). For the OLS-NF, the COPML max displacement of the VFT,CG was ▽20.23, ▽7.61 (p = 0.001, p = 0.031), the COPAP max displacement of the VFT/CG, the NVFT/CG was ▽1.95 (p = 0.009, p = 0.007), the COPAP max displacement of the VFT/NVFT, the VFT/CG, the NVFT/CG was ▽23.76, ▽33.92 and ▽8.21 (p < 0.001). Analysis of the COPML velocity or COPAP velocity (Figure 2). For the OLS-NF, the COPML velocity of the VFT/CG, the NVFT/CG was ▽14.23, ▽9.95 (p < 0.001, p = 0.006), the COPML velocity of the VFT/CG, the NVFT/CG was ▽21.01, ▽13.81 (p = 0.001, p = 0.002). Analysis of the COPML velocity of the VFT/CG, the NVFT/CG was ▽9.10, ▽6.88 (p < 0.001, p < 0.002). Analysis of the COP radius and COP area (Figure 3). For the OLS-NF, the COP radius of the VFT/NVFT, the VFT/CG was 15.72, ▽25.71 (p = 0.031, p = 0.001), the COP area of the VFT/NVFT, the VFT/CG was ▽31.26, ▽41.21 (p = 0.047, p = 0.005). For the OLS-VF, the COP radius of the VFT/NVFT, the VFT/CG was ▽8.98, ▽17.13 (p = 0.014, p = 0.001), the COP area of the VFT/NVFT ▽30.38, ▽37.67 (p < 0.001, p < 0.001).
Analysis of COP parameters in the TSNDL/TSDL

For TSNDL/TSDL, analysis of the COP parameters was no significant difference in the interaction effect between Groups*Times (p>0.05).

Effect of the time (pre- and post-test)

Analysis of the main effect of COP parameters was significantly difference in times (p<0.05). Analysis of the COPML max displacement or COPAP max displacement (Figure 1). For TSNDL-NF, the COPML max displacement of the VFT and NVFT was ▽20.46 (p=0.005, p=0.014), the COPAP max displacement of the VFT was ▽26.73 (p=0.002). For TSDL-NF, the COPML max displacement of the VFT was ▽29.97 (p=0.003), the COPAP max displacement of the VFT was ▽24.15 (p=0.031). For TSNDL-VF, the COPML max displacement of was the VFT was ▽12.75 (p=0.025), the COPAP max displacement of the VFT was ▽18.27 (p=0.001). Analysis of the COPML velocity or COPAP velocity (Figure 2). For TSNDL-NF, the COPML velocity of the VFT and NVFT was ▽8.70 (p=0.001), the COPAP velocity of the VFT was ▽13.61 (p=0.003). For TSDL-NF, the COPML velocity of the VFT was ▽3.48 (p=0.009), the COPAP velocity of the VFT was ▽11.35 (p=0.004). For TSNDL-VF, the COPML velocity of the VFT was ▽3.19 (p=0.037), the COPAP velocity of the VFT was ▽7.53 (p=0.047). For TSDL-VF, the COPML velocity of the VFT was ▽6.59 (p<0.001), the COPAP velocity of the VFT was ▽6.57 (p=0.002). Analysis of the COP radius and COP area (Figure 3). For TSNDL-NF, the COP radius of the VFT was ▽33.35 (p=0.001), the COP area of the VFT was ▽39.48 (p<0.001).

Comparison between groups (VFT, NVFT and CG)

The main effect of the groups was significantly difference in the COPML velocity of TSNDL-NF and COPML max displacement of the TSDL-VF (p<0.05). For the TSNDL-VF, post hoc analysis showed a significant decrease in the VFT/NVFT and the VFT/CG (▽7.62, p=0.009 and ▽9.18, p=0.001). For TSDL-VF, post hoc analysis showed a significant decrease in the VFT/NVFT and the VFT/CG (▽30.56 and ▽29.58, p<0.001). There no difference was found in favor of any posture of the COPAP max displacement, COPML/AP velocity, COP radius and COP area in the post-intervention effect.

Discussion

The purpose of this study was to perform balance training for participants with the VF technique provided by a smart wearable device of COP, in order to observe the effect of this technique on the static balance posture control of women. After four weeks of balance training, the results showed that visual feedback
training can improve the stability of human posture control by OLS and TS static balance training on VFT intelligent App.

In this study, the decrease in COP$_{ML}$ and COP$_{AP}$ displacement in VFT demonstrated that the participants could control body sway in a considerably stable manner with the help of real-time VF information. The body integrates vision, vestibular sense, and somatosensory through the central nervous system (CNS) to maintain human balance performance [16]. After the balance training of external VF, the results of COP$_{ML}$/COP$_{AP}$ displacement decreased in OLS with participants’ dominant/non-dominant leg illustrating that the use of technology-assisted App to provide VF training can help reduce the displacement in the AP and ML directions. In addition, the sway and posture changes in the AP direction are closely related to ankle neuromuscular function. The “ankle strategy” can improve ankle stability and reduce COP displacement to improve balance ability [17]. The “ankle strategy” can maintain the body balance in AP direction showing the static posture balance of standing. In this study, the decrease in AP and ML displacement of the COP indicated that the technique-assisted training may increase the balance control ability to reduce body sway and displacement variation after the participation of VF.

In OLS, the parameters of COP mean velocity, COP$_{ML}$ velocity, and COP$_{AP}$ velocity of VFT after four weeks of training; the NVFT was not different before and after training in the NF test, but there was a difference in the VF test, and the CG remained unchanged. Meanwhile, the COP mean velocity, COP$_{ML}$ velocity, and COP$_{AP}$ velocity in VFT were significantly lower than those in the NVFT and CG. In TS, the COP mean velocity, COP$_{ML}$ velocity, and COP$_{AP}$ velocity in VFT decreased after four weeks of training, and there was no difference between the NVFT and CG. Previous studies have found that the smaller the displacement velocity, the better the balance control ability when using VF training [18]. In this study, VF training using smart auxiliary equipment may help participants maintain better physical stability. When the human body performs visual feedback training, the central nervous system controls the body’s goal-directed movements through relevant mechanisms [19]. The study showed that posture sway in the ML direction is controlled by adduction/abduction of the hip joint mechanism, while the postural sway in the AP direction is controlled by plantar flexion/dorsiflexion of the ankle joint mechanism [20]. In this study, the decrease in COP$_{ML}$ velocity and COP$_{AP}$ velocity in the VFT may be caused by the goal-directed movement of the ankle and hip joint mechanism regulated by the CNS during VF training. Past studies have found that balance training stimulates proprioception and increases sensory motor nerve signal transmission to improve balance control ability [21], and balance training will strengthen muscular activity and improve the stability of the balance mechanism [22]. Therefore, training without the assistance of smart devices will strengthen muscle activity, and the central nervous system will mobilize the relevant muscle groups for goal-directed movements during the VF test to improve balance. However, the VFT conducts visual feedback training during the training process and the CNS controls the relevant muscle groups to perform goal-directed movements during training, so that the training effect of the visual feedback training group is higher than that of the general training group. Therefore, the CNS mobilizes more motor neurons to increase the physical stability when performing VF training in OLS and TS.
In OLS, the parameters of COP area and COP radius of VFT decreased after four weeks of training; the NVFT and CG remained unchanged. Meanwhile, the COP area and COP radius in the VFT were significantly lower than those of the NVFT and CG. The results demonstrate that using smart wearable auxiliary VF for training has better balance ability than not wearing smart wearable auxiliary training or remaining untrained. Previous studies have shown that the COP radius and the COP area can reflect the static stability of the human body in the process of OLS; the larger the COP area and COP radius, the worse the stability [23]. Therefore, balance training with visual feedback assisted by smart insoles can help participants maintain physical stability. The decrease in COP radius and COP area is primarily due to conscious control by the human body based on the visual information obtained from VF [24]. During the training process, the participants could integrate VF information and motor sensory information to maintain physical stability under the control of the CNS [25]. Previous studies have found that training with VF provided by smart devices can improve balance ability. For example, training with VF provided by a balancer (Pro-kin) or balance board (Wii Fit) can reduce the COP radius and COP area of participants and increase the physical stability after training [26]. Therefore, the decrease in COP area and COP radius after training in VF provided by smart insoles may also be due to the increase in visual information. In TS, the COP area and COP radius of the VFT decreased after four weeks of training, and there was no difference between the NVFT and CG. Consistent with the results of the VFT in OLS, it was observed that physical stability in TS also increased after VF training. In addition, previous studies have pointed out that smart wearable devices are VF to the body's COM, and the COM VF will strengthen autonomous control and reduce posture sway, thereby achieving more efficient posture control or improving balance [27]. The training without smart auxiliary equipment only adjusts itself under the original sense organ system, and cannot judge the position effectively through the VF [28]. Therefore, the balance ability of the NVFT cannot be significantly improved, and the use of VF assisted by smart insoles for training will provide more VF information to strengthen the physical autonomous control ability and improve physical balance.

**Limitations**

The limitation of this study is that experiments were performed with a small sample size of participants. In addition, the adaptation effects of training may not be detected sufficiently with the small amount of training the participants underwent. Therefore, although the COP parameter values of VFT increased after training compared with CG\NVFT, its training effect needs to be further tested with more sample size. In addition, the study only assessed the static standing of the subjects in stable posture, without further discussion on the postural balance under unstable plane/interference of external forces, which will be the focus of our next study.

**Conclusion**

VF training can assist proprioception to reduce COP movement and enhance balance ability. With the increasing difficulty of balancing task, the balancing mechanism relies more on visual feedback. In this
study, the need for visual feedback in the balanced posture of one foot was significantly higher than that of the two feet. It is particularly important to use smart wearable devices to improve the body's ability to maintain balance.

**Abbreviations**

COP
Center of Pressure; VFT: Visual feedback balance training group; NVFT: Non-visual feedback balance training group; CG: Control group; COPAP: COP Anteroposterior; COPML: COP Mediolateral; COM: Center of Mass; OLS: One Leg Stance; TS: Tandem Stance; OLS-NF: One Leg Stance Non-visual feedback; OLS-VF: One Leg Stance-Visual feedback; TSDL-NF: Tandem Stance (dominant leg in back)-Non visual feedback; TSDL-VF: Tandem Stance (dominant leg in back)-Visual feedback; TSNDL-NF: Tandem Stance (non-dominant leg in back)-Non visual feedback; TSNDL-VF: Tandem Stance (non-dominant leg in back)-Visual feedback; CNS: Central nervous system.

**Declarations**

**Ethics approval and consent to participate**

The study was approved by the Research Ethics Committee of Hualien Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation (IRB109-053-B). Participants were informed of the experimental procedures and risks and provided their written informed consent prior to attending several familiarization sessions.

**Consent for publication**

Not applicable.

**Availability of data and materials**

The data collected and analyzed in the present study are not publicly available due to ethical restrictions, but are available from the corresponding author upon request.

**Competing interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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**Authors’ contributions**
ILW and LIW conceived and designed the study. SJX and YL performed the experiments. SJX and YL were responsible for collecting data. RH, RJJ and KKZ reviewed and edited the manuscript. ILW and CSH revised the manuscript. All the authors have read and approved the final version of the manuscript.

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