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Improving static balance ability with trainings supported by somatosensory-based feedback system

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Abstract

To support trainings for static balance ability improvement, in this study, we developed a somatosensory-based feedback system (SFS) using Kinect technology. Three training tasks such as knees crouch, rotating upper body and rotating upper body with a ball in hands were designed according to the static balance ability training method. Forty-four participants volunteered to participate in the study. The participants completed these tasks by performing three movements during a six-week period. Feedback, either positive or negative, on the participants' static balance performance was provided by the SFS to adjust their posture and static balance. We tested the effectiveness of the SFS on improving the static balance ability in an experiment. The participants were randomly assigned to a control group (n = 22) and an experimental group (n = 22). The participants in the experimental group completed the training tasks with the support of the SFS, whereas the participants in the control group completed the training tasks without any feedback. A static balance ability pretest was administered before the training and a static balance ability posttest after the training. Differences between two groups on tests' results were compared. In addition, the participants in the experimental group completed intermediate tests (the same test as the pre- and post-test) during the training. Three main findings were obtained. First, there was no difference between the two groups in the static balance ability pretest; however, the experimental group outperformed the control group on the static balance ability posttest. Second, the participants' scores for the single barefoot standing using the dominant leg with eyes opened (SFOE) and single barefoot standing using the dominant leg with eyes closed (SFCE) testing tasks were higher than those in the double barefoot standing with eyes opened (DFOE) and double barefoot standing with eyes closed (DFCE) testing tasks. Third, there were improvements in swing path, swing speed, swing amplitude, and area research variables. According to interviews with the participants, the SFS was useful, as it provided feedback to the static balance performance and they used it to adjust their postures and balance. Based on the results, we suggest applying the SFS to trainings for static balance ability as it can improve the static balance ability.

Keywords: Somatosensory-based feedback system, Static balance ability, Training

Introduction

Balance ability plays an important role in our daily lives because it is needed in many of our activities such as to maintain stable posture, perform physical exercises or properly react to various stimuli (Pollock et al., 2000). Therefore, balance ability received a lot of attention in academia and research. That is, scholars tried their best to explore some innovating ways to train and measure static balance ability of people of different ages.

Due to recent advancements in information technologies, we are able to use different technology-assisted methods for training and measuring static balance ability. Previous studies have used visual feedback provided by information technologies, e.g., game-based visual feedback (Yi et al., 2013), Sensoneck device (Lee et al., 2015), virtual reality or augmented feedback (Anson et al., 2013), Balance Master (Kahraman et al., 2016), Belgium Footscan (Zhang & Shi, 2012), motion tracking systems (Windolf et al., 2008), and other techniques. Balance Master, for example, includes a pressure sensor, a computer and special software to measure balance (Kahraman et al., 2016). The force station can record a pressure signal generated by body sway, which is converted to data and transferred to the computer with the analysis of the center of pressure (COP) data to measure the body balance (Harris et al., 1982). Zhang and Shi (2012) used the Belgium Footscan flat pressure system to measure the static balance of individuals of different ages by the COP trajectory length and envelope area parameters. Three-dimensional motion capturing systems, such as Vicon, collect 3D movement data to analyze the balance level (Windolf et al., 2008). However, there are agreements that equipment for this type of research is expensive and it is difficult to use these methods outside of research labs (In et al., 2016).

Because of the rapid technological development, other computing devices (i.e., cheaper with substantial capacities) are emerging for measuring and training balance ability in a broader population (DiStefano et al., 2009). Thus, these technologies can be used at home or small scale educational institutions. One example is the Kinect for Windows (Guo et al., 2022a, 2022b). This device involves the somatosensory peripheral of the game controller Xbox360; it automatically tracks human movements based on 20 joints and 3D coordinates (Lan et al., 2018; Pfister et al., 2014). Researchers have claimed that the Kinect tool is convenient and cheap (Ed-Doughmi & Ayachi, 2022); it also includes a 3D motion capture system (Chuang et al., 2017; Guo et al., 2022a, 2022b; Köpsel et al., 2016; Lan et al., 2018; Meng & Kong, 2020). This is why Kinect has been applied to measure motor coordination performance (Bacha et al., 2020; Lopes et al., 2022), postural control (Clark et al., 2012; Maudsley-Barton et al., 2020) and rehabilitation training (Chuang et al., 2017; Ning et al., 2022; Zhao et al., 2020). KinectV2 is the latest released and improved tool. Compared with the first version, KinectV2 improved the skeletal tracking stability and accuracy through a higher fidelity in depth (Mortazavi & Nadian-Ghomsheh, 2018). It is able to track 6 complete skeletons and acquire 25 joint coordinates per individual (Parisi, 2020). In addition, the new active infrared is able to identify actions in the dark and reduce the requirements of the operating environment (Su et al., 2020).

Scholars have concluded that the somatosensory device (KinectV2) is both a valid and reliable instrument for assessing different aspects of balance (Clark et al., 2015; Yang et al., 2014). To the best of our knowledge, however, not many researchers have attempted to apply Kinect to train static balance ability or measure it. In this study, we aimed to address this limitation. Informed by related theories and studies, we developed the Kinect-based feedback system for improving static balance ability. We validated the outputs from our system by comparing them with those obtained by other tools, such as the Balance Master. We employed the SFS in our study only after we ensured that the output of the system is reliable and valid. In this study, the SFS was employed to provide feedback, e.g., positive / negative, related to the participants' balance performance. The feedback was then used by the participants to improve the balance performance. We investigated how the system can improve the static balance ability of participants.

Literature review

Balance is defined as the ability to achieve, maintain and restore body posture (Soyuer, 2020). Human's balance ability includes static balance ability and dynamic balance ability. The static balance ability refers to the human body in a certain position to maintain a stable state. The static balance ability training needs more time to keep the same posture. It's more difficult to maintain sustained training. The posture of the body can be maintained based on information received from different sensory systems (i.e., the somatosensory, vestibular and visual) (Gribble & Hertel, 2004). Thus, an individual maintains body posture through integrated visual, vestibular, and somatosensory inputs from throughout the body by continuously stabilizing the position and motion of the body (Lee et al., 2013). For example, the vestibular system enables sensing organs to regulate equilibrium; the somatosensory system enables sensing kinesthesia and proprioception of joints. The visual system enables balance to be maintained by referring to the verticality of the body and head motion (Bronstein, 2016). Thus, it is critical that these systems work in tandem. If any of the systems are not involved in information processing, the balance ability becomes poor (Lee et al., 2013), e.g., balance is more likely to be lost in a situation with closed eyes than in a situation with open eyes (Redfern et al., 2001).

Medical and medical allied disciplines focusing mostly on elderly individuals and individuals with neuromuscular diseases, motor deficits, and other deficits have paid substantial attention to balance ability (Anson et al., 2013; Hoskovcová et al., 2013). However, the balance control ability is also important for healthy individuals (Choi et al., 2010; Lee et al., 2013). Balance ability plays a key role in our lives as it is required in many activities of daily living, such as to maintain stable posture, perform physical exercises and properly react to various stimuli (Pollock et al., 2000). Balance ability is linked to motor and movement skill development (Condon & Cremin, 2014). Balance is required for normal function (Franjoine et al., 2010). Thus, poor balance may affect everyday performance. There is a high probability that poor balance may cause injury risks, which may lead to health problems (Hrysomallis, 2011). Therefore, the development of balance ability in individuals with medical disorders, elderly individuals and healthy individuals is important (DiStefano et al., 2009). Many studies have focused on developing and improving balance ability in recent years. In these studies, various training methods were adopted to improve the balance ability (Choi et al., 2010). Especially, by the age of 23 for women and by the mid-20 s for men, they are fully developed and their athletic abilities gradually reach their highest levels. Without training, athletic ability begins to decline. The study focus on young people' continued training to improve or maintain their balance ability. For example, motor imagery, Swiss ball workouts, visual feedback training, and muscle strength were conducted (Moran & O'Shea, 2019).

Previous studies have paid substantial attention to visual feedback training (Luque-Moreno et al., 2021). These studies have indicated that postural control can be improved if additional sensory information is provided, e.g., visual information. This argument is in line with the sensory weighting hypothesis (Haran & Keshner, 2008; Zijlstra et al., 2010) and motor learning theory (Cano-de-la-Cuerda et al., 2015; Roller et al., 2012); the former explains processes that lead to the improvement of balance ability and the latter describes how specific skills, e.g., balance ability are acquired and retained (Pasma et al., 2012). According to the sensory weighting hypothesis, postural balance can be achieved if the vestibular, visual, and somatosensory systems are integrated (Gaerlan, 2010; Haran et al., 2008). These sensory systems produce posture and balance control related information, which is received by the central nervous system and is subsequently used for the motor outcome (In et al., 2016; Lee et al., 2015). The idea behind reweighting is that when the central nervous system is using this input in the production of postural behaviors, more reliable information is weighted more strongly than less reliable information (Pasma et al., 2012). Because the visual system is used as the primary sensory system for maintaining upright postural control, providing individuals with visual feedback may substantially enhance their balance performance (Gaerlan, 2010). This visual feedback may be used as a substitute or an augmentation in sensorimotor integration of the central nervous system (Zijlstra et al., 2010). When individuals are provided with visual feedback on their posture, they can check it in real time, identify postural changes and use this information to control and maintain their posture (dos Anjos et al., 2016). Motor learning theory describes and explains internal processes that are associated with practice and experience to acquire specific skills, e.g., balance ability, and produce relatively permanent changes in how motor activities are elicited (Cano-de-la-Cuerda et al., 2015). Motor learning results in changes in the central nervous system of an individual that enable retaining or storing learned information in the brain and is referred to as memory (Roller et al., 2012). For example, after practice or experience to control posture and balance, the motor recall and ability to control posture and balance can be enhanced (Gaerlan, 2010).

Method

The ethical issues relevant to the research and the restrictions under which the data were collected and reported were considered in the present research under ethic code number 0003. The study followed the Institutional Ethical Guidelines and the investigation was carried out following the rules of the Declaration of Helsinki of 1975.

Subjects

Forty-four graduate students volunteered to participate in our study. Their demographic information is presented in Table 1. Half of the participants were male and half of the participants were female, and they were 22–24 years old. The participants majored in social science/science; none of the participants had a history of mobility and balance impairments or neural and structural impairments or a clinical disability. They were randomly divided into two groups: an experimental group (n = 22) and a control group

Table 1 Participant demographic profiles ($n = 44$)

Demographic characteristics	Control group ($n = 22$)		Experimental group ($n = 22$)	
	Frequency	Percentage	Frequency	Percentage
Gender				
Female	11	50	11	50
Male	11	50	11	50
Age (years old)				
21	1	4.5	0	0
22	4	18.2	5	22.7
23	5	22.7	5	22.7
24	9	40.9	9	40.9
25	1	4.5	2	9.1
26	2	9.1	1	4.5
Department				
Social Science	12	54.5	16	72.7
Science	10	45.5	6	27.3
Study for the degree				
Graduate	22	100	22	100

(n = 22). The participants in the two groups received the same training for the same duration, and the only difference between the two groups was the feedback on the participants' static balance performance during the training; the feedback (either positive or negative) was provided to the experimental participants, whereas the control participants did not receive any feedback.

The experimental procedure

Figure 1 shows the research procedure for this study. First, we collected the participants' demographic information. Written informed consent was obtained from the students at the same time. Second, we introduced our training to the participants. Third, a pretest (static balance ability) was administered to the participants. Fourth, we divided the participants into two groups (i.e., control and experimental), and they participated in our training. The training lasted for approximately 25 min, three times per week for six weeks. The control participants did not receive feedback, whereas the experimental participants received feedback (positive or negative) from the system on their static balance performance during the training. In addition, after each training, the static balance ability intermediate test was administered to the experimental participants. Finally, we administered a posttest (static balance ability) and conducted one-on-one semi structured interviews with the participants.

Our training and feedback from Kinect

Three training tasks as knees crouch, rotating upper body and rotating upper body with a ball in hands were selected from the static balance ability training method proposed in Borghuis et al., (2008). Table 2 provides detailed information regarding our training, and Fig. 2 demonstrates the three main movements.

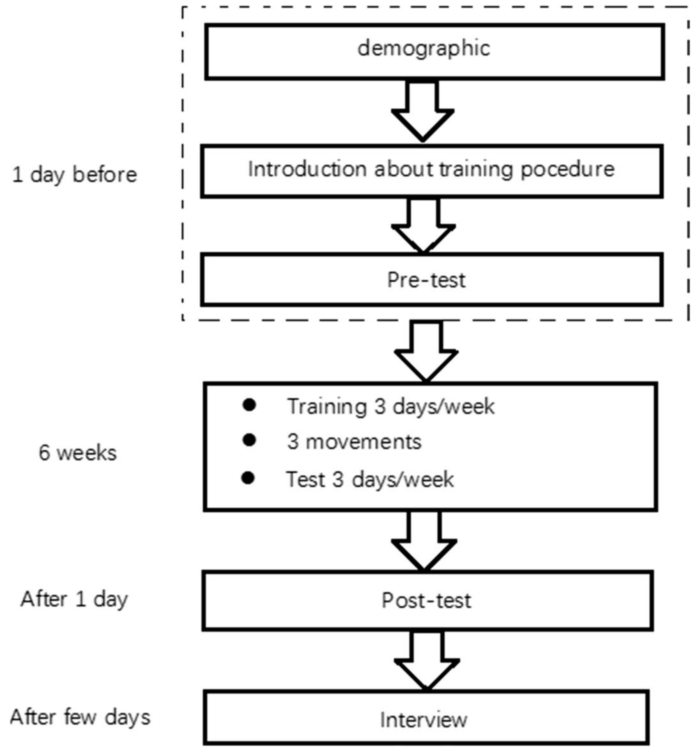

Fig. 1 Research procedure

Table 2 Details of our training

Week	Frequency	Movement 1	Movement 2	Movement 3
1	5	Hold a squat position for 10 s	Fix in rotating position for 5 s	Fix in rotating position for 5 s
2	6	Hold a squat position for 12 s	Fix in rotating position for 6 s	Fix in rotating position for 6 s
3	6	Hold a squat position for 12 s	Fix in rotating position for 6 s	Fix in rotating position for 6 s
4	7	Hold a squat position for 12 s	Fix in rotating position for 6 s	Fix in rotating position for 6 s
5	7	Hold a squat position for 12 s	Fix in rotating position for 6 s	Fix in rotating position for 6 s
6	6	Hold a squat position for 10 s	Fix in rotating position for 6 s	Fix in rotating position for 6 s

(1) Knees crouch. This movement is a squat movement. The participant must stand with his/her feet placed slightly wider than his/her hips. The toes must be pointed slightly outward. The arms are placed on the thighs, and the back is straight. The participant squats down until the hip joint reaches a level slightly higher than the knees. He/she looks straight ahead when squatting. The participant remains in a squat position for approximately 10 s. He/she subsequently stands up. Knee crouch enables training of the rectus abdominis, tensor fascia lata, tectus femoris and gluteus maximus.

(2) Rotating upper body with dumbbells in hands. The participant must sit on a Swiss ball. His/her arms are lifted to the sides at shoulder height. He/she holds a dumbbell in each hand. The participant must rotate the upper body to the left and remain in this position for approximately 5 s. He/she subsequently rotates to the right and

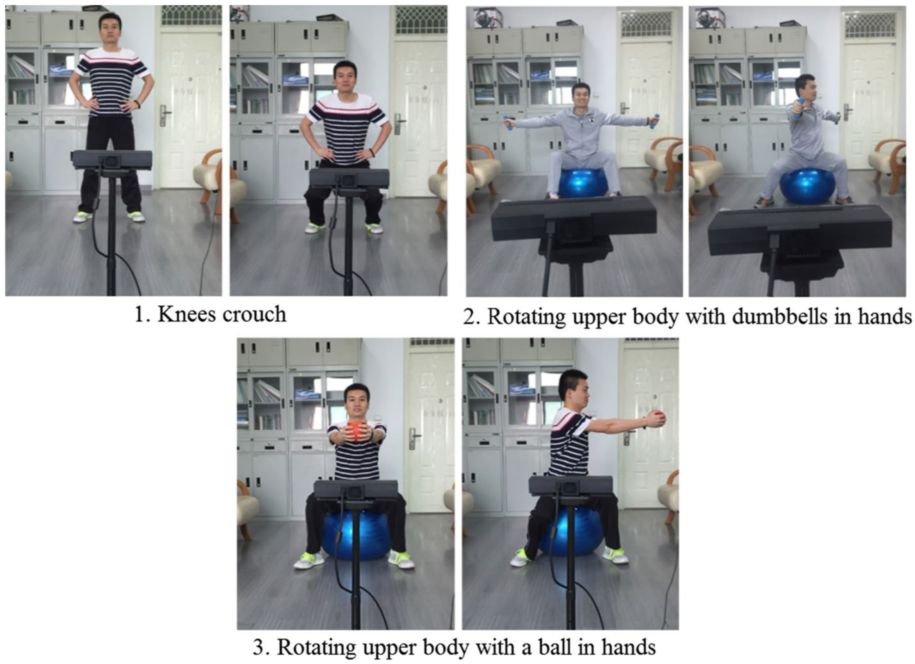

Fig. 2 Three main movements

remains in this position for the same amount of time. Finally, he/she rotates to the initial position. Rotating the upper body with dumbbells in the hands trains the deltoideus and obliquus externus muscles.

(3) Rotating upper body with a ball in hands. The participant must sit on a Swiss ball. His/her arms are lifted in front at shoulder height. He/she holds a small ball in the hands. He/she must rotate the upper body to the left and remain in this position for approximately 5 s. He/she subsequently rotates to the right and again remains in this position for the same amount of time. Finally, he/she must rotate back to the initial position. Rotating the upper body with a ball in the hands trains the biceps brachii and obliquus externus muscles.

The Somatosensory-Based Feedback System (SFS) was developed by MLC lab. The KinectV2 tool was employed for SFS to capture the participants' movements and provide them with feedback regarding how well they performed the movements. KinectV2 records about 30 frames of center of gravity data per second, while 20 s records about 6000 frames of center of gravity data. It describes the swing process of the center of gravity and reflects the swing process of the human body in maintaining a static position. Compared to Footscan Balance7.7, made by RSscan international company in Belgium, the root mean square error of center of gravity deviation is less than 7 mm. There is consistent motion tracking accuracy with the Footscan Balance7.7.

The SFS used standard movements stored in the system to compare with the movements of the participants; the system subsequently provided feedback based on the difference—False (incorrect) or True (correct). The participants received feedback immediately after they completed a movement. For example, Fig. 3a shows that the participant has the correct position (the value is True) before the Knee crouch movement.

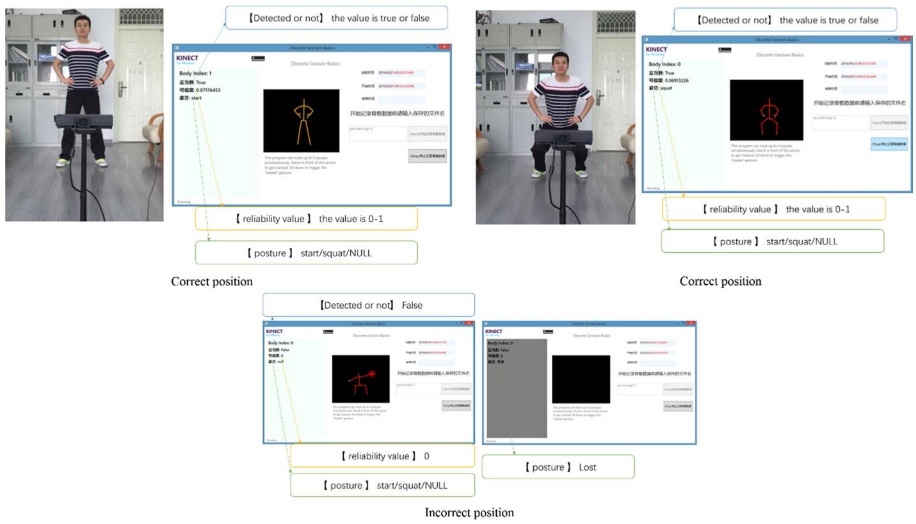

Fig. 3 Feedback mechanism

In the squat position (Fig. 3b), the participant also has the correct position (the value is True). However, the value is False in Fig. 3c, which indicates that the participant's position is incorrect or the participant is out of the Kinect visibility. This feedback can help a participant to correct his/her position.

Instruments

The study used both quantitative and qualitative measures for balance assessment. The reason is because the data from different sources can support each other to make conclusion more robust.

Static balance ability tests: We administered the following tests in our study: (a) the pretest (static balance ability) measured the balance ability prior to the training; (b) the intermediate tests (static balance ability) measured the balance ability during the training; and (c) the posttest (static balance ability) measured the balance ability after the training. We designed the test following the recommendations of earlier previous studies (Clark et al., 2010, 2015). The following four tasks were assessed in the test:

- Double barefoot standing with eyes opened (DFOE): participants stand upright for 20 secs looking ahead to the mark points, their feet are slightly moved apart, and their hands are slightly clenched.
- Double barefoot standing with eyes closed (DFCE): participants also stand upright for 20 secs, their feet are slightly moved apart, their hands are slightly clenched, and their eyes are closed.
- Single barefoot standing using the dominant leg with eyes opened (SFOE): participants stand upright on the dominant leg for 10 secs looking ahead to the mark points and their hands are slightly clenched.
- Single barefoot standing using the dominant leg with eyes closed (SFCE): participants stand upright on the dominant leg for 10 secs, their hands are slightly clenched and their eyes are closed.

Static balance ability is the capacity to maintain the body posture and control the body's center of gravity (the center of gravity is defined here as the point at which the entire mass or weight of the body may be considered to be concentrated (Mohammed, 2012), particularly in a limited support surface (Mancini & Horak, 2010). The center of gravity is constantly shaking in the process of maintaining a stable posture. The static balance is quantified by the displacements of the center of gravity. We measured the participants' balance ability with respect to the following four variables:

(1) The mean swing path (MSP) of the center of gravity is the average value of the distance between the current moment and the previous movement. A body can swing in the medial–lateral (ML), anterior–posterior (AP) and superior-inferior (SI) directions. A smaller swinging path value is associated with better static balance.
(2) The mean swing amplitude (MSA) of the center of gravity is the difference between the mean value of the position of the center of gravity and the average of the absolute value of the body's position with respect to the center of gravity at all times.
(3) The mean swing speed (MSS) of the center of gravity is the amplitude of the average swing of the body's center of gravity in one-time unit.
(4) The mean area (MA) is the average number of different data, and this average can reflect the degree of dispersion of a set of data.

We measured the balance ability as the difference between the center of gravity and deviations from the center of gravity. The instrument scale method was employed and was used to avoid the interference of subjective factors and reduce the error of testing results.

We employed the KinectV2 during our training and the tests. The KinectV2 recorded information regarding 25 joint points of the participants during our training and tests. Visual Builder Gesture (VGB), a tool of Microsoft Kinect for Windows SDK 2.0, generated the set of standard movements. The Kinect Studio captured and recorded all data. We compared the data from the participants' movements and the set of standard movements to provide feedback during the training and information regarding movement correctness. Many educational researchers have successfully employed the KinectV2 and Visual Builder Gesture in their studies (Austinat & Gieselmann, 2013; Kang, et al., 2015; Köpsel et al., 2016; Mgbemena, et al., 2016). Previous studies have demonstrated that the KinectV2 and Visual Builder Gesture are reliable tools for educational research.

The sampling frequency is approximately 30 Hz. The center of gravity is calculated using the "coefficient method" proposed by Hong and Ye (1982), and the center of gravity position is instant feedback. Combined with the Kinect equipment and the experimental environment, this study employs the coefficients that are commonly used by German data, and the position of the body's center of gravity is calculated according to the following formula:

$$\mathrm{G}_{\mathrm{pos}} = \sum K_i * J_i \tag{1}$$

where *Gpos* represents the position coordinates of the gravity center; J_i represents the joints' position coordinates; and K_i represents the coefficients in the formula.

The Footscan Balance 7.7 flat foot pressure test system (RScan, Belgium) is used as a control test (hereinafter referred to as Footscan), which consists of a 50 cm * 40 cm pressure distribution test plate and a balanced set of acquisition and analysis software. It obtains precise plantar pressure measurements with 4096 sensors at a scanning rate of up to 300 Hz. To keep in line with the Kinect, it is set to 30 Hz.

Static balance is the capacity to maintain the body posture and control the body's center of gravity, particularly in a limited support surface (Mancini & Horak, 2010). The center of gravity is constantly shaking in the process of maintaining stable posture. The static balance is quantified by the displacements of the center of gravity (COG). The swinging length (SL) in the medial–lateral (ML), anterior- posterior (AP) and superior-inferior (SI) directions, the swinging velocity (SV) in the ML, AP and SI directions and the envelope area (EA) in the horizontal plane of the COG were calculated as a measuring scale of the static balance referring Footscan Balance system (Hoskovcová et al., 2013).

The swinging length represents the stability and modification of body swaying. A smaller swinging length is associated with better static balance. The SLx is the total length of body swaying in the medial–lateral direction. The SLy is the total length of body swaying in the anterior–posterior direction. The SLz is the total length of body swaying in the superior-inferior direction. The swinging length of body swaying is calculated according to the following formulas:

$$\mathrm{SL_x} = \sum_{t=1}^{n-1} |X_t - X_{t+1}| \tag{2}$$

$$\mathrm{SL_y} = \sum_{t=1}^{n-1} |Y_t - Y_{t+1}| \tag{3}$$

$$\mathrm{SL}_z = \sum |Z_t - Z_{t+1}| \tag{4}$$

where SL_x, SL_y and SL_z are swinging lengths of the COG in the ML, AP and SI directions; X_t and X_{t+1} are the ML coordinates of the COG in the frame and next frame. Y_t and Y_{t+1} are the AP coordinates of the COG in the frame and next frame.

The swinging velocity is the swinging length of body swaying in unit time. The swinging velocity represents the speed of body swaying. The swinging velocity of body swaying is calculated according to the following formulas:

$$SV_x = SL_x / T \tag{5}$$

$$SV_y = SL_y / T \tag{6}$$

$$SV_\mathrm{Z} = SL_\mathrm{Z} / T \tag{7}$$

where SV_x, SV_y and $\mathrm{SV_z}$ are the swinging velocities of the COG in the ML, AP and SI directions; T is the testing time of each trial.

The envelope area is the shape and area size of body swaying in the horizontal direction. A smaller envelope area is associated with better static balance. The envelope area of the 95% confidence ellipse is calculated by the convhull function in Matlab2013. There is no obvious swinging posture in the four tests of the SI direction; thus, SLz and SVz are ignored.

Overall, we found that the measuring scale of static balance with KinectV2 had excellent retest reliability and good concurrent validity when referred with the Balance Master. Therefore, we conclude that the static balance measurement with KinectV2 is reliable and valid. Thus, we employed it for our study.

We conducted in-depth, one-on-one semi-structured interviews at the end of the training with all experimental participants. The interviews protocol was developed by two experienced researchers following general recommendations of Creswell (2014). The interviews protocol contained open-ended questions in which the experimental participants were asked about their experience with using our Kinect-based feedback system, opinions regarding the development of their balance ability, and perceptions regarding our system. Some items of the interview protocol were as follows: "Please describe in details your experience to use SFS." "Do you think your balance ability improved in this study?" "Was SFS was useful for your static balance performance?" The interviews protocol was reviewed by an expert in computer science and educational technology field, and it was modified based on provided comments and suggestions. Each interview took approximately 20 min.

We conducted analysis of variance (ANOVA) to measure the difference in the pretest and posttest scores between the participants in the two groups. We also employed t-tests (paired sample) to evaluate the differences between test scores before and after our training.

Results and discussion

The results of the tests from the two groups with respect to the four tasks are shown in Tables 3 and 4. The analysis of variance test results indicated there were no differences in the scores for the pretest with respect to the four testing tasks. However, the scores

Table 3 Results of the paired t-test: the difference between pre-training and post-training of the control ($n=22$) and experimental ($n=22$) group on every testing measurement

Testing measurement*	Pre-training		Post-training		*F*	*p*
	M	SD	M	SD		
Experiment group						
MSP	156.52	8.20	114.92	10.03	0.003	0.00
MSA	33.06	7.90	22.61	1.87	0.08	0.00
MSS	23.91	10.54	21.75	8.45	0.04	0.00
MA	162.44	29.43	117.41	20.38	0.08	0.00
Control group						
MSP	159.73	9.01	126.63	1.13	12.45	0.00
MSA	34.71	10.34	30.34	11.45	58.00	0.00
MSS	24.15	15.57	21.68	8.54	10.56	0.01
MA	156.13	30.67	134.33	26.04	27.72	0.00

*Every measurement is the summary of the measurement in the four tasks: DFOE, DECE, SFOE and SFCE

Table 4 Results of the independent sample t-test: the difference between the control ($n=22$) and experimental ($n=22$) group in pre-training and post training on every testing measurement

Testing measurement*	Experiment group		Control group		*F*	*p*
	M	SD	M	SD		
Pre-training						
MSP	156.52	8.20	159.73	9.01	0.003	0.45
MSA	33.06	7.90	34.71	10.34	0.08	0.56
MSS	23.91	10.54	24.15	15.57	0.04	0.12
MA	162.44	29.43	156.13	30.67	0.08	0.60
Post-training						
MSP	114.92	10.03	126.63	11.45	12.45	0.01
MSA	22.61	1.87	30.34	1.13	58.00	0.01
MSS	21.75	8.45	21.68	8.54	10.56	0.12
MA	117.41	20.38	134.33	26.04	27.72	0.00

*Every measurement is the summary of the measurement in the four tasks: DFOE, DECE, SFOE and SFCE

of the experimental participants for the DFOE ($F=12.45$, $p<0.05$), DFCE ($F=58.00$, $p<0.05$), SFOE ($F=10.56$, $p<0.05$), and SFCE ($F=27.72$, $p<0.05$) tasks were higher than those of their counterparts. Our findings suggest that the study treatment was beneficial for improving the static balance ability.

We subsequently compared the participants' scores for the four testing tasks with respect to the four variables of balance ability. Table 5 and Fig. 4 show the results. According to the table, there are statistically significant differences in the results obtained before and after our training for test 1 ($t=2.474$, $p<0.05$), test 2 ($t=3.171$, $p<0.05$), and test 4 ($t=2.930$, $p<0.05$) of the swing path. The results also show significant differences for test 2 ($t=3.171$, $p<0.05$), test 3 ($t=2.194$, $p<0.05$), and test 4 ($t=2.907$, $p<0.05$) of the swing speed. Moreover, there is a significant difference between the results for test 4 ($t=4.489$, $p<0.05$) of the swing amplitude and test 4 ($t=4.686$, $p<0.05$) of the area.

The different colored lines in Fig. 4 represent different testing tasks. According to the figure, the scores of the participants change, i.e., decrease, over time. The improvement in the balance ability is substantially better for the SFOE and SFCE testing tasks. There is also an improvement in the balance ability for the DFOE and DFCE testing tasks; however, it is not as good as for the first two testing tasks. This finding suggests that our feedback system was useful to improve the performance of the participants. Trend lines in the figure also confirm our findings and show that the results of the participants' performance improve.

In the interviews, most of the experimental participants indicated that their balance ability improved. They stated that the feedback mechanism (see Fig. 3) was very helpful; the reason is that the system provided feedback so that the participants could adjust their movements and postures accordingly. This finding is in line with those obtained in other studies. Researchers have claimed that visual feedback is helpful for learning accurate motions through the adjustment of errors observed during task performance (Horak 2006; In et al., 2016; Lee et al., 2015). Our results are in line with the sensory weighting hypothesis and motor learning theory. According to the sensory weighting hypothesis, providing additional sensory information, such as visual feedback, improves the static balance ability (Haran et al., 2008; Pasma et al., 2012; Zijlstra et al., 2010), and motor

Table 5 Results of the paired sample t-test: four measurements under the four testing tasks for experimental participants ($n = 22$)

Task	Swing path MSP				Swing speed MSS				Swing amplitude MSA				Area MA			
	M	**SD**	***t***	***p***	**M**	**SD**	***t***	***p***	**M**	**SD**	***t***	***p***	**M**	**SD**	***t***	***p***
DFOE																
Pre-training	138.9	54.41	2.474	0.03	7.12	2.24	2.16	0.79	15.03	1.87	0.09	0.12	22.87	6.85	0.08	0.03
Post-training	109.65	40.12			5.73	1.76			11.32	1.22			18.21	5.67		
DFCE																
Pre-training	179.67	53.33	3.171	0.05	9.98	6.85	3.171	0.08	25.7	3.49	1.09	0.2	23.17	15.48	1.484	0.14
Post-training	110.49	33.71			5.99	1.68			19.04	2.25			20.33	8.72		
SFOE																
Pre-training	134.07	27.32	1.28	0.04	37.13	53.29	2.26	0.57	37.35	2.78	0.12	0.02	90.84	30.9	0.21	0.03
Post-training	107.34	31.92			35.76	11.31			25.82	2.41			85.7	21.12		
SFCE																
Pre-training	173.42	60.01	2.93	0.00	41.41	11.76	2.82	0.29	54.15	5.36	3.49	0.00	512.86	125.43	3.96	0.00
Post-training	132.23	55.12			39.52	8.89			34.24	3.7			345.4	113.32		

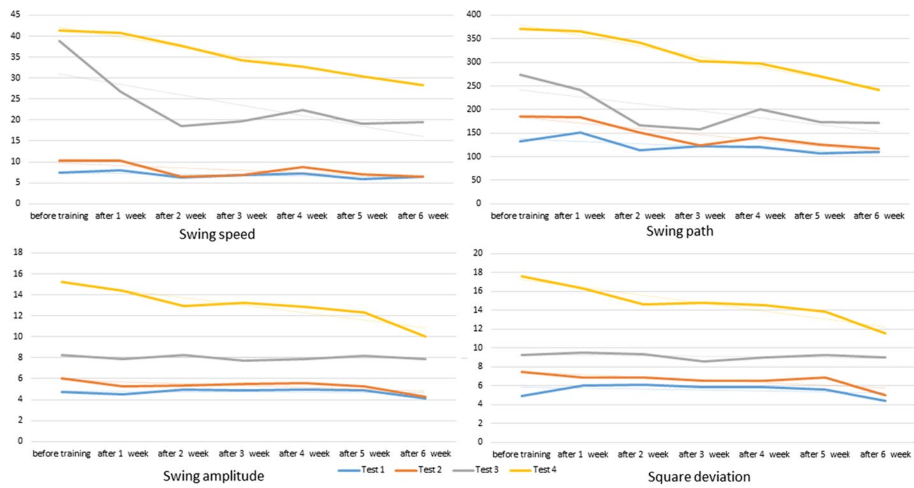

Fig. 4 Results of the tests for different testing tasks before and after our training

learning theory suggests that the balance ability can be acquired and retained after practice or exercise (Cano-de-la-Cuerda et al., 2015; Roller et al., 2012). This hypothesis is not only relevant for cases in which the surface or standing conditions are stable. Horak (2006) claimed that dependency on visual input increased for postural control as the surface or standing conditions became unstable. Thus, for example, for improving balance ability when an individual stands on one leg, visual feedback can be more beneficial. This is the reason why the SFOE and SFCE testing task results were better than the DFOE and DFCE testing task results.

Conclusion

In this study, we obtained three main findings. First, there was no difference between the two groups in the static balance ability pretest; however, the participants in the experimental group outperformed their counterparts in the static balance ability posttest. Second, the participants exhibited better progress in terms of the balance ability in conditions where their eyes were closed and/or when they were standing on the dominant leg compared with when their eyes were open and/or when they were standing on both legs. Third, the Swing path, Swing speed, Swing amplitude, and Area of the participants also improved after the training. Based on these results, it is suggested that the system was beneficial to improve the participants' static balance ability. Furthermore, based on the results, it is suggested that the system may be employed: (1) the system is reliable and valid for balance ability measurement; (2) the system facilitates static balance ability improvement; and (3) the system is affordable in terms of setting it up in locations outside of research labs and price.

Several scholars have employed visual feedback (Anson et al., 2013; In et al., 2016; Kahraman et al., 2016; Lee et al., 2015; Windolf et al., 2008; Yi et al., 2013; Zhang & Shi, 2012), and some of them have used the Kinect tool (Clark et al., 2012, 2015; Pfister et al., 2014; Yang et al., 2014). However, not many studies have applied Kinect to train and measure balance ability. Our main contribution is that we applied the Kinect tool to train and measure the static balance ability, and we validated our measurement approach based on the results obtained from the Balance Master tool.

Our findings have significant implications for teaching and learning in contexts related to physical education and other domains when static balance ability and related movements are considered. Although there are many applications of our approach to teaching and learning in different contexts, we only provide a few examples. One should note that regardless of the specific context that our approach is applied, standard movements and postures related to this specific context should be recorded and stored in the somatosensory-based feedback system. The system will subsequently compare the stored data with the movements and postures of a student and provide positive or negative feedback based on the difference. Our approach can be applied in art education, language learning, science, technology, engineering and math (STEM) education. Ballet is one subject of art education in which it is important to learn correct individual movements and postures. For this purpose, Classical Ballet Technique is commonly used; it is a manual that contains step-by-step guidelines to different individual movements and postures for a student to follow (Warren, 1989). During and after the learning process, the instructor needs to provide feedback to a student regarding the student's performance of these movements and postures. It is a time consuming process for the instructor to check how well a student learns and performs, and it may overwhelm the instructor when too many students require observation. If we store standard movements and postures from the manual, a student can learn movements and postures independently without the involvement of the instructor. The system will provide instant and reliable feedback to a student based on stored data. Second or foreign language learning is another field in which our approach may be applicable. Students can learn new vocabulary and test their retention and understanding of newly learned words by interacting with our system through their body movements, i.e., kinesthetic interaction. This learning method is based on the total physical response (TPR), i.e., the coordination of language and physical movement (Hwang et al., 2014). For example, students need to make movements or gestures related to words, and the system will compare them with those stored in the system database to provide positive or negative feedback. In STEM education, students can learn concepts such as symmetry, sequence and arrangement, and our approach can assist them in the learning process. For example, when students need to assemble an object (e.g., an engine for engineering class, a building model for architectural class, or a geometric figure for geometry class) using sample parts, the system can capture student movements to determine their correctness in terms of the sequence and arrangement, as well as the symmetry of an object's parts assembling. The system will notify students whether or not a certain movement was correct. Finally, there are other applications of our approach outside of learning and teaching contexts. Finn and Frone (2004) suggested that academic dishonesty is a significant problem among students. Our approach can be used to address this issue in the following way. The system can sense changes in the posture of a student during verbal communication and provide feedback in case a possible intentional deceit was identified. A student can be judged against the truthfulness based on changes in posture while engaged in verbal communication. For example, Rotenberg and Sullivan (2003) conducted a study to determine how body movement cues may be used to infer deception and found that children who displayed active rather than non-active body movement exhibited more lying. Rotenberg and Sullivan (2003) suggested that their movements were associated with anxiety.

Limitations and future research direction

We acknowledge several limitations of this study. First, we focused on the balance ability of the participants before and after the training to evaluate the effectiveness of the system. Thus, the data and its analysis are not comprehensive, and there is a need to collect additional data and analyze it in future studies. Second, only the static balance ability was considered in this study. We should also consider the dynamic balance ability in the training process in future research; in this case, we will perform a more comprehensive analysis related to different scenarios and balance abilities. Next, the involved sample was small and had similar demographic profiles. Furthermore, the duration of the training was short. Therefore, the sample size must be increased, the demographics of participants diversified, and the training extended in future studies. In addition, we will focus on other modalities in the future to provide feedback. For example, we will develop a verbal feedback system using advanced information technologies. We assume that verbal feedback received via an auditory information processing channel can be useful in improving the balance ability in individuals with preferences in verbal learning style.

Abbreviations

SFS Somatosensory-based feedback system
SFOE Single barefoot standing using the dominant leg with eyes opened
SFCE Single barefoot standing using the dominant leg with eyes closed
DFOE Double barefoot standing with eyes opened
DFCE Double barefoot standing with eyes closed
COP Center of pressure
MSP Mean swing path
ML Medial–lateral
AP Anterior–posterior
SI Superior-inferior
MSA Mean swing amplitude
MSS Mean swing speed
MA Mean area
VGB Visual Builder Gesture
SL Swinging length
SV Swinging velocity
EA Envelope area
COG Center of gravity
ANOVA Analysis of variance

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Author contributions

Conceptualization, WW1 and WW2; methodology, WW1, WW2 and RS; software, WW1 and WW2; validation, WW1, WW2 and RS; formal analysis, WW1, WW2 and RS; investigation, WW1 and WW2; writing—original draft preparation, WW1 and WW2; writing—review and editing, RS; supervision, WW2. All authors read and approved the final manuscript.

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Availability of data and materials

The dataset will be provided on request after we finish this project.

Declarations

Competing interests

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