Feasibility of Using Tetrax Biofeedback Video Games for Balance Training in Patients With Chronic Hemiplegic Stroke

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Abstract

Background: Decreased weight bearing on the affected lower limb and poor weight shifting are common after a stroke occurs. The Tetrax biofeedback system is a center-of-pressure controlled video game system designed for patients with balance deficits. Although it is a commercial product, information about its clinical use for patients affected by stroke is limited.

Objective: To investigate the feasibility and potential efficacy of the Tetrax biofeedback system for balance training in patients with chronic stroke.

Design: Feasibility study.

Setting: Rehabilitation department of a medical center.

Participants: Participants who had sustained a hemiplegic stroke at least 6 months prior to enrollment but were still able to stand independently for more than 5 minutes.

Methods: Participants were randomly assigned to an intervention group (IG) or control group (CG). All participants received conventional rehabilitation training. The IG also received 20 minutes of exposure to Tetrax biofeedback games controlled by change in center of pressure 3 times a week for 6 weeks.

Main Outcome Measurements: The primary outcome was feasibility, addressed by adherence, safety, and satisfaction. The secondary outcome was efficacy, which was evaluated by the subtests of physiological profile assessment, posturography, Timed Up and Go, and Forward Reach tests. We used percentage change (post-training score – pretraining score/pretraining score) to quantify the intervention effects. Mann-Whitney U tests were used to analyze differences in percentage of change between groups.

Results: A total of 14 participants were assigned to the IG, and 13 were assigned to the CG; 12 participants in the IG and 11 in the CG completed the study. In the IG group, those who completed the 6-week intervention attended 89.5% of planned sessions. No major adverse events or falls occurred within the intervention sessions. With use of 5-point Likert scales, participants rated their enjoyment of Tetrax games as 4.33/5.0, their motivation as 4.17/5.03, and perceived helpfulness as 4.25/5.0. The IG demonstrated a significantly greater improvement in reaction time ($P = .002$), proprioception ($P < .001$), symmetric weight bearing ($P = .027$), Timed Up and Go ($P < .001$), and Forward Reach ($P < .001$) compared with the CG.

Conclusions: Using Tetrax biofeedback video games for balance training is a feasible adjunctive program that may augment conventional therapy in persons affected by chronic hemiplegic stroke.

Introduction

Balance deficits are frequently reported in stroke survivors, with 83% having impaired balance after an acute stroke [1]. The reduced ability to control balance has been associated with ambulatory dysfunction and an increased risk of falls [2]. Therefore, one of the major components of rehabilitative intervention after a stroke occurs is to improve balance control.
bearing were noted [8]. However, patients might easily lose interest in performing stereotyped, repetitive, weight-shifting tasks. Lack of interest impairs the effectiveness of the therapeutic exercise. Enriched virtual environments could optimize motor learning by manipulating practice conditions that engage motivational, cognitive, motor control, and sensory feedback—based learning mechanisms [9]. Some video games, which are classified as nonimmersive virtual reality systems, are designed with the relevant concepts of neuroplasticity [10]. Coupling of biofeedback exercise directly to video games has been developed and has received a high degree of interest [11]. The use of center of pressure (COP)-controlled, game-based exercise regimes has been reported to improve subjects’ dynamic balance control [11-16]. The majority of such studies rely on off-the-shelf systems with commercial software designed for entertainment, not specifically for rehabilitation purposes. Such programs may be too challenging or inappropriate for persons with balance deficits. We previously demonstrated that the commercial exergaming system, Nintendo Wii Fit, is beneficial for balance function in persons with chronic stroke [16]. However, we also found that patients with moderate spasticity or slow movement usually struggled with playing commercial games and felt frustrated. In addition, the difficulty levels of commercial games are usually not adjustable.

Commercial systems developed specifically for therapeutic training are rare. The Tetrax biofeedback system [17] is a COP-controlled, video game–based exercise system designed for patients with either orthopedic or neurologic problems. Although it is a commercial product, limited information about the feasibility of clinical use for patients with balance deficits, such as stroke, is available. Safety is the primary concern because there is high risk of falling or musculoskeletal injury for hemiplegic patients performing weight-shifting movements. It is also not known if patients would accept and be satisfied using such exergaming balance training. In addition, the potential beneficial effects of Tetrax games training are currently unknown. Therefore, the objectives of this study were to examine the feasibility and potential efficacy of the Tetrax biofeedback system for balance training in patients with chronic hemiplegic stroke. It was hypothesized that using Tetrax biofeedback games for balance training would be feasible and clinically beneficial for patients with chronic hemiplegic stroke.

**Methods**

**Subjects**

The Ethics Research Committee of the study hospital approved the study. All participants provided their written informed consent prior to participation in the study. This study was conducted in the department of rehabilitation of a tertiary care hospital.

Patients were recruited for the study if they had sustained a hemiplegic stroke at least 6 months prior to enrollment, were older than 18 years, were able to understand verbal instructions and learn, had adequate visual acuity (appropriate correction was allowed), and had impaired balance (Berg balance test score <56) but had the ability to stand independently (without assistance from any device) for more than 5 minutes. Patients with bilateral hemispheric or cerebellar lesions, receptive aphasia, severe visual field deficits or hemineglect, or any condition that prevented them from completing the program, such as transportation issues or medical problems, were excluded from the study.

Participants were randomly allocated to either the intervention group (IG) or control group (CG) at a 1:1 ratio by using a computer-generated randomization schedule.

**Procedures**

All participants received conventional outpatient rehabilitation therapy (which accounted for an average of 50 minutes of physiotherapy and an additional 50 minutes of occupational therapy per day), 3 days a week, in an outpatient setting.

The IG received additional Tetrax biofeedback balance training 3 days per week (20 minutes per day) for 6 weeks in the same outpatient setting. The Tetrax system was equipped with 4 independent force plates under the toes and heels (Figure 1). The foot pressure was acquired via each force plate. An interface box captured the data from the force plates for display on a personal computer, which contained the Tetrax biofeedback games software. The video games were controlled via the change in the player’s COP.

The Tetrax biofeedback exercise system included 11 games. These games were designed to help patients improve their balance by using various software challenges, and each was created to focus on a different aspect of balance control. Eight games were chosen based on common balance deficits after a stroke. The therapeutic goals included the achievement of even weight distribution and improvement in right-left and front-back weight transfer. The following 8 games were chosen to improve balance (Figure 2):

1. Catch: Catch one ball by moving the other ball. The movable ball is moved with changing pressure of the patient’s feet.
2. Skyclub: Move the baseball glove by using right-left movement of the patient’s feet to catch the baseballs.
3. Tag: Move the soccer player by using front-back movement of the patient’s feet to avoid the soccer balls.
4. Gotcha: Move the bowling pins by using right-left movement of the patient’s feet to avoid the bowling balls.
5. Speedball: Move the basketball hoop by using front-back movement of the patient’s feet to catch the basketballs.
6. Immobilizer: Keep the top of each of the columns within the set section. The columns change with differing pressure of the 4 foot parts on the plates.
7. Target: Move a red ball by changing pressure of the patient’s feet to catch targets in different directions.
8. Freeze: Keep the ball inside the circle. The ball was moved by differing pressures of the patient’s feet and kept in position when the patient remained steady, even when the ball was invisible.

The Skyball and Gotcha games emphasized left-right weight shifting; Tag and Speedball, anterior-posterior weight shifting; Immobilizer, static symmetric weight bearing; and Freeze, full weight bearing of a limb. The therapeutic challenge level was adjusted by target size, number of targets appearing on the screen at the same time, speed of target movement, and range of percentage of the participant’s weight that must be placed to move the virtual objects. At the end of each game, the final score and percentage of corrected hits on the left/right side are shown on the screen to give objective feedback about the participant’s performance. The supervising therapist chose 3-5 games for each intervention session and set the challenge level. The game selection and challenge progression were individualized according to the ability and needs of each participant. For example, the Skyball and Gotcha games would be selected for patients with a left-right weight-shifting problem, whereas Tag and Speedball games would be selected for patients with an anterior-posterior weight-shifting problem.

Outcome Measures

The feasibility of using the Tetrax biofeedback system for balance training in patients with chronic stroke was the primary outcome of interest, specifically focusing on adherence, safety, and satisfaction. Adherence was represented by session attendance. Safety was assessed by recording adverse events, including falls both within the treatment sessions and during the study period. Satisfaction was evaluated at the end of the 6-week intervention. Participants used 5-point Likert scales rating enjoyment, motivation, and perceived helpfulness of the Tetrax games from “strongly disagree” (1) to “strongly agree” (5). We also asked participants to compare the enjoyment and helpfulness of the Tetrax biofeedback games and conventional rehabilitation training. Participants used “yes/no” responses regarding continued use of the game and whether they would recommend that other patients receive the games training.

The possible efficacy of Tetrax games was the secondary outcome of interest and was assessed by tests involving both body function and activity domains. The body functions were assessed using subtests of physiologic profile assessments and posturography. Balance activities were assessed by Timed Up and Go (TUAG) and Forward Reach (FR) tests. Participants were assessed before and after the 6-week intervention.

Physiologic Profile Assessment Subtests

The physiologic profile assessment is a validated battery of sensorimotor measurements used to identify subjects at risk of falling [18]. Four subtests were used in this study, including (1) proprioception (in degrees) of knee joints using a lower limb matching task with an inscribed vertical protractor placed between the seated participant’s legs; (2) maximal isometric quadriceps strength (in kilograms) measured while sitting using a spring gauge; (3) simple reaction time (in milliseconds) using a light stimulus and a finger press on a switch as the response; and (4) postural sway area (in centimeters squared) using a sway meter to measure body displacement at the waist level with the participant standing on a foam rubber mat for 30 seconds under 2
conditions—eyes open and closed. Maximal medial—lateral and anterior—posterior sway (in centimeters) were summed to calculate the final score for each condition. Better performance was indicated by larger scores of quadriceps strength and lower scores of proprioception, reaction time, and sway area.

**Figure 2.** The 8 Tetrax system games used in the study. (1) Speedtrack. (2) Skyball. (3) Tag. (4) Gotcha. (5) Speedball. (6) Immobilizer. (7) Target. (8) Freeze.

The Tetrax posturography system is based on the assessment of the vertical pressure fluctuations on 4 independent force plates, each placed beneath the
heels and toes of the subject while standing in an upright position. The weight percentages on the heel and toe force plates by the affected foot were summed as the total amount of weight loading on the affected leg. The closer the values were to 50%, the more symmetric was the weight bearing.

**Forward Reach and Timed Up and Go Tests**

For the FR test [19], the participants stood next to a wall with their unaffected arm raised to 90° and their fingers extended. The distance (in centimeters) that a subject could reach forward without moving or lifting the feet was measured. The inter-rater and intra-rater reliabilities were usually high, in the range of 0.93-0.99 [20].

In the TUAG test [21], participants were asked to rise from a standard chair, walk a 3-m distance, turn, walk back to the chair, and sit down. The time required to complete the test (in seconds), beginning at the word “go” and ending when the participant’s back touched the backrest of the chair, was recorded. The TUAG test examines several movements necessary during activities of daily living, such as standing up, sitting down, turning, and walking. It showed excellent reliability (interclass correlation coefficient >0.95) in people with chronic stroke [21].

**Statistical Analysis**

The Statistical Package for the Social Sciences (version 12.0 for Windows, IBM Corp, Armonk, NY) was used for statistical analyses. Descriptive statistics were used to summarize baseline characteristics and feasibility data. Based on the small sample size, we used Mann-Whitney U tests and $\chi^2$ tests to compare the demographics and clinical data between groups. To help quantify the magnitude of intervention effects of each intervention, we used percentage of change for further analyses. The percentage of change was determined by post-training score — pretraining score/pretraining score. Mann-Whitney U tests were used to analyze differences in percentage of change between groups. All significant tests were 2-tailed, and differences were considered to be statistically significant at $P < .05$.

**Results**

**Adherence**

Thirty-one patients with hemiplegic stroke were screened for eligibility. Three patients were excluded because they did not meet the inclusion criteria, and one did not give informed consent; thus 27 patients were included in the study. After baseline assessment, 14 and 13 patients were randomly assigned to the IG and the CG, respectively. During the intervention period, 2 patients in the IG withdrew from the study, including one patient with back pain caused by an incidental fall in the bathroom after 6 training sessions and another who refused to continue after 12 training sessions. In the CG, one patient withdrew because of worsening of pre-existing hydrocephalus requiring shunt insertion, and another patient withdrew because of a transportation problem. Thus 23 patients (12 in the IG and 11 in the CG) completed the study (Figure 3). In the IG

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**Figure 3.** Subject recruitment and attrition flowchart.
group, those who completed the 6-week intervention attended 89.5% of planned sessions. The main reasons for missed sessions were personal issues not related to the intervention.

**Safety**

No major adverse events or falls occurred within the intervention sessions. Three patients reported mild pain in their lower limbs at an early stage of the intervention. This pain did not disrupt the study. After several sessions of the intervention, the reports of pain subsided spontaneously.

**Satisfaction**

Twelve participants who completed the intervention programs provided comments. Ten participants (83%) agreed or strongly agreed that the Tetrax games were enjoyable; the mean enjoyment score was 4.33 ± 0.78. Four participants found the Tetrax games more enjoyable than their routine rehabilitation training. However, 3 participants reported that their enjoyment of playing the games declined by the end of training because they became familiar with the games. Nine participants (75%) agreed or strongly agreed that the games increased their motivation for balance training; the mean motivation score was 4.17 ± 1.03. Ten participants (83%) agreed or strongly agreed that the Tetrax games were helpful for balance function; the mean helpfulness score was 4.25 ± 0.97. Three participants reported that such game intervention was as useful as conventional therapy, 4 reported that it was complementary to conventional therapy, and 3 reported that video games were better than conventional therapy. Eight participants (67%) wanted to continue the training as part of their routine rehabilitation training. Eleven participants (92%) recommended that other patients receive the Tetrax biofeedback training. The participants preferred the Catch game, followed by the Gotcha game; only one participant liked the Immobilizer game.

**Training Effects**

No differences in demographics or baseline balance-related variables were observed between groups (Tables 1 and 2).

Intervention effects of both groups are summarized in Table 2. Compared with the CG, the IG demonstrated a significantly greater improvement both in body function and activity domains, including reaction time ($P = .002$), proprioception ($P < .001$), symmetric weight bearing ($P = .027$), the TUG test ($P < .001$), and the FR test ($P = .01$) (Table 2).

**Discussion**

Our findings suggest that Tetrax balance game training is a feasible and effective intervention for patients with chronic stroke. Research has been published in favor of intensive and repetitive task-specific training for functional recovery after a stroke [22,23]. However, conventional repetitive exercises usually cause patients to lose interest. Lack of interest can decrease the potential effectiveness of the therapy. The engaging nature of a game-based approach may serve to increase motivation and repetitive practice [24,25]. Similar to other exergaming studies [16,26], the adherence rate (89.5%) of the IG was high. Participants’ enjoyment and perceived benefit for their balance function were also high. However, we noted that the types of games in the Tetrax biofeedback system were limited compared with the games in commercial entertainment systems; therefore, some participants lost interest in playing the games at the late stage of the intervention. Only two thirds of

Table 1

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Intervention Group (n = 12)</th>
<th>Control Group (n = 11)</th>
<th>$P$ Value</th>
</tr>
</thead>
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<tr>
<td>Age, y</td>
<td>52.75 (46.70; 62.90)</td>
<td>55.20 (45.30; 65.50)</td>
<td>.951</td>
</tr>
<tr>
<td>Gender</td>
<td></td>
<td></td>
<td>.99</td>
</tr>
<tr>
<td>Male</td>
<td>8 (66.7)</td>
<td>8 (72.7)</td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>4 (33.3)</td>
<td>3 (27.3)</td>
<td></td>
</tr>
<tr>
<td>Type of stroke</td>
<td></td>
<td></td>
<td>.99</td>
</tr>
<tr>
<td>Infarction</td>
<td>9 (75)</td>
<td>8 (72.7)</td>
<td></td>
</tr>
<tr>
<td>Hemorrhage</td>
<td>3 (25)</td>
<td>3 (27.3)</td>
<td></td>
</tr>
<tr>
<td>Affected side</td>
<td></td>
<td></td>
<td>.220</td>
</tr>
<tr>
<td>Right</td>
<td>8 (66.7)</td>
<td>4 (36.4)</td>
<td></td>
</tr>
<tr>
<td>Left</td>
<td>4 (33.3)</td>
<td>7 (63.6)</td>
<td></td>
</tr>
<tr>
<td>Onset duration, mo</td>
<td>17.50 (10.67; 21.93)</td>
<td>18.60 (10.47; 32.53)</td>
<td>.559</td>
</tr>
<tr>
<td>Assistive device</td>
<td></td>
<td></td>
<td>.667</td>
</tr>
<tr>
<td>None</td>
<td>9</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Cane</td>
<td>1</td>
<td>1</td>
<td></td>
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<tr>
<td>Quadrice</td>
<td>2</td>
<td>3</td>
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</table>

The values are presented as median [first quartile; third quartile] or N (%).
participants wanted to continue the training. In addition, participants preferred games with more variations and tolerable level of challenge; only one participant liked the immobilizer game, which is similar to the force plate biofeedback training. Bower et al. [27] pointed out that acceptability of the game-based intervention may have been enhanced through the provision of a larger range of activities, more engaging and varied interfaces, aligning the tasks more closely to participant goals, and enabling individuals to work at their level of challenge. Our findings support their recommendation.

Importantly, no major adverse events occurred within the treatment sessions in this study. However, 3 participants reported having mild pain in their lower limbs at an early stage of intervention, possibly as a result of repeated weight shifting movements. Mild and short-lasting pain incidents have also been reported in other exergaming studies [26,28]. It is suggested that post-exercise pain should be carefully monitored and that activities be adapted where necessary. Stretching exercises were recommended before each Tetrax biofeedback balance training session, and training intensity should be slowly increased to avoid such adverse effects.

This study demonstrated that, in addition to the conventional rehabilitation training for chronic stroke, 6 weeks of balance training with the Tetrax biofeedback system might improve participants’ balance within both body function and activity levels. First, in the body function domain, it improved symmetric weight bearing. This beneficial effect is synergistic with the benefit from biofeedback force plate systems [8]. We chose games with the intention of either making weight bearing more symmetrical, such as the Immobilizer game, or increasing the weight-bearing stance of the affected leg, such as the Gotcha and Speedball games. According to the task-specific learning theory, the improvement in symmetric weight bearing was not surprising. In addition, we also noted an improvement in proprioception of the affected leg after Tetrax training. This effect was possibly due to repetitive weight shifting during the training course that increased joint compression, thereby improving proprioceptive feedback. Finally, faster reaction times were noted after the Tetrax games intervention. In the video games, the targets were random and varied in direction and speed, and thus the participants were required to make timely, goal-directed shifts in the COP to produce the appropriate response within seconds. Such training may enhance the immediate response of participants, and therefore their reaction time decreased.

Second, in the activity domain, several studies have reported no clinical benefit from use of force plate biofeedback training alone (without interactive computer games) in functional balance activity, as measured by either Berg balance test or TUAG scores [8,29]. Conversely, the effects of the interactive

<table>
<thead>
<tr>
<th>Variable</th>
<th>Intervention Group (n = 11)</th>
<th>Control Group (n = 12)</th>
<th>Percentage of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscle strength, kg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knee extension, affected side</td>
<td>28.83 (12.50; 31.00)</td>
<td>26.83 (12.50; 37.17)</td>
<td>0.10 (0.05; 0.20)</td>
</tr>
<tr>
<td>Nonaffected side</td>
<td>31.00 (21.83; 38.50)</td>
<td>35.17 (25.00; 38.33)</td>
<td>0.22 (0.00; 0.23)</td>
</tr>
<tr>
<td>Reaction time, ms</td>
<td>249.30 (235.80; 270.40)</td>
<td>236.61 (208.40; 254.90)</td>
<td>0.08 (0.04; 0.13)</td>
</tr>
<tr>
<td>Proprioception, cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With eyes closed, cm²</td>
<td>3.44 (2.11; 12.01)</td>
<td>4.91 (2.02; 7.78)</td>
<td>0.42 (0.24; 0.62)</td>
</tr>
<tr>
<td>Reaction time, ms</td>
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<td>0.08 (0.04; 0.13)</td>
</tr>
<tr>
<td>Weight bearing, affected leg, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>With eyes closed, cm²</td>
<td>3.44 (2.11; 12.01)</td>
<td>4.91 (2.02; 7.78)</td>
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</tr>
<tr>
<td>Timed Up and Go, s</td>
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<tr>
<td>Weight bearing, affected leg, %</td>
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<td>0.08 (0.04; 0.13)</td>
</tr>
<tr>
<td>Forward reach distance, cm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight bearing, affected leg, %</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

The values are presented as medians [first quartiles; third quartiles]. * Statistically significant at P < 0.05.
computer game exercises were beneficial in functional balance activities [15,16]. We had a similar finding, with the IG showing greater improvement in the TUAG test compared with the CG. By combining force plate and interactive computer games as biofeedback training, subjects were required to perform episodic body movements in order to interact with the video game. These random goal-oriented movements might be more helpful in improving functional performance than the constant feedback from a force plate [15,30]. We also found significantly more improvement of FR distance in the IG compared with the CG, probably because of the repeated front-back movements required during certain Tetrax games training.

**Limitations**

This study had several limitations. Tetrax games were played on a rigid surface with no progression to a compliant surface, thus potentially limiting the balance demands and the balance cost of the exercises. However, even at the late stage of intervention, some participants still had difficulty playing games on the rigid surface, and thus playing on a compliant surface may not be suitable for them.

Investigation of efficacy was limited by the small sample size, use of a control group that did not receive an equivalent amount of additional therapy, and participants’ engagement in concurrent therapy. Caution also must be exercised when attempting to generalize our results, because our findings were based on relatively young stroke survivors (average age: 54 years) who did not have severe cognitive deficits and were able to stand independently to some extent. The duration of the intervention was short (20 minutes per session for 3 sessions per week for 6 weeks), which may have underestimated the effects of the intervention. Lack of follow-up assessment also limited the documentation of carryover effects of the Tetrax biofeedback system. The assessor was not blinded to the group allocation, which was another drawback of our study. In addition, because we excluded patients who could not complete the 6-week training program, our participants might have a higher than usual adherence rate.

**Future Study Design**

The results in this feasibility study were not powered to make any definitive conclusion about the efficacy of Tetrax biofeedback training. A single blinded, randomized, controlled study recruiting an adequate sample size of participants with varying ages and testing against a dose-matched control group is needed to explore the effects of this intervention. In addition, assessing the long-term effects of Tetrax biofeedback training is also suggested.

**Conclusion**

Using Tetrax biofeedback video games for balance training is a feasible adjunctive program that may augment conventional therapy in persons with chronic hemiplegic stroke. Further study to provide more robust data about the efficacy of this intervention is warranted.

**References**


Disclosure

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