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Does A Virtual Reality-Based Dance Training Paradigm Increase Balance Control in Chronic Stroke Survivors? A Preliminary Study

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Abstract

Purpose: To examine the feasibility and effect of a virtual reality-based dance training paradigm in improving balance control and physical activity levels.

Method: Community-dwelling individuals with hemiparetic stroke (N=11) received a virtual reality-based dance paradigm for 6 weeks using the commercially available Kinect dance video game "Just Dance 3". The change in balance control was evaluated by the Limits of Stability test (Neurocom Inc.). The post-training changes in self-initiated center of pressure response time (RT), the movement velocity (MV), the maximum excursion (MXE) were examined. Changes in physical activity during dance training were assessed using Omran HJ-321 Tri-Axis Pedometer. The gaming scores were recorded from the Kinect software after each game (during training).

Result: Post-training the RT was significantly reduced (pre vs. post, p<0.05). Similarly, post-training, MV and MXE were significantly higher (p<0.05). Number of steps during dance intervention significantly increased from the 1st to the 20th session (p<0.05).

Conclusion: Results validate the feasibility of this short duration high-intensity protocol for improving balance control and physical activity in chronic stroke survivors.

Keywords: Dance; Balance control; Physical activity

Introduction

Stroke is one of the major causes of long-term adult disability leading to dependence in activities of daily living, with more than 800,000 incidences each year [1]. A stroke event causes a number of deficits that contribute to impaired balance control. This loss of balance has been determined as a major risk factor for falls in individuals with stroke [2]. Forty to 70% of community-dwelling stroke survivors experience detrimental falls every year [3]. The consequences of falling include hip fracture, soft tissue injuries, fear of falling, hospitalization, increased immobility, and disability [4]. Among these consequences, reduced falls self-efficacy has been highly correlated to recurrent falls in stroke survivors [3]. The combined effect of impaired balance control, fall incidence and reduced falls self-efficacy dispose chronic stroke survivors to sedentary behaviors, which in turn reduces physical activity levels, community reintegration and quality of life, thus increasing cardiovascular deconditioning, risk of secondary stroke and mortality [5,6].

Balance training for chronic stroke survivors shown to be efficacious in outpatient rehabilitation centers, includes methods, such as sit-tostand training, weight bearing and postural symmetry training, and agility exercises [7]. Albeit falls are still occurring at a rate of 40% among the high functioning community-dwelling stroke survivors, with the risk of falling being twice that of age similar healthy adults [3]. Further, the reduced motivation and compliance towards the conventional interventions in comparison to virtual reality rehabilitation exhibited amongst community-dwelling stroke survivors makes it difficult to receive the maximum benefits from these methods [8,9].

Literature demonstrates that methods such as "biofeedback" and "repetitive task training" have established efficacy for improving motor recovery in the chronic stroke population. Under the biofeedback training methodology, individuals are provided with visual or auditory feedback about their weight distribution and the trajectory of the center of pressure while performing balance control tasks [7]. However, in repetitive task training methodology, individuals are provided as many opportunities as possible to practice repeatedly. Thus, a rehabilitation paradigm that integrates these evidence-based findings to reduce fall risk, and simultaneously increasing motivation and compliance to intervention, might improve rehabilitation gains targeted towards fallrisk prevention.

To enhance the level of biofeedback, an alternative medium, such as virtual reality (VR), has been applied to rehabilitate chronic stroke survivors. Recent studies demonstrate VR rehabilitation being largely used in addressing balance control deficits in this population [10,11]. A recent review evaluated the efficacy of virtual reality-based rehabilitation on balance and mobility disorders in stroke rehabilitation [11]. Findings from this review indicate that VR-based rehabilitation has an added advantage over non-VR-based interventions in the recovery of balance control while performing functional tasks. The authors suggest that some of the factors (e.g., repetitive variable practice, enhanced engagement, motivation, added feedback, etc.) associated with the VR systems and the training paradigms used could be responsible for this additional improvement.

Another alternative intervention increasingly used in rehabilitation settings to improve balance control in people with neurological disorders is dance therapy [12,13].

Dance movements may be particularly helpful for individuals with stroke, as it facilitates continuous center of pressure displacements within the individual's stability limits. Recent research has shown

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that training strategies implementing continuous center of pressure displacements will provide potential for weight shift training towards the paretic limb, resulting in improved symmetry in weight distribution [14]. Symmetrical weight distribution during standing and walking is associated with improved performance on voluntary balance control and reduced fall risk among chronic stroke survivors [15,16]. Dance steps would also require practicing single limb-stance, thus facilitating improvement in single limb stance duration. The capacity to improve single-limb stance duration in the paretic limb has been shown to rapidly improve dynamic stability (approximately 4 weeks) [17]. Additionally, dancing would involve fast, repetitive, full-body movements. Rapid movement training has been previously shown to decrease response time of self-initiated postural weight shifts (decreased time to initiate center of pressure excursion on the limits of stability test) while performing functional tasks in older adults [18]. Increased response time in hemiparetic stroke is one of the main predictors for decline in movement initiation and performance [19]. Thus, dance could have a holistic practice approach, which can be used as a complementary therapy to conventional interventions for reducing fall risk in community-dwelling stroke survivors.

Though dance has been shown to successfully improve balance control among various populations such as older adults, Parkinson's disease and Multiple Sclerosis [13,20-22], there is little research on the effects of such rehabilitation among stroke survivors. Until recently, there is only one case study that examined the effects of a partnered tango dance program on chronic stroke survivors and has provided preliminary evidence of such therapy on an increase in clinical balance (Berg Balance Scale and Timed Up and Go Test), gait and endurance measures (6-Minute Walk Test) [23].

Recent studies have also demonstrated that increasing physical activity in stroke survivors improves balance control and could reduce their fall-risk [24]. The recommended frequency of physical activity for stroke survivors is ≥ 3 days per week, with duration of 20 to 60 minutes per session, depending on the individual's functional capacity [25,26]. Despite the positive effect of physical activity on balance control in this population, the average number of steps walked per day is approximately 2800 to 3000 steps/day, far below the daily step counts recorded from age-matched sedentary healthy older adults (5000–6000 steps/day) [27,28]. These findings thus suggest a need for the identification of alternative forms of compliant and effective rehabilitation methods, which incorporate balance control training along with facilitation of regular physical activity into the daily life of community-dwelling stroke survivors.

In regards to the above mentioned, off-the-shelf, lower-cost VR gaming systems like Kinect (Microsoft Inc.) have shown improvements in posturography, functional balance and gait performance in chronic stroke survivors [8,10,29]. Some studies have also demonstrated the transition of these VR training-induced balance and gait improvements to functional mobility, thus suggesting it to be an effective tool for enhancing physical activity in this population group [30,31]. Given the preliminary evidence of virtual reality and dance for improving balance control, this study would like to propose, a novel cost-effective virtual reality-based dance training intervention using the commercially available off-the-shelf Kinect gaming system, in order to provide a more holistic intervention while addressing recommended frequency of physical activity.

The purpose of this pilot study was to examine the feasibility, compliance and effectiveness of a virtual reality-based OR VR-based dance for the most clarity training paradigm in improving balance

control, falls self-efficacy along with achieving recommended levels of physical activity in community-dwelling individuals with hemiparetic stroke. We hypothesized that participants would demonstrate increased balance control (on posturography and functional measures) along with greater scores on Falls Self-Efficacy Scale and Intrinsic Motivation Inventory Scale post-intervention. There would also be an increase in physical activity across the training sessions as measured by the increase in number of steps.

Methods

Participants

Eleven ambulatory adults with self-reported chronic hemiparetic stroke participated in the study after obtaining informed consent. Participants were recruited by posting flyers at various stroke support groups, local neurologists' offices, outpatient rehabilitation clinics and research centers. The Institutional Review Board of the University of Illinois approved the study.

Participant eligibility

Individuals with hemiparetic stroke (>6 months), as confirmed by the participant's physician, were included. They were required to have the ability to stand independently for at least 5 minutes without the use of an assistive device. Participants' mean \pm SD disability status quantified using the Modified Rankin Scale, ranged from mild to moderate disability (2.72+0.49). Participants with other neurological (e.g., Parkinson's disease, vestibular deficits, peripheral neuropathy or unstable epilepsy) and musculoskeletal disorders were excluded. Individuals with cardiovascular disorders as assessed by resting heart rate (>85% of age-predicted maximal) and resting oxygen saturation (<95) were also excluded.

Protocol

A schematic diagram of the study protocol, demonstrating the chronological sequence of intervention for 6 weeks is represented in Figure 1.

Community-dwelling individuals with hemiparetic chronic stroke received virtual reality-based or VR-based dance rehabilitation for 6 weeks using the commercially available Kinect dance game (Microsoft Inc., Redmond, WA, U.S.A.) "Just Dance 3". The six week session was delivered in a high-intensity tapering method with the first two weeks consisting of 5 sessions/week, next two weeks of 3 sessions/week and last two weeks of 2 sessions/week, for a total of 20 sessions [32,33]. The dance rehabilitation protocol consists of participants performing a 10 minutes each of warm-up and cool down stretching exercises before and after the training to reduce risk of exercise related adverse effects. Participants played on 10 songs for the first 2 weeks, progressing to 12 songs during the 3nd and 4th weeks with an addition of 2 more songs of their choice during the last two weeks. Participants played on alternating slow- and fast-paced songs (each maximum of 4 minutes in duration) with a five minutes break after a set of one slow and fast song for the first two weeks. For the following two weeks, once the participants reached a resting heart rate of ≤ 85 beats/min as measured by the Panasonic EW3109W, they were allowed to dance to the next song. This way all the participants were able to undertake the progression regimen used in this study. The projected total time spent on rehabilitation ranged from 1 hour and twenty five minutes to one hour and forty minutes for all the participants. Subjects wore a gait belt and a researcher provided external assistance (contact guard support) and supervised the subjects, so that no falls occurred during the intervention period.



Figure 1: Schematic diagram of the study design, illustrated with the screen shots of the Kinect "Just Dance 3" games (songs numbers) used for the intervention. The intervention was 6 weeks long and consisted of 20 sessions. The protocol for each session consisted of participants performing a 10 minutes each of warm-up and cool down stretching exercises before and after the training to reduce the risk of exercise related adverse effects. Participants' played on 10 songs for the first 2 weeks, progressing to 12 songs during the 3nd and 4th weeks with an addition of 2 more songs of their choice during the last two weeks. Participants played on alternating slow and fast-paced songs. The six weeks soion was delivered in a high-intensity tapering method with the first two weeks consisting of 5 sessions/week, next two weeks of 3 sessions/week and last two weeks of 2 sessions/week totaling to 20 sessions.

Outcome measures

Feasibility and compliance: We examined the feasibility by assessing the number of falls and shortness of breath. Compliance of participants to the training sessions were assessed by recording the number of missed training days for all the participants. We divided the compliance to two categories, one was for the vigorous, first two-week training sessions and the other was for the tapering, four-week training sessions.

Also the participants completed three assessments: one-week preintervention, (mid-intervention) 10th training session, and one-week post-intervention on balance control, physical activity, and functional measures. The details of each test are described below.

Balance control measures

Reactive balance control task: Voluntary balance control was assessed using the Limits of Stability (LOS) test protocol of the Equitest (Computerized Dynamic Posturography) [34]. The LOS test required participants to be secured with a safety harness. The LOS test assesses impairment of voluntary balance control by quantifying the participant's ability to move their center of pressure (lean their body) to their stability limits without losing balance, stepping, or reaching for assistance. While standing on stable force plates, participants were asked to transfer their center of pressure toward the forward direction spaced at 45° intervals around the body's CoP, as displayed on a

monitor in real time. They were instructed to hold the leaning position until the test was completed. The target chosen in this study was directly in front, i.e., the forward direction, so as to allow evaluation of the ability to voluntarily move the CoP to position within the LOS which is fundamental to mobility tasks such as reaching for objects, transitioning from a seated to standing position (or standing to seated), and walking. The duration of each trial was about 8 seconds. Two familiarization trials were conducted, after which data was collected. The outcome measures consisted of a temporal variable, response time and spatial variables, movement velocity and maximum excursion of the CoP. Response time was the time in seconds between the command to move and the onset of patient's movement. Movement velocity was the average speed of the CoP movement in degrees per second. Maximum excursion of the CoP was the maximum distance up to which the participant is able to shift their center of gravity towards the target: it was calculated as the distance of the first movement toward the designated target, expressed as a percentage of maximum limits of stability distance towards the theoretical limit (100%). The theoretical limit is the physiological maximum that a person can lean given their height without loss of balance, falling, or taking a recovery step.

Reactive balance control task: Reactive balance control was assessed using the Motor Control test (MCT) protocol of the Equitest (Computerized Dynamic Posturography). Similar to the LOS test protocol participants were secured with a safety harness. The MCT assesses the ability of the participants to quickly recover balance control

following an unexpected external platform perturbation. Participants were informed to expect a sudden movement of the fore plates and maintain balance during the test without touching the walls around, taking a step, reaching for assistance or falling at any point within the trial. The largest perturbation magnitude of forward translation available was used for testing purpose and 3 trials that lasted for 25 second duration were conducted. The translation amplitude was calculated by the formula: displacement=2.25 x [height (in m)/72)]. Based on an average height of 1.5 m, the displacement would be equal to 4.7 cm. The duration of each large perturbation trial was about 8 seconds. Two familiarization trials were conducted, after which data was collected. Weight symmetry, a spatial variable was assessed with the two force platforms connected to a computer, allowing independent measurement of vertical forces between the feet and the surface of the platforms. The percentage of the body weight carried by each lower extremity is obtained using computer programs, with the affected and the unaffected lower extremity measured independently.

Physical activity measure: Changes in the physical activity during the 20 sessions of dance training were recorded using the Omran HJ – 321 Tri-Axiz Pedometer. The accumulated literature evidence provides support that the simple and inexpensive pedometer, which measures the number of steps, is a valid option for assessing physical activity in research and practice [33,35]. The Omron pedometer features advanced Tri-axis sensor technology, which allows accurate measurement of physical activity. The pedometer had to be worn on an adjustable elastic waist belt perpendicular to the ground. This was reported to be the most precise mounting position out of four mounting positions proposed by the manufacturer of this model (Omron healthcare, INC., Made in China). To ensure correct application, a research assistant carefully demonstrated the mounting of the pedometer on the waist belt and asked the participants to provide a repeat demonstration.

Gaming scores: The gaming scores were recorded from the Kinect software. The scores for each game, both fast ("I Was Made For Loving You", "Party Rock Anthem", "Pump It", "Apache" (Jump On It), "Gonna Make You Sweat" (Everybody Dance Now) and slow ("Dynamite", "Price Tag", "Baby One More Time", "Something"- Stupid", "I Don't Feel Like Dancin") songs, were recorded across all the twenty training sessions for each participant.

Functional outcome measures: Standardized clinical outcome measures were used to assess balance control (Berg Balance Scale [BBS]), risk of falls (Timed Up and Go Test [TUG]) and fear of falling (Fall Efficacy Scale [FES]) one-week pre-intervention, (mid intervention) 10th training session and one week post-intervention. The Berg Balance Scale has been used for assessing balance control in stroke survivors and has strong reliability, validity, and responsiveness to change [33,36]. The Timed Up and Go Test, is an objective measure of basic mobility and balance maneuvers that assesses risk of falls [33,37]. Similarly, the Fall Efficacy Scale has been used extensively for evaluating fall-related self-efficacy and higher activity avoidance [38,39].

Motivation: In addition to the functional outcome measures, motivation to rehabilitation was measured with Intrinsic Motivation Inventory (IMI) Scale [33,40,41]. It has been used in several experiments related to intrinsic motivation, self-regulation and has good evidence of being reliable [33].

Statistical Analysis

A one way repeated measures ANOVA was performed to determine, if there was any change in performance in self-initiated CoP response time, movement velocity maximum excursion and weight symmetry, along with changes in functional measures, such as Berg Balance Scale, Timed Up and Go Test and Fall Efficacy Scale and Motivation Inventory Scale between one-week pre-intervention, (mid-intervention) 10th training session and one week post- intervention followed by post hoc paired t-tests. Since the response time was expected to decrease post-intervention, lower scores would indicate a higher performance. Increased scores in movement velocity and maximum excursion were directly proportional to better performance. Equal symmetry of bodyweight distribution on both legs represented by weight symmetry scores would be 0. If the non-paretic side carried more weight, the score would be >0, and if the paretic side carried more weight, the score would be <0. As the BBS score was expected to increase post-intervention, higher scores would indicate a higher performance, while decreased scores in TUG and FES would be directly proportional to better performance. Greater values in IMI would indicate higher compliance to training. To determine the changes in physical activity and gaming scores, one way repeated measures ANOVA was done on the sum of all the number of steps and the gaming scores respectively during the first day intervention, (mid-intervention) 10th training session and one week post- intervention scores followed by post hoc paired t -tests. To determine the changes in physical activity and gaming scores over intervention period the total number of steps and scores recorded for each session was linearly regressed with the number of training sessions (one through twenty). A correlation analysis was conducted between balance control (RT and MV) and change in physical activity over the intervention period (number of steps during 1st and 20th training session). The classification used for correlation was: <0.49, weak; 0.50 to 0.69, moderate; and \geq 0.70, strong. A significance level (a) of 0.05 was chosen for statistical comparisons performed using SPSS software version 17.0 for analysis.

Page 4 of 10

Results

Demographics

Demographic data for the participants are presented in Table 1. Participants were individuals with chronic stroke having an onset of 9.72 3.32 years. The recruited participants had 36.37% (n=4) left side involved and 63.64% (n=7) right side involved hemiplegia. The study consisted of eleven individuals (60.75 ± 5.12 years) with 5 males and 6 females with body weight of 93.48 ± 41.27 and height of 169.27 ± 8.80.

Feasibility and compliance

The intervention was safe and feasible with participants having no falls, or shortness of breath. In regards to the compliance to the present training protocol, out of the 11 participants only two of them missed one session each, due to a personal commitment and physical sickness respectively in category one (vigorous first two week, consisting of 5 sessions/week). All the other subjects were present for the category two that consists of the remaining four-week training sessions (two weeks of 3 sessions/week) with the feasibility to reschedule their training days.

Balance outcomes

Significant differences in self-initiated CoP response time [F(2,

Subject	Gender M/F	Age (year)	Weight (kg)	Height (cm)	Involved Side(L/R)	Stroke Type (H/I)	Onset (year)
n=11	5/6				4/7	5/6	
Mean		60.75	93.48	169.27			9.72
SD		5.12	41.27	8.80			3.32

L=Left, R=Right, H=Hemorrhagic, I=Ischemic

Table 1: Demographics and stroke characteristics of study participants.

Page 5 of 10

20) =6.659, (p<0.05)], movement velocity [F(2, 20) =15.913, (p<0.01)] and maximum excursion [F(2, 20) =3.863, (p<0.01)] were noted among pre-intervention, (mid intervention) 10th training and post-intervention session. Post-hoc analysis showed significantly decreased response time from pre-intervention to the (mid intervention) 10th training session (p<0.05), and post-intervention (p<0.01). Movement velocity significantly increased from pre- to post-intervention (p<0.01), along with a consistent increase from pre-intervention to (mid-intervention) 10th training session (p<0.05) and from the (mid-intervention) 10th training session (p<0.05) and from the (mid-intervention) 10th training session to post-intervention (p<0.05). There was also a significant increase of maximum excursion from pre- to post-intervention (p<0.05) with also a significant increase from (mid-intervention) 10th training session to post-intervention (p<0.05) (Figure 2).

Physical activity measure

Each participant recorded a mean of about 172 steps per song for the slow song and 245 for the fast song on session 1. These steps significantly increased to 245 for slow and 356 for fast by the (mid intervention) 10th training session. The total sum of number of steps across all songs/session there was a significant increase in number of steps recorded between the 1st ,10th and last (20th) session [F(2, 20) =29.342, (p<0.01)]. The number of steps increased from 1249.44 \pm 489 on the 1st session to 2375 \pm 551.6 on the (mid-intervention) 10th training session (p<0.05). Participant continued to increase the number of steps taken from (mid-intervention) 10th to 20th training session with 3010 \pm 785 steps recorded at 20th session (p<0.05) (Figure 3a) Furthermore, there was a significant linear increase in total number of steps across sessions [y=1490.3e0.0335x, R2 of 0.5208 (p<0.05)] (Figure 4a).

Gaming scores

There was a significant main effect of gaming scores between the 1st, 10th, and last (20th) session [F (2, 20) =3.405 (p<0.05)]. Sum of all the gaming scores/session recorded increased from 18099 \pm 8071.74 on the 1st session to 22138 \pm 7351.37 on the (mid-intervention) 10th training session. Participants continued to increase the gaming scores taken from (mid-intervention) 10th training session to the 20th training session with 26950 \pm 6660.399 recorded at 20th session. There was a significant increase of the gaming scores between the 1st and 20th







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session (p<0.05) (Figure 3b). A significant linear increase in gaming scores was noted across sessions [y=327.29x+21771, R2 of 0.5407 (p<0.05)] (Figure 4b).

Functional outcome measures

coefficient.

A significant main effect of training among pre-intervention, (midintervention) 10th training and post-intervention sessions was observed in Berg Balance Scale (BBS) with [F (2, 20) =21.245, (p<0.01)]. Post hoc comparisons indicated that the BBS scores significantly increased from pre- to post-intervention (p<0.05), along with a consistent increase from pre-intervention to the 10th training session (p<0.05) and from the (mid-intervention) 10th training session to post-intervention (p<0.05). A similar main effect of training was observed between pre-intervention, (mid-intervention) 10th training and post-intervention sessions for the Timed Up and Go Test (TUG) with [F(2, 20) =44.763, (p<0.01)]. Post hoc analysis showed that the TUG the scores significantly decreased from preintervention to the 10th training session (p<0.01). There was difference in TUG scores between the (mid-intervention) 10th session and postintervention (p>0.05) and scores on the post-intervention session were significantly lower than the pre-intervention session (p<0.05). Significant differences in Fall Efficacy Scale were seen among pre-intervention, (mid- intervention) 10th training and post-intervention session with [F (2, 20) =12.103, (p<0.01)] and post hoc comparisons revealed falls self-efficacy (Falls Efficacy Scale) increased significantly pre- to (midintervention) 10th training session (p<0.01), and pre to post-intervention session (p<0.01), with no difference between the (mid-intervention) 10th and the post-intervention session (Figure 5).

Motivation

Overall, there was a significant main effect of training on motivation with [F(2, 20) = 36.677, (p < 0.01)]. Post-hoc analysis showed a significant increase in motivation, demonstrated with Motivation Intrinsic Scale pre- to 10th training session which was maintained post-intervention (p<0.05 between pre and post-intervention sessions) (Figure 6).



Figure 5: Means (± SD) changes in one week pre-intervention – Wk (week) 0, (mid intervention) 10th training session – Wk (week) 2 and one week post-intervention scores of individuals performance – Wk (week) 7 on function measures, such as a) Berg Balance Scale (BBS) b) Timed Up and Go Test (TUG) c) Falls Efficacy Scale (FES). As the BBS score was expected to increase post-intervention, higher scores would indicate a higher performance, while decreased scores in TUG and FES were directly proportional to better performance. Significant differences with intervention indicated by * represent p<0.05.

Correlation between balance control and physical activity

The participants number of steps from the 1st and 20th training session correlated with the pre-post intervention scores for response time [R2 of 0.5089 (p<0.05)] and movement velocity [R2 of 0.5488 (p<0.05)], showing a moderate correlation (Figure 7).

Discussion

The present study evaluated the feasibility and effect of a virtual reality-based dance training paradigm in improving physical function in community-dwelling chronic stroke survivors. The results supported the hypothesis that this paradigm offered in a high intensity, tapering fashion was feasible and effective in improving balance control, falls self-efficacy, and motivation levels. There was also an increase in physical activity, as measured by the number of steps during the course of the training sessions.

The results indicated that there was a significant training-induced improvement in the dance gaming scores from pre- to post-intervention and this improvement translated to the participants temporal (response time) and spatial (movement velocity and maximum excursion) anticipatory balance outcomes as measured on the limits of stability test. There are several possible mechanisms that could have led to such improvement in balance performance. During the virtual reality-based dance rehabilitation, individuals go through a set of repeated internal (self-generated) perturbations with each movement sequence that they perform are required to initiate voluntary weight shifting to different spatial locations more quickly without losing their base of support. Such training requires training of both higher cognitive functions and anticipatory postural control – to prepare the body to comprehend



Figure 6: Means (<u>+</u> SD) of scores on the Intrinsic Motivation Inventory (IMI) Scale one week pre-intervention – Wk (week) 0, (mid intervention) 10^{m} training session – Wk (week) 2 and one week post-intervention scores. Greater values indicate higher compliance to training. Significant differences with intervention indicated by * represent p<0.05.

and respond to the next sequence of movement strategies that appear on the screen [42]. This challenges their ability to make timely and appropriately directed steps and trains their ability to maintain balance through complex tasks requiring stability and mobility.

The virtual environment also provides real-time visual, auditory, and proprioceptive feedback, which are fundamental in motor learning in stroke survivors [43]. Such feedback modes can lead to improvement of motor abilities in the virtual environment, and are transferrable to activities of daily living in the real environment [33,44]. Another factor that steered the improvement in balance control could have been the repetitive task-specific training provided in our study, which has shown to induce significantly greater neuroplastic changes than conventional methods [33,45]. Lastly, the virtual reality environment could have reduced psychological constraints, such as fear of falling, that has been shown to increase one's limits of stability, particularly in the forward direction.

Furthermore, an increase in the number of steps across the training sessions may reflect the improved ability to execute balance-related aspects of the gaming tasks, such as the ability to perform controlled and rapid movements near the limits of stability and weight shifting. An improvement in this ability is supported with the positive correlation seen between number of steps (measured at the 1st and the 20th training session) with the balance outcome measures (pre- to post-intervention), such as response time and movement velocity. These outcome measures assess the ability to initiate voluntary weight shifting to different spatial locations rapidly without losing their base of support, the same aspects required for successful performance in gaming tasks. Alternatively, the increased number of steps may reflect an increased endurance, as suggested by recent literature, where it is demonstrated that dance as a training paradigm may be effective in improving cardiorespiratory fitness among individuals with neurological conditions [33,46]. Also, the short duration - high intensity training protocol implemented in this study exceeded the required amount of physical activity (20-60 minutes per session, 3-5 sessions per week), recommended by the American College of Sports Medicine for seeing a clinically meaningful benefit in endurance levels [47].

Most of the participants where adherent to the rehabilitation paradigm in this study (98% for vigorous first two weeks, consisting of 5 sessions/week and 100% for two weeks of 3 sessions/week and last two weeks of 2 sessions/week). This suggests that the training protocol could have induced a positive and meaningful experience, which in turn promoted compliance and motivation for regular participation. In line with our findings, studies demonstrate that virtual reality (VR) rehabilitation, in comparison with conventional methods, provides the



Figure 7: Correlation between physical activity (number of steps (# of steps) during 1st and 20th training session) and balance control measures (pre-intervention and post intervention a) Response time (RT) in seconds (s) and b) Movement velocity (MV) in degrees/second (d/s).

subject with high levels of motivation and compliance and a strong sense of presence in the virtual environment [8,48]. Recent studies have also demonstrated that people with neurological disorders are motivated to attend dance classes regularly, have a high rate of compliance with a low dropout rate, and often continue with the activity after the study period [49,50]. Immersion in the virtual environment has been demonstrated as a critical component to positive gaming experience [33,51]. Significantly, improved score on the Intrinsic Motivation Inventory post-rehabilitation further lent support to the above.

Mirror Neuron System or Action Observation Network (AON) system as defined in the literature, is referred to as the sets of neurons that could be activated, during observation or actual performance of an action [52,53]. It is also indicated that training or activation of AON could result in cortical plasticity [54]. Furthermore, recent studies have also shown that dance based training activates both AON system and other brain centers that help in balance control [55]. VR-based dance training provided in this study, facilitated subjects to observe the dance steps in the game providing opportunity for the activation of both AON (observing and performing) and centers of balance control in the brain. This activation improved cortical plasticity and could explain the significant increase in balance outcome measures.

In this study, there was a significant 4-point change on Berg Balance Scale, which was very close to the minimal detectable change of 4.13 points for individuals with chronic stroke [33,56]. For the TUG the participants improved by 3 seconds, which exceeds the minimal detectable change of 2.9 seconds [57]. Fall Efficacy Scale also improved by two points. These positive changes in functional outcome measures indicate that virtual reality-based dance training could improve balance control in individuals with chronic stroke and could be a meaningful clinical application for this population.

The training protocol in the current study was designed to provide a short-duration, high-intensity tapering method of training for 20 sessions across a span of 6 weeks, each session lasting 1.5 hours long. Results of the study indicate that the above protocol dosage was appropriate and effective in rehabilitating chronic stroke survivors. Hackley et al. [32] and Bronner et al. [58] evaluated similarly structured protocols for subjects with Parkinson's disease and healthy young adults respectively. Hackley et al. [32] trained subjects using a tango dance protocol for 2 weeks, having a total of 10 sessions, each session being 1.5 hours long. Results from their study reported an increase in Berg Balance Scale and percentage of time spent in stance during forward walking. Bronner et al. [58] trained healthy young adults using a Xbox Kinect, Dance Central game based training protocol for a total of 7-9 sessions for twice per week, each session being 30-40 minutes long. Results from their study reported an increase in gamming scores with no improvement on kinematic data for sagittal plane mean peak angular displacement of hip and knee. Study by Bronner et al. [59], could have resulted in conflicting results due to the reduced intensity of training per session (30-40 min per session), in addition to that the training was provided for young adult population, hence there could have been a ceiling effect. A meta-analysis of 24 therapeutic training studies, comprising of balance/flexibility, aerobic and Tai chi based training protocols on gait speed was evaluated among studies with elderly population [60]. The study reported that high intensity programs, defined as training protocols with more than 180 minutes per week, had a significant effect on habitual gait speed among the elderly. Thus, the results from the current study, Hackley et al. [32] and the meta-analysis concur on the effectiveness of short duration, high-intensity protocol. Additionally, our study used the tapering method for training. Recently, a handful of intervention studies have reported that tapering method minimizes accumulated fatigue without compromising acquired performance on functional measures and reduction of fatigue for training regimen may also increase compliance [61]. Our study used the tapering method of reducing the number of days, as the training progressed; we maintained a minimum of around 180 minutes per week. Thus, the results from the current study, Hackley et al., the meta-analysis and Mujika et al. concur on the effectiveness of short-duration, high-intensity tapering method.

Page 8 of 10

The results of this study are in agreement with previous studies in other neurological populations that have used dance as an intervention tool to improve balance and functional mobility. Although most of these studies have not used virtual reality-based dance training, their results similar to ours have found improvements in balance control (Berg Balance Scale), mobility (Timed-Up-and-Go Test), and falls selfefficacy (Fall Efficacy Scale) in older adults and Parkinson's disease [13,62]. One systematic review and meta-analysis including randomized controlled trials of individuals with Parkinson's disease compared dance rehabilitation with other conventional rehabilitation methods, such as muscle strengthening, functional mobility, strength/flexibility, and balance control trainings and found that dance rehabilitation was superior than the other interventions in significantly enhancing balance control and quality of life [21,33]. Additionally, other studies done with older adults and Parkinson's disease have reported greater compliance with dance rehabilitation due to it being more a more enjoyable and satisfying experience [23,63,64].

Our results should be interpreted with caution due to the small sample size and lack of a control group. Furthermore, we did not have a long-term follow-up to examine how long the obtained benefits on balance control and physical activity were retained postintervention. However, the feasibility and compliance to the protocol along with the improvements in balance control and physical activity shown in this study lends support to the possibility that dance could be a feasible intervention for individuals with chronic stroke. Future studies could incorporate dance as an adjuvant therapy into clinical treatment program and assess its long-term efficacy for translation into community ambulation.

To conclude, the results from this study adds to the recent literature supporting the feasibility and effectiveness of a virtual reality-based dance training paradigm in improving balance control along with physical activity levels. Several clinical guidelines now recommend incorporating physical activity and a structured exercise program after stroke for achieving an increase in function mobility and decreasing risk of a second cardiovascular accident. Given the results of this study, virtual reality-based dance gaming using an off-the shelf gaming console could be incorporated as a clinical intervention to address fallrisk and community mobility limitations in chronic stroke survivors.

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Page 9 of 10

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Page 10 of 10

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