Does Virtual Reality-based Kinect Dance Training Paradigm Improve Autonomic Nervous System Modulation in Individuals with Chronic Stroke?

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Abstract

Background—Physical inactivity and low resting heart rate variability (HRV) are associated with an increased cardiovascular deconditioning, risk of secondary stroke and mortality. Aerobic dance is a multidimensional physical activity and recent research supports its application as a valid alternative cardiovascular training. Furthermore, technological advances have facilitated the emergence of new approaches for exercise training holding promise, especially those methods that integrate rehabilitation with virtual gaming.

Objective—The purpose of this study was to evaluate cardiac autonomic modulation in individuals with chronic stroke post-training using a virtual reality – based aerobic dance training paradigm.

Methods—Eleven community-dwelling individuals with hemiparetic stroke [61.7 (± 4.3) years] received a virtual reality-based dance paradigm for 6 weeks using the commercially available Kinect dance video game “Just Dance 3.” The training 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, with a total of 20 sessions. Data obtained for HRV analysis pre- and post-intervention consists of HRV for ten minutes in (1) supine resting position; (2) quiet standing. High-frequency (HF) power measures as indicators of cardiac parasympathetic activity, low-frequency (LF) power of parasympathetic-sympathetic balance and LF/HF of sympatho-vagal balance were calculated. YMCA submaximal cycle Ergometer test was used to acquire VO₂ max pre- and post-intervention. Changes in physical activity during dance training were assessed using Omran HJ-321 Tri-Axis Pedometer.

Results—After training, participants demonstrated a significant improvement in autonomic modulation in the supine position, indicating an improvement in LF=48.4 (± 20.1) to 40.3 (± 8.0), p=0.03; HF=51.5 (± 19) to 59.7 (± 8), p=0.02 and LF/HF=1.6 (± 1.9) to 0.8 (± 0.26), p=0.05]. Post-training the participants had significantly higher VO₂ max. Number of steps during dance intervention significantly increased from the 1st to the 20th session (p<0.05).

Conclusion—The current study is the first to assess the effect of a virtual reality-based aerobic dance training paradigm on HRV among individuals with chronic stroke. Given that the paradigm used in this study improves cardiac autonomic control, future studies should incorporate dance as an adjuvant therapy into clinical treatment program and assess its long-term efficacy.

Keywords

Dance; heart rate variability; stroke; physical activity
INTRODUCTION

Cardiovascular and cerebrovascular disorders are a major cause of mortality worldwide [1]. Stroke is the fifth leading cause of mortality in the United States, with more than 800,000 incidences each year [2]. Nonfatal stroke results in detrimental long-term disability, with around 75% of stroke survivors diagnosed with cardiac disease [3]. Studies have shown that debilitations caused by cerebrovascular disorders bring upon adverse changes in the autonomic function and lead to cardiac impairment [4]. The combined effect of autonomic function and cardiovascular deconditioning, increases the risk of secondary stroke and mortality [5].

Several studies have also proposed that autonomic dysfunction will eventually lead to an anatomical asymmetry between the right and left cerebral hemispheres in the central nervous system (CNS) control of the autonomic nervous system [6]. The central autonomic network, which is organized into closely interconnected forebrain, pontomesencephalic, bulbopontine and the spinal levels and the frontoparietal cortical areas is particularly damaged. The most common clinical manifestation of autonomic dysfunction include abnormalities in heart rate and blood pressure regulation (reflecting cardiovascular autonomic dysfunction), pain modulation control, integration of behavioral responses to stress, loss of reflexes of respiration and circulation control. These alterations in the CNS system function may cause end-organ damage, predispose to cardiovascular events without any evidence of primary cardiac impairment and has also been shown to correlate with the neurological deficits [7].

Heart rate variability (HRV) was developed as a noninvasive method used to assess the autonomic modulation of the cardiac function through the sino atrial node [8,9]. Heart rate variability reflects the number of heart rate (HR) fluctuations around the mean HR. The HR fluctuations reflect altered balance of the autonomic nervous system tone characterized by increased sympathetic and/or decreased parasympathetic activity and is a widely accepted method for quantifying neural cardiac control [10]. Sympathetic over activity has been linked to a procoagulant state and also to risk factors for atherosclerosis, including metabolic syndrome, obesity and subclinical inflammation [11,12]. The high-frequency (HF) component of HRV, spanning approximately the range of 0.15–0.4 Hz, is attributed to respiration-induced heart rate modulation and is mediated primarily by parasympathetic outflow. A lower-frequency (LF) component of HRV, typically defined as 0.04–0.15 Hz, is believed to rather reflect a mixture of sympathetic and parasympathetic activities. The ratio of LF to HF (LF/HF) component of HRV, quantifies the changing relationship between sympathetic and parasympathetic nerve activities (i.e., the sympatho-vagal balance) [13]. Various studies have demonstrated that decreased HRV among individuals with Stroke has been associated with increased mortality [14].

Habitual physical activity (PA) has been associated with increased HRV indices in young and older healthy adults [15,16]. Especially, moderate to vigorous intensity of PA in healthy older adults has displayed improvement of the autonomic modulation to the sinoatrial node, as assessed by HRV [17]. Several possible mechanisms may be involved in PA improving cardiac modulation but specifically, it alters the balance between the sympathetic accelerator and the parasympathetic depressor in favor of greater vagal dominance, resulting in a decrease in resting HR and an increase in HRV [18]. Recent research has demonstrated that PA enhances autonomic control of the heart as indicated by training induced reductions in heart rate or increase HRV [19]. Studies on young adult population also shows an increase in parasympathetic tone after PA [20,21]. Intervention studies in young and healthy older adults have concentrated particularly on aerobic training for cardiovascular conditioning, demonstrating an increase in HRV and a decrease in resting heart rate after substantial periods of aerobic exercise [22]. Another alternative form of aerobic exercise being increasingly used in rehabilitation settings for improving physical activity is “dance therapy” [23]. Dance is one of the most desirable PA, which can have a similar effect to walk-jog exercise [24].

In addition to dance, virtual reality (VR) rehabilitation methods offer highly customizable, controllable and multimodal simulations [25]. Virtual reality technology-based training has been proposed to engage individuals in long-term PA, by promoting adherence through motivation [26]. In addition, VR games played by chronic stroke survivors have been shown to promote moderate to vigorous exercise intensity [27]. These methods could possibly lead this population to engage in interventions, along with improved cardiovascular fitness. Despite the positive gains, because of high cost, VR systems are still unavailable in many rehabilitation settings [28]. Off the shelf, low-cost video gaming systems like the Wii (Nintendo Co., Kyoto, Japan) and Kinect (Microsoft Inc, Redmond, WA, USA.), augmented by a virtual environment, provide stroke survivors a similar virtual experience and effective physical activity training [29,30].
In this study we examined a novel cost-effective virtual reality-based aerobic dance training, comprised of Xbox Kinect gaming to lay the foundation for an alternative aerobic exercise paradigm. The purpose of the present study was to evaluate the effect of autonomic cardiac modulation in community-dwelling chronic stroke rehabilitation. We hypothesized that there would be a significant improvement in HRV, in both supine and standing position, when comparing post- to pre-training values.

**METHOD**

**Study design and cohort characteristics**

Eleven community-dwelling ambulatory adults with chronic hemiparetic stroke participated in the current study after providing 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 at Chicago approved the study.

**Participant eligibility**

Individuals with chronic hemiparetic stroke (> six 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 ± SD disability status quantified using the Modified Rankin Scale [31,32] 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) or musculoskeletal disorders were excluded. All participants were screened for medications known to alter heart rate and excluded with any history of respiratory or cardiac diseases. Participants with indications of cardiovascular abnormalities as assessed by resting HR (> 85% of age-predicted maximal) and resting oxygen saturation (< 95%) were also excluded.

The participants were instructed to abstain from caffeine, alcohol, nicotine, and strenuous exercise 12 hours before each training session in an effort to reduce any effect of stimuli on the cardiovascular system. They were also instructed to make an attempt to have a full night’s sleep, light meal, and wear comfortable clothing and shoes that allowed adequate mobility during training. All procedures were carried out in the afternoon to standardize the influence of circadian rhythm. Evaluations and tests were performed in a room with controlled temperature (22–24°C) and relative humidity (40–60%).

**Procedures**

**Clinical evaluation**

Participants were initially required to complete a questionnaire on both self and family history. After which their height and weight was measured and their body mass index was calculated (kg/m²).

**Heart rate variability**

**Instrumentation**—Heart rate variability was measured using a wrist-based heart rate monitor (Polar RS800CX, Polar, Finland) with high reliability and validity. Polar® heart rate monitor consisted of electrode belt, transmitter W.I.N.D. and a heart rate monitor. The electrode belt and transmitter supported recording and processing of R–R intervals at a frequency of 1000 Hz and 2.4 GHz transfer between the belt and heart rate monitor.

**Data collection**—The participants skin was cleaned with alcohol and air-dried. Then, the electrode belt was strapped around the chest. Cefar® electrode transmission gel (Cefar-Compex Scandinavia AB) was applied liberally to promote conductivity. The participant was initially instructed to lie down on a couch in supine position without moving. Heart rate variability was recorded for ten minutes. Once done, the participants were asked to stand for 10 minutes, and similarly, data were collected. During both standing and lying down, the participants were instructed not to sleep or talk. The RR intervals of approximately three minutes in duration were selected for spectral analysis. The three-minute sets were resampled in the time domain using an antialiasing filter, with a sampling frequency of 1 Hz. An autoregressive spectral model was applied to the selected segments and the spectrum was calculated. Spectral power was calculated in the high-frequency (HF: 0.15 Hz < f < 0.4 Hz) and low-frequency (LF: 0.04 Hz < f < 0.15 Hz) bands. The LF/HF ratio (sympathovagal balance index) was also calculated. The percentage power in the LF (LF %) and HF (HF%) bands was calculated, based on the power of the respective bands and the total power of the set of RR intervals.

**YMCA submaximal cycle Ergometer test**—The YMCA test protocol was according to the procedure explained in the Y’s Way to Physical Fitness [33]. YMCA submaximal cycle ergometer test was shown to be a valid test in comparison to the conventional treadmill walking test [34]. Each participant was given a brief explanation of the test protocol. Once done, they were asked to begin exercising on a cycle ergometer at 25W on 50 rpm. Power output progression was based on the
participant’s HR response to the first stage of exercise. Each stage of the YMCA test lasted for 3 minutes. Whenever, the participant HR varied > 5 beats min⁻¹ between the last 2 minutes of each stage, they were required to cycle for an additional minute to ensure steady state. This method was used until HRs for the last 2 minutes were within ± 5 beats min⁻¹. In the scenario, where a participant’s HR did not reach a plateau or they failed to maintain the cadence, the test was considered invalid. The test was designed to have three stages: one 25W warm-up stage, and two additional submaximal stages. Heart rate was assessed using a Panasonic EW3109W monitor during the last 15 seconds of each stage.

Physical activity (PA) measure—Changes in the PA during the first, tenth, and last session of dance training were recorded using the Omran HJ – 321 Tri-Axis Pedometer. Research 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 [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.

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

Exercise Training Protocol

Intervention—Subjects received VR dance-based rehabilitation for 6 weeks using the commercially available Kinect dance game—“Just Dance 3” (Microsoft Inc, Redmond, WA, USA). The six-week training intervention was delivered using a high-intensity tapering method with the first two weeks consisting of 5 sessions/week, next two weeks at 3 sessions/week and last two weeks at 2 sessions/week for a total of 20 sessions [36,37]. The dance rehabilitation protocol consists of participants performing 10 minutes of warm-up and cool down stretching exercises before and after training to reduce the risk of exercise related injury. Participant’s played on 10 songs for the first 2 weeks, progressing to 12 songs during the 3rd and 4th weeks with an additional two songs of their choice during the last two weeks. Participants played on alternating slow and fast-paced songs (each maximum of 4 minutes duration) with a five-minute 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 HR ≤ 85 beats/min, measured by the Panasonic EW3109W, they were allowed to play the next song. The projected total time spent during each training session ranged from 1 hour 25 minutes to 1 hour 40 minutes for all subjects. In this way, all the participants were able to undertake the progression regimen used in this study in a similar manner. 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. The Schematic diagram of the study design, illustrated with the screen shots of the Kinect “Just Dance 3” games (song numbers) used for the intervention is represented elsewhere [38].

Statistical analysis

The VO2 max from the YMCA submaximal cycle ergometer test was computed with the following formula:

For males:

\[ \text{VO}_{2\text{max}} \text{ (ml min}^{-1}\text{kg}^{-1}) = (10.51 \times \text{watts}) + (6.35 \times \text{wt in kg}) – (10.49 \times \text{age}) + 519.3 \]

For females:

\[ \text{VO}_{2\text{max}} \text{ (ml min}^{-1}\text{kg}^{-1}) = (9.39 \times \text{watts}) + (7.7 \times \text{wt in kg}) – (5.88 \times \text{age}) + 136.0 \]

The SPSS version 20 statistical package was used for all analyses (IBM, Armonk, NY). The Kolmogorov–Smirnov test was used to determine the distribution (normal or non-normal) of the data collected. The Student’s paired t-test was used for key comparisons pre- and post-intervention. Statistical significance was defined as \( p<0.05 \) for all the tests.

RESULTS

Demographic data for all the participants in the study 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 hemi-
plegia. The study consisted of 11 individuals (60.75 ± 5.12 years) with five males and six females with body weight of 93.48 ± 41.27 and height of 169.27 ± 8.80. The majority of subjects were women and right hemisphere involvement was more common. A mean BMI level exceeding 30 kg/m² indicates the participants had a significant amount of excess body mass.

Heart rate variability
Heart rate variability data during supine and standing pre- and post-intervention resulted in a significant alteration in HRV in the supine position post-intervention (p < 0.05). Pre- and post-HRV comparisons for individual participants collectively illustrate that after receiving dance based aerobic intervention, subjects demonstrated a significant improvement in autonomic modulation in the supine position (p< 0.05), indicating an improvement in vagal tone (Figure 1).

YMCA submaximal cycle Ergometer test
Participants showed significant gains in VO₂max (p < 0.05) suggesting a significant increase in aerobic capacity post-intervention in comparison to pre-intervention (Figure 2a).

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 the first session. These steps significantly increased to 245 for slow and 456 for fast on the last (20th) training ses-

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**Table 1. Demographics and stroke characteristics of study participants.**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Gender M/F</th>
<th>Age (year)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Involved Side (L/R)</th>
<th>Stroke Type (H/I)</th>
<th>Onset (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>n = 11</strong></td>
<td>5/6</td>
<td>60.75</td>
<td>93.48</td>
<td>169.27</td>
<td>4/7</td>
<td>5/6</td>
<td>9.72</td>
</tr>
</tbody>
</table>

L = Left, R = Right, H = Hemorrhagic, I = Ischemic, M = Male, F = Female, BMI = Body mass index

Figure 1. Means (+SD) scores on the heart rate variability test for one week pre-intervention – Wk (week) 0 and one week postintervention (a) heart rate, (b) high frequency (HF), (c) low frequency (LF), (d) LF/HF. Significant differences with intervention indicated by * represent p < 0.05.
For the total sum of number of steps across all songs/session, there was a significant increase in number of steps recorded between the first and last training session \[F(2, 20) = 29.342, \ (p < 0.01)\]. The number of steps increased from 761.38 ± 401.82 on first session to 1679.9 ± 496.98 steps recorded at tenth session (Figure 2b).

**Feasibility and compliance**

The intervention was safe and feasible with participants having no falls or shortness of breath. In regards to compliance with 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 and last two weeks of 2 sessions/week) with the feasibility to reschedule their training days.

**DISCUSSION**

The purpose of this study was to investigate autonomic heart rate modulation adjustments in patient with stroke, in supine and standing postures, using HRV analysis before and after a novel aerobic training program. The findings in this study confirms the hypothesis that an aerobic exercise training using a Kinect dance game—“Just Dance 3” (Microsoft Inc, Redmond, WA, USA) significantly improves vagal tone.

Few studies have evaluated the effect of aerobic exercise training in stroke survivors. Following a 12-week bicycle ergometry physical conditioning program, stroke survivors demonstrated improvements in peak exercise workload capacity and Tennessee self-concept scale scores [39]. In another randomized control trial, chronic stroke survivors received a 10 week bicycle ergometry exercise program. This study showed improvement in maximal exercise, VO2 by 14% and suggested that aerobic training in stroke survivors can improve cardiovascular fitness comparable to levels similar to that expected in healthy adults [40]. These studies have showed improvement in exercise capacity with conventional protocols, such as stationary bicycling. However, evaluation of an alternative medium, such as virtual reality-based aerobic dance training for which chronic stroke population has shown higher rate of adherence and motivation in comparison to conventional methods, has not been yet done. Also, as cardiovascular fitness is brought about by sustained physical activity, training paradigms that facilitate regular physical activity into daily life is crucial for this population.

Heart rate variability is, to a degree, influenced by age-related alterations in the balance between parasympathetic and sympathetic modulation, occurring throughout the developmental processes, which results in greater variation of HRV behavior in each decade of life [41]. The present study demonstrated that the supine position elicited greater sympathetic autonomic predominance in HR [42].

Assessment of HRV in both the supine and standing positions is common practice; these postural adjustments, however, are reflective of different components of autonomic function. Increased vagal tone in the
supine position is a desirable characteristic, which is in fact what was found in the current study. Therefore, pre- and post-intervention findings in the supine position should be considered the primary study endpoint, allowing us to conclude aerobic exercise training using a virtual reality-based aerobic dance improves vagal tone in stroke survivors. Increased sympathetic activity in the standing position is a normal physiologic response. This fact occurs because of the hydrostatic bypass caused by blood displacement from the central region to the lower extremities, thus reducing cardiac output and arterial blood pressure, as well as promoting activation of arterial and cardiopulmonary receptors [43]. In addition, there is also sympathetic activation caused by adrenergic stimulation, by the Frank–Starling mechanism, by stimulation of the renin–angiotensin–aldosterone system, and by other neurohormones [44]. Thus, no alteration in vagal modulation in the standing position from pre- to post-intervention is not surprising.

The peripheral pathway, spinal pathways, and brainstem circuits of the autonomic nervous system have been studied extensively [45,46]. However, little is known about the hemispherical influence on the autonomic control of cardiac rhythm or pseudomotor drive. In the study published by Korpelainen et al. [47] central disinhibition was suggested as the cause of contralateral hyperhidrosis for the great majority of individuals with hemispherical lesions. While this aspect requires further analysis, our findings are novel in the sense that they are the first to indicate that exercise training has the potential to improve vagal tone in individuals with chronic stroke. Future research should assess the potential for hemispherical influence on heart rate variability improvements postintervention in individuals with stroke.

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 [48]. As suggested by the recent literature, increased number of steps seen post-training in this study could have resulted in an increased endurance, as shown with the improved scores on six-minute walking test among stroke survivors. Further, endurance training has shown to positively influence how the autonomic nervous system controls cardiovascular function. Studies have also demonstrated that dance as a training paradigm may be effective in improving cardiorespiratory fitness among individuals with neurological conditions [49,50].

Most of the participants were adherent to the rehabilitation paradigm in this study (98% for first two weeks, consisting of 5 sessions/week and 100% for next 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 adherence for regular participation. In line with our findings, studies demonstrate that virtual reality rehabilitation, in comparison with conventional methods, provides the subject high levels of motivation and compliance and a strong sense of presence in the virtual environment [51]. Also, recent studies have also demonstrated that people with neurological disorders are motivated to attend dance classes regularly, have a high rate of adherence with a low dropout rate and often continue with the activity after the study period [38,52]. Immersion in the virtual environment has been demonstrated as a critical component to positive gaming experience [53]. Would virtual reality-based dance paradigms provide a multidimensional intervention approach for increased long-term compliance and cardiovascular fitness and hence reduced mortality in stroke survivors? This warrants further research with a randomized controlled trial, including a larger sample size and long-term follow-up.

To conclude, the results from this study support the effectiveness of a virtual reality-based aerobic dance training paradigm on improving heart rate variability in individuals with stroke. Moreover, implementing alternating forms of adherent and effective rehabilitation methods, such as dance with the help of off the shelf lower-cost gaming console virtual-reality gaming systems like Kinect (Microsoft Inc) add to the novelty of our study. Given the results, virtual reality-based dance gaming could be incorporated as a clinical intervention to address physical activity and cardiovascular fitness in community-dwelling chronic stroke survivors.

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