Dance-Based Exergaming To Improve Physical Function In Aging and Stroke

By

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Submitted as partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Kinesiology, Nutrition, and Rehabilitation in the
Graduate College of the University of Illinois at Chicago, Chicago, 2018

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Dedicated to my family — my husband (Raj), children (Shivani and Manaswini), parents (Shanthi and Subramaniam and my brother (Raj). Their constant encouragement and everlasting support have been crucial in all my endeavors through this research.

Acknowledgments

My thesis became a reality with great support and guidance from many individuals. I would like to extend my sincere thanks to all of them.

Foremost, I want to offer this endeavor to the God Almighty for the wisdom he bestowed upon me, and the strength, peace of mind, and good health to finish this research.

After which, I am highly indebted to Dr. Tanvi Bhatt for her guidance, supervision, and support throughout this endeavor. She has continuously encouraged me with my research and allowed me to explore and grow as a research scientist. I appreciate all her time, resources, funding, and mentoring to make my Ph.D. experience an inspiring delight. She is and will remain, my role model for a researcher, mentor, and teacher. I would like to thank the members of my Ph.D. committee, Alexander Aruin, Gay Girolami, Shane Phillips, and Susan Hughes for their time, helpful advice, and insightful suggestions on my research during the comprehensive exam, proposal, and thesis. I would also like to extend thanks to all the faculty and staff of UIC for helping and guiding me through the entire process.

I am thankful to all of my colleagues in the lab for being a part of this journey. I am grateful to Tejal, Rini, Prakruti, Ernest, Jay, Alison, Shamali, Emma, Riddhi, Lakshmi, Gonzalo, Anna, Shivani, Kavya, and Susy for their enthusiasm, as well as for their help and the experience that they have provided me with while working on various projects and during different phases of my research. I would also like to thank all who participated in this study; if not for them nothing would have been possible.

I would like to express my gratitude towards my family for all of their encouragement and support throughout this process. I wish to give my heartfelt thanks to my beloved and supportive husband, Raj, to whom I would like to express my unfailing gratitude. He was my PILLAR of constant encouragement even when the tasks seemed arduous and insurmountable.

I also would like to thank my lovable children, Shivani and Manaswini, who were very understanding and served as my motivation and inspiration for pursuing this undertaking, as well as my parents, Shanthi and Subramaniam, and my brother, Raj. If not for their dreams, loving upbringing, and nurturing I would not be who I am today.

Last but not least, I am much indebted to my in-laws who taught me that the distance between insanity and genius is measured only by success.

Savitha Subramaniam

Contribution of Authors

Chapter 1 is a literature review of the research questions of this dissertation. Ms. Alison Schenone assisted in editing this chapter. Chapter 2 represents an unpublished manuscript (Subramaniam, S., Bhatt, T. Does a dance-based exergaming training paradigm assist in successful aging in older adults? A preliminary study) for which I was the primary author. My research mentor, Dr. Tanvi Bhatt contributed to guide the research. Ms. Alison Schenone assisted in editing this chapter. Chapter 3 represents an unpublished experiment, and I anticipate that this will be published (Subramaniam, S., Wang, S., Bhatt, T. Dance-based exergaming for upper extremity rehabilitation in community-dwelling individuals with chronic stroke) for which I was the primary author. Dr. Tanvi Bhatt contributed to review and edit the manuscript. Shuaijie Wang had helped in the analysis of the data. Ms. Alison Schenone assisted in editing this chapter. Chapter 4 represents unpublished experiment and I anticipate prompt submission and publication (Subramaniam, S., Wang, S., Bhatt, T. Effect of a dance-based exergaming on movement kinematics and community ambulation among individuals with chronic stroke) for which I was the primary author. My research mentor, Dr. Tanvi Bhatt contributed to guide the research. Ms. Alison Schenone assisted in editing this chapter. Chapter 5 represents a published manuscript on partial data (Subramaniam, S., Bhatt, T. Does a dance-based exergaming training paradigm increase balance control in individuals with chronic stroke? A preliminary study) for which I was the primary author. My research mentor, Dr. Tanvi Bhatt contributed to reviewing and writing of the manuscript. Chapter 6 represents a comparison of the efficacy of a novel dance-based exergaming training for increasing physical function in aging and stroke. My research mentor, Dr. Tanvi Bhatt contributed to review the manuscript. Ms. Alison Schenone assisted in editing this chapter. Chapter 7 represents my synthesis of the research presented in this dissertation and conclusions.

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List of Abbreviations

HRV - Heart Rate Variability

VR – Virtual Reality

DBExG – Dance-Based exergaming

ICF - Classification of Functioning, Disability, and Health

CoP - Center of Pressure

HR – Heart Rate

UE – Upper Extremity

CoM – Center of Mass

BoS – Base of support

ADL – Activities of Daily Living

CNS – Central Nervous System

AMSTAR - Assessment of Multiple Systematic Reviews

GRADE - Grading of Recommendations Assessment, Development and Evaluation

SOMC - Short-Orientation-Memory-Concentration

PA - Physical Activity/ Peak acceleration

MT – Movement Time

BD – Burst Duration

MIT – Movement Initiation Time

EMG – Electromyography

ABC – Activities Balance Confidence scale

TUG – Timed-up- Go test

AP – Antero-Posterior

ML – Medio-lateral

MCT – Motor Control test

LOS – Limits of Stability test

LO – Liftoff

BBS - Berg Balance Scale

FES - Fall Efficacy Scale

IMI - Intrinsic Motivation Inventory Scale

RT – Reaction Time

MXE – Maximum Excursion

MV – Movement velocity

WS – Weight symmetry

HF – High frequency

RMSSD - Root Mean Square of the Successive Differences

Chapter I - Introduction

1.1 Background

Aging and neurological diseases are the leading causes of fall prevalence and activity limitation in the United States. Most falls are linked to impaired balance control, gait instability, and worsening cognition, which are common symptoms in both aging individuals and individuals with neurological diseases, and this leads to physical inactivity. A sedentary lifestyle has been shown to be associated with increased risk for cardiovascular deconditioning, secondary stroke, and mortality. This, compounded with limitations in using the upper extremity (UE), increases fall-risk and decreases overall community functioning. Methods incorporating plasticity induced motor (re)learning and recovery are possible to address these UE limitations (Hallett, 2001). Some factors are thought to increase plasticity-based rehabilitation, such as task-oriented movement practice in a functional, engaging, challenging and meaningful method, with rehabilitation addressing not only body structures, but also their function, activity, and participation level (Bickenbach, 2012; Kwakkel, Kollen, & Krebs, 2008; Levac et al., 2016; Oujamaa, Relave, Froger, Mottet, & Pelissier, 2009; Timmermans, Seelen, Willmann, & Kingma, 2009). Evidence suggests significant effects of rehabilitation for older and neurologically impaired individuals with chronic stroke (Corbetta, Imeri, & Gatti, 2015; Page, Gater, & Bach, 2004; van der Lee et al., 1999). Recovery is correlated with the frequency and intensity of exercise (Garber, McKinney Js Fau - Carleton, & Carleton, 1992; Henderson, Korner-Bitensky, & Levin, 2007; Krebs, Volpe, & Hogan, 2009; Kwakkel et al., 2008). There are increasing community locations, and other facilities are offering rehabilitation in the form of conventional, recreational, and alternative (Yoga, Tai-chi) therapy (Ge et al., 2017; Lawrence et al., 2017; Zou et al., 2018). However, implementation of these techniques is tedious, resourceintensive, and costly; often requiring the transportation of individuals to specialized facilities, and long-term participation in physical activities is low among older individuals and those with disabilities (Henderson et al., 2007; Laver, George S Fau - Thomas, Thomas S Fau - Deutsch, Deutsch Je Fau - Crotty, & Crotty, 2015). Another alternative form of intervention which is being increasingly used in rehabilitation settings for improving motor function, cardiovascular fitness, cognitive ability, and physical activity (PA) profiles in older and neurologically impaired individuals is dance therapy (K. H. Cho, Lee, & Song, 2012)'(Fernandez-Arguelles, Rodriguez-Mansilla, Antunez, Garrido-Ardila, & Munoz, 2015; Hecox, Levine, & Scott, 1976). Dance is one of the most desirable forms of PA, and it can have a similar effect to walk-jog exercise (Garber, McKinney Js Fau - Carleton, & Carleton). Intervention studies in both young and healthy older adults have focused mainly on aerobic training for cardiovascular conditioning and demonstrated an increase in heart rate variability (HRV) and a decrease in resting heart rate after substantial periods of aerobic exercise (Hsu, Hsieh, Hsiao, & Chien). Recent studies have also demonstrated that exergaming –based rehabilitation methods when compared to conventional rehabilitation methods were shown to provide enhanced feedback about movement characteristics and improve motor task learning and execution for individuals with neurological deficits (K. H. Cho et al., 2012). Such rehabilitation methods could facilitate more interesting forms of interventions to be provided with less supervision while increasing functional recovery (Campos Jl Fau - Bulthoff & Bulthoff, 2012). Exergaming –based rehabilitation methods provide a highly customizable, controllable, and multi-modal simulation using visual, vestibular, auditory, and tactile inputs for rehabilitation, which generates high levels of motivation and compliance, and provides enhanced physical and cognitive benefits (Henderson et al., 2007; Laver et al., 2015). To address the shortcomings of conventional therapy for providing rehabilitative interventions, we would like to propose a dance and exergaming –based protocol. This protocol would be for upper and lower extremity conditioning and fall-risk prevention, and it would be an effective adjuvant therapy, addressing several limitations of conventional therapy while simultaneously providing the required benefits.

1.2 Statement of the Problem

New effective therapeutic approaches are essential for improving participant's compliance and impacting functional outcomes. Such innovative rehabilitation paradigms should also have the potential to primarily address the challenges of linking multiple domains of the International Classification of Functioning, Disability, and Health (ICF), particularly with regards to negating impairment at the body function/structure level (e.g., cardiovascular fitness, cognitive motor interference -CMI), increasing activity levels (e.g., increased PA), and improving community participation levels (e.g., increased community integration).

1.3 The Significance of the Problem

Currently, a lack of data impedes progress in the field of rehabilitation with adjuvant therapy for this population group. The importance of this project transcends rehabilitation for both aging and neurologically impaired individuals.

1.4 Conceptual Framework

Motor function - Methods such as “biofeedback” and “repetitive task training” have established efficacy for improving motor recovery in older adults. To provide biofeedback and repetitive task training, alternative mediums such as exergaming and dance have been used. Dance movements may be advantageous for older adults, as they facilitate continuous center of pressure (CoP) displacements within the individual’s stability limits. This results in improved symmetry in weight distribution, which in turn is associated with improved balance and gait while also reducing fall-risk. Additionally, dancing involves fast and repetitive full-body movements that could decrease the response time of self-initiated postural weight shifts (decreased time to initiate CoP excursion on the limits of stability test) while performing functional tasks in older adults. One of the main predictors for a decline in the initiation and performance of motor control, leading to falls in older adults is increased response time. Thus, dance-based exergaming training could improve motor control, providing a more holistic intervention while addressing recommended levels of PA.

Cardiovascular Fitness - Debilitations caused by sedentary aging adversely impact autonomic function and lead to cardiac impairment. Habitual, moderate to vigorous PA has been associated with increased HRV (the noninvasive method used to assess the autonomic modulation of the cardiac function through the sinoatrial node) and decreased resting heart rate (HR) indices for older adults. Several possible mechanisms may be involved in PA’s improvement of cardiac modulation, but it is specifically known to alter 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.

Community Ambulation and Fall Self-Efficacy - Increasing motor function and endurance could reduce fall-risk (Hwang & Braun, 2015). Individual’s risk for falls is highly correlated with fall self-efficacy and community ambulation, therefore, the proposed protocol aims to improve fall self-efficacy and community ambulation among this population group through increased PA.

1.5 Purpose of the Study

The purpose of this thesis is to evaluate the effect of a novel dance-based exergaming rehabilitation paradigm for increasing PA levels. It will also evaluate the paradigm's translation to enhanced motor (upper and lower extremity) function and improved cardiovascular function, in addition to its translation to increased community ambulation and decreased falls among older and neurologically impaired adults. To fulfill the purpose of this thesis, we would like to propose the following aims:

Aim 1:

The final purpose of this study is to evaluate the efficacy of a novel dance-based exergaming training paradigm for increasing PA levels while also evaluating its translation to increased motor functioning, increased community ambulation, and decreased falls among community-dwelling older adults.

Hypothesis:

Post-training, group A, who received dance-based exergaming training, will show significant improvement in motor function (balance, gait, and endurance) which will result in improved cardiorespiratory fitness (HRV) compared to their pre-training scores and also compared to group B who received education on conventional exercise and fall prevention programs.

Aim 2:

The purpose of the study is to quantify the effect of a high-intensity, dance-based exergaming training by evaluating the change in paretic upper extremity (UE) movement control on a stand-reaching (i.e. functional) task and examining the range of maximum shoulder joint excursions and the maximum shoulder joint angles that occur during the performance of dance movement for individuals with chronic stroke.

Hypothesis:

The findings of this study would confirm the hypothesis that participants would demonstrate increased performance outcomes (shorter reaction time and movement time) and increased performance production outcomes (movement initiation time and peak acceleration) on a functional stand-reaching task when comparing post-training to pre-training. Likewise, participants would demonstrate increased shoulder joint excursion and increased maximum shoulder joint angle in both flexion and abduction directions.

Aim 3:

The purpose of this study is to determine the role of a custom-designed, dance-based exergaming training protocol in improving movement kinematics during dance routines, while also improving PA levels, to determine if these improvements would translate to improved home and community-based activity profiles among individuals with chronic stroke.

Hypothesis:

We hypothesize that comparing post-training to pre-training results; will validate the effect of this dance-based exergaming training protocol for training center of mass (CoM) stability in anteroposterior and mediolateral directions while decreasing extremity joint angles on the paretic side. These improvements, in addition to gait improvement, will result in a change in PA profiles and community ambulation for individuals with chronic stroke.

Aim 4:

The purpose of this study is to examine the feasibility and effectiveness of a dance-based exergaming training paradigm for improving compliance and improving balance control, fall self-efficacy, and voluntary and reactive response to slip-like treadmill perturbations, along with evaluating its ability to assist community-dwelling individuals with hemiparetic stroke in achieving recommended levels of PA.

Hypothesis:

We hypothesized that when comparing post-training to pre-training, participants would demonstrate increased voluntary control on posturography and functional measures and increased reactive balance control on CoM position (XCoM/BoS) and velocity (XCoM/BoS) relative to the base of support (BoS) at compensatory touchdown. This would be demonstrated by increased stability, along with higher scores on a fall self-efficacy scale and on an intrinsic motivation inventory scale, post-intervention. There would also be an increase in PA throughout the training sessions which would be measured by the increase in number of steps.

Aim 5:

The purpose of this study was to compare the effect of a dance-based exergaming training paradigm for increasing PA levels while also evaluating its translation to increased motor functioning, increased community ambulation, and decreased falls between healthy aging and aging with stroke.

Hypothesis:

We hypothesized that when comparing the effect of dance-based exergaming training post-training to pre-training, both groups would equally demonstrate increased voluntary control on posturography, increased reactive balance control on CoM position (XCoM/BoS) and velocity (XCoM/BoS) relative to the base of support (BoS) at compensatory touchdown, gait improvement, resulting in an equal significant change in PA profiles and community ambulation for healthy aging and aging with stroke groups

1.6 Organization of Thesis

This thesis proposal is organized into eight chapters. Chapter I provide an overview of the background, research question, and the importance of the research, as well as a summary of the conceptual framework for all of the investigations. Chapters II-VII tests the aims of the experiments. Chapter VIII is the bibliography.

CHAPTER II

Evaluation of the efficacy of a novel dance-based exergaming training paradigm for increasing physical activity levels and subsequent evaluation of its translation to increased motor function, increased community ambulation, and decreased falls for community-dwelling older adults

2.1 Introduction

Age-related deficits, including decreased motor control, impaired balance control, gait instability, and worsening cognition result in a high risk for adverse health outcomes, especially increased risk for falls, which in turn reduces PA levels (Seidler et al., 2010; Wingert, Welder, & Foo, 2014). The reduced PA profiles predispose older adults to sedentary behaviors resulting in decreased quality of life, and these can increase cardiovascular deconditioning, decrease community integration, and increase the risk of mortality (Burtscher, 2015). It is estimated that by 2030, 20% of the US population will be older than 65 years of age. Research supports the importance of habitual PA and has shown it to have beneficial effects on motor control and cardiorespiratory fitness. Habitual PA has been associated with increased HRV indices (cardiovascular fitness) in healthy old and young adults (Fernandez-Arguelles et al., 2015; Foster, Golden, Duncan, & Earhart, 2013b; Hottenrott, Hoos, & Esperer, 2006; Mandelbaum, Triche, Fasoli, & Lo, 2015; Sharp & Hewitt, 2014b). Limited success in initiating and retaining older adults' PA indicates a critical need to explore a rehabilitation paradigm that targets achieving recommended levels of PA, while collectively addressing motor function and cardiovascular fitness, and translating the acquired improvements to long-term community integration for fall-risk prevention. Dance-based therapy is rooted in a solid neurophysiological basis to create a well-rounded rehabilitation therapy for older adults to improve their motor function, cardiovascular fitness, cognitive ability, and PA profiles (Hwang Pw Fau - Braun & Braun, 2015; Lakes et al., 2016; McCord P Fau - Nichols, Nichols J Fau - Patterson, & Patterson, 1989). However, future studies still need to analyze the efficacy of dance, along with the need to inspect changes to cardiovascular fitness, long-term retention, and translation to community measures of PA and falls for older adults. exergaming-based (e.g., Kinect Microsoft Inc, Redmond, WA, U.S.A.) dance training will also offer highly customizable, controllable, and multimodal simulations that induce high levels of motivation and compliance due to a strong sense of presence in the gaming environment (Chang et al., 2004). Based on this conceptual framework, integrating dance with exergaming could potentially facilitate cardiovascular fitness while providing individuals with a form of PA that simultaneously offers decision-making opportunities to facilitate complex cognitive processing required for community-living. Additionally, the integration addresses motor control and functional mobility leading to a better quality of life. Thus the purpose of this study was first to evaluate the efficacy of a novel dance-based exergaming (DBExG) training paradigm for increasing PA levels for community-dwelling adults, and then to evaluate its translation to the increased motor and cognitive function, as well as its translation to increased community ambulation and decreased falls. We first hypothesized that group A, which received DBExG training, will show significant improvement in motor function (balance, gait and endurance) which will result in improved cardiorespiratory fitness (HRV) post-training, compared to their pre-training scores and compared to group B which received the current standard of care which was education on conventional exercise and fall prevention programs. Secondly, we hypothesized that group A would have reduced CMI with decreased dual task motor and cognitive costs for balance and gait tasks post-training, compared to their pre-training performance and to that of group B (education on conventional exercise and fall prevention program). Lastly, we hypothesized that group A will have increased community ambulation (increased # of steps), increased community participation (Improved Community Integration scale), and decreased fear of falling (Fall Self- Efficacy scale) post-training, compared to their pre-training and group B.

2.2 Methods

Design, Participants, and Recruitment: The study used a randomized controlled trial design where participants were randomly assigned either to the DBExG group (Group A) or to the control group (Group B). Twenty subjects participated in the study (n =10 for each group). Participants were recruited using various forms of advertising including flyers, e-mails, print advertisements, and community presentations.

Subject Screening: Participants with any neurological, musculoskeletal, cardiovascular, or any other systemic disorders were excluded. They were also excluded if they had any drug usage or any severe visual impairment. Participants did not proceed with the testing if their resting HR > 85% of age-predicted maximal heart rate, if they were unable to stand for at least 5 minutes without an assistive device (length of dance game), or if they had a history of the spine or long bone fracture in the last 6 months. To be included, participants had to be ≥ 65 years of age, answer a general health questionnaire, complete a Physical Activity Scale for the Elderly (PASE), and achieve a minimum score of 8 on the Short Orientation-Memory-Concentration Test (SOMCT) which would prove “normal” cognitive performance. Additionally, participants had to give informed consent, which was reviewed by the Institutional Review Board.

Feasibility and Compliance: We examined feasibility by assessing participants' number of falls and shortness of breath. Participants' compliance with the training sessions was assessed by recording the number of missed training days for each participant. We divided the compliance to two categories, one was compliance for the vigorous first two weeks of training sessions, and the other was for the tapering next four weeks of training sessions.

The participants also completed assessments for balance control, PA, and functional measures, which were performed three times (one-week pre-intervention, mid intervention during the 10th training session, and one-week post-intervention). The details of each of these tests are described below.

2.3 Outcome Measures

Balance Control Measures

Intentional Balance Control Task: Voluntary balance control was assessed using the Limits of Stability (LOS) test protocol from Equitest (Computerized Dynamic Posturography). The LOS test required participants to be secured in a safety harness. The LOS test evaluates impairment of voluntary balance control by quantifying the participants' ability to move their CoP, by leaning their body, to their stability limits without losing balance, stepping, or reaching for assistance. Participants were asked to transfer their CoP while standing on stable force plates in the forward direction until a 45° interval around the body's CoP was displayed on a monitor in real time, and they were 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) to allow evaluation of the participants' capacity to voluntarily move the CoP to a position within the LOS which is fundamental for mobility tasks such as reaching for objects, progressinging from a seated to standing position (or standing to seated), and walking. The duration of each trial was about eight seconds. One familiarization trials was performed, after which data began to be collected. The outcome measures consisted of a temporal variable (response time -RT) and a spatial variables (movement velocity -MV of the CoP). Response time was the time in seconds between the command to move and the onset of participants' movement. Movement velocity was the average speed of the movement of the CoP in degrees per second.

Reactive Balance Control: Reactive balance was assessed using a slip-like perturbation test in stance. Kinematic data was collected using an eight-camera motion capture system at 120 Hz with Cortex-64 3.6.1 software [Motion Analysis, Santa Rosa, CA]. Twenty-nine reflective markers from a Helen Hayes marker set were placed on bilateral bony landmarks, on the head, and on the trunk, and these were used to collect full body kinematics values and then to compute the CoM position and joint angles of the participants. Following this, the processing and extraction of the variables of interest was performed using a customized MATLAB code [Math Works, Natick, MA]. To identify perturbation onset, one marker was placed on the treadmill belt. The obtained data from the marker was low pass filtered using a fourth-order Butterworth filter with a cutoff frequency of 6 Hz. The load cell data was sampled at 1200 Hz and was synchronized with the motion capture system using an analog-to-digit converter. A single slip-like support surface perturbation was induced in the forward direction from a standing position using a motorized treadmill (ActiveStep, Simbex, Lebanon, New Hampshire). Participants were instructed to stand in a comfortable position with feet shoulder width apart before the onset of the slip. They were held by a safety harness system which was attached via ropes to prevent the participants' knees from touching the treadmill belt if they were to fall. Participants were exposed to a single, large-magnitude forward perturbation at 0.67 m/s for 0.19 m with an acceleration of 16.75 m/s ^{2}. They were asked to execute a natural response to maintain their balance and prevent falling. The CoM position in the anterior-posterior direction was illustrated relative to the most posterior heel position ($X_{CoM/BoS}$) and was normalized to the foot length. The CoM velocity was computed by the first order differentiation of the CoM position and was normalized to a dimensionless fraction of g × h, where g is the acceleration due to gravity and h is the body height. The CoM velocity was taken relative to the velocity of the most posterior heel marker of the BOS ($\dot{X}_{COM/BOS}$). Postural stability was computed as the CoM position ($X_{CoM/BoS}$) and velocity ($\dot{X}_{COM/BOS}$)relative to the BoS at the first step touch-down (TD). More negative values for $X_{CoM/BoS}$ and $\dot{X}_{COM/BOS}$ imply the CoM is posterior to the BoS with a slower velocity contributing toward instability in the backward direction.

Gait Parameters: Gait speed and step length were recorded using an electronic mat GaitRite (CIR Systems, Inc., Sparta, NJ). It consists of sensors embedded into a 12 foot by 2-foot mat which measures spatial and temporal gait parameters using the accompanying GaitRite software (GaitRite Gold, Version 3.2). To record steady-state walking patterns, subjects were asked to begin walking about one meter before stepping on the mat and were told to keep walking until about two meters beyond the mat. Gait speed was recorded and defined as the distance walked during the walking time for that specific trial. Gait speed was selected to evaluate the change in motor function, as the effect of a concurrent cognitive task has been shown to be most evident for this variable.

Dual-task (DT) Conditions: Under DT conditions, subjects performed the intentional balance control test and the GaitRite test while counting backward. The counting backward test required transient holding and processing of existing and new information to assess working memory function.

Physical Activity Measure: Changes in at-home PA during the 20 sessions of dance training were recorded using the Omran HJ – 321 Tri-Axis Pedometer. Previous literature evidence supports the use of a simple and inexpensive pedometer, which measures the number of steps, as a valid option for assessing PA in research and in practice (Fabre, Chamari, Mucci, Masse-Biron, & Prefaut; Rand, Eng, Tang, Jeng, & Hung, 2009). The Omron pedometer features advanced Tri-axis sensor technology which allows accurate measurement of PA. The pedometer was worn on an adjustable elastic waist belt perpendicular to the ground. This was determined to be the most precise mounting position of the four mounting positions proposed by the pedometer manufacturer (Omron healthcare, INC., Made in China). To ensure correct usage, a research assistant carefully demonstrated the mounting of the pedometer on the waist belt and asked the participants to provide a repeat demonstration.

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. The Polar® heart rate monitor consisted of an electrode belt, a 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 with 2.4 GHz transfer between the belt and the heart rate monitor.

Data Collection: Before using the electrode belt, the participants' skin was cleaned with alcohol and was allowed to air-dry. 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 the supine position without moving. HRV was recorded for ten minutes. Once complete, the participants were asked to stand for ten minutes, and similarly, HRV data was collected. While 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 both 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 calculated. The percentage power in the LF (LF%) and HF (HF%) bands was also calculated based on the power of the respective bands and the total power of the RR interval set.

Functional Outcome Measures: Standardized clinical outcome measures were used to assess balance control (Berg Balance Scale [BBS]), risk for falls (Timed Up and Go Test [TUG]), and fear of falling (Fall Efficacy Scale [FES]) one-week pre-intervention and one-week post-intervention. The BBS has previously been used for assessing balance control in older adults and has both strong reliability and validity, and a high responsiveness to change. The TUG is an objective measure of basic mobility and balance maneuvers that determines participants' risk for falls. Similarly, the FES has been used extensively for evaluating fall-related self-efficacy and higher activity avoidance.

Motivation: In addition to the functional outcome measures, motivation for rehabilitation was measured using the Intrinsic Motivation Inventory (IMI) Scale. It has been used in several experiments related to intrinsic motivation and self-regulation, and it has been proven reliable in these studies.

Intervention: Group A received a high-intensity, tapering intervention five days/week for two weeks, followed by three days/week for two weeks, and ending with two days/week for two weeks for a total of 20 sessions with each session lasting about 1 hour and 40 minutes, including rest breaks and warm-up and cool-down time. Group A received DBExG training, while Group B received a one-hour education on conventional exercise and fall prevention programs

Protocol: A schematic diagram of the study protocol, demonstrating the chronological sequence of intervention for six weeks, is presented in figure 1. Community-dwelling, hemiparetic chronic stroke survivors received six weeks of DBExG training rehabilitation using the commercially available Kinect dance game [Microsoft Inc, Redmond, WA, U.S.A.] "Just Dance 3". Exergaming -based dance training consisted of a high-intensity tapering method of training, which included five sessions/week for the first two weeks, three sessions/week for the next two weeks, and two sessions/week for the last two weeks, for a total of 20 sessions (Fabre, Chamari, et al.; Hackney & Earhart, 2009b). To reduce the risk of exercise-related adverse effects, participants performed ten minutes each of warm-up and cool-down stretching exercises before and after the training. For the first two weeks, participants danced for ten songs. The participants then danced for 12 songs for the next two weeks, and finally ended with dancing for 14 songs for the final two weeks. Participants were presented with alternating slow- and fast-paced songs, which were each, a maximum of four minutes long. A mandatory five-minute break was provided after each set of one slow and fast song for the first two weeks. From the third week onwards, the participant's HR was measured by the Panasonic EW3109W after each song, and as long as it was ≤ 85 beats/min, they were allowed to proceed to the next song without having to wait the mandatory rest of five minutes after a set of one slow and one fast song. The approximate time taken for one training session ranged from one hour and twenty-five minutes to one hour and forty-five minutes. To prevent falls from occurring during the intervention, participants wore a gait belt and a researcher provided contact guard external assistance during the training.

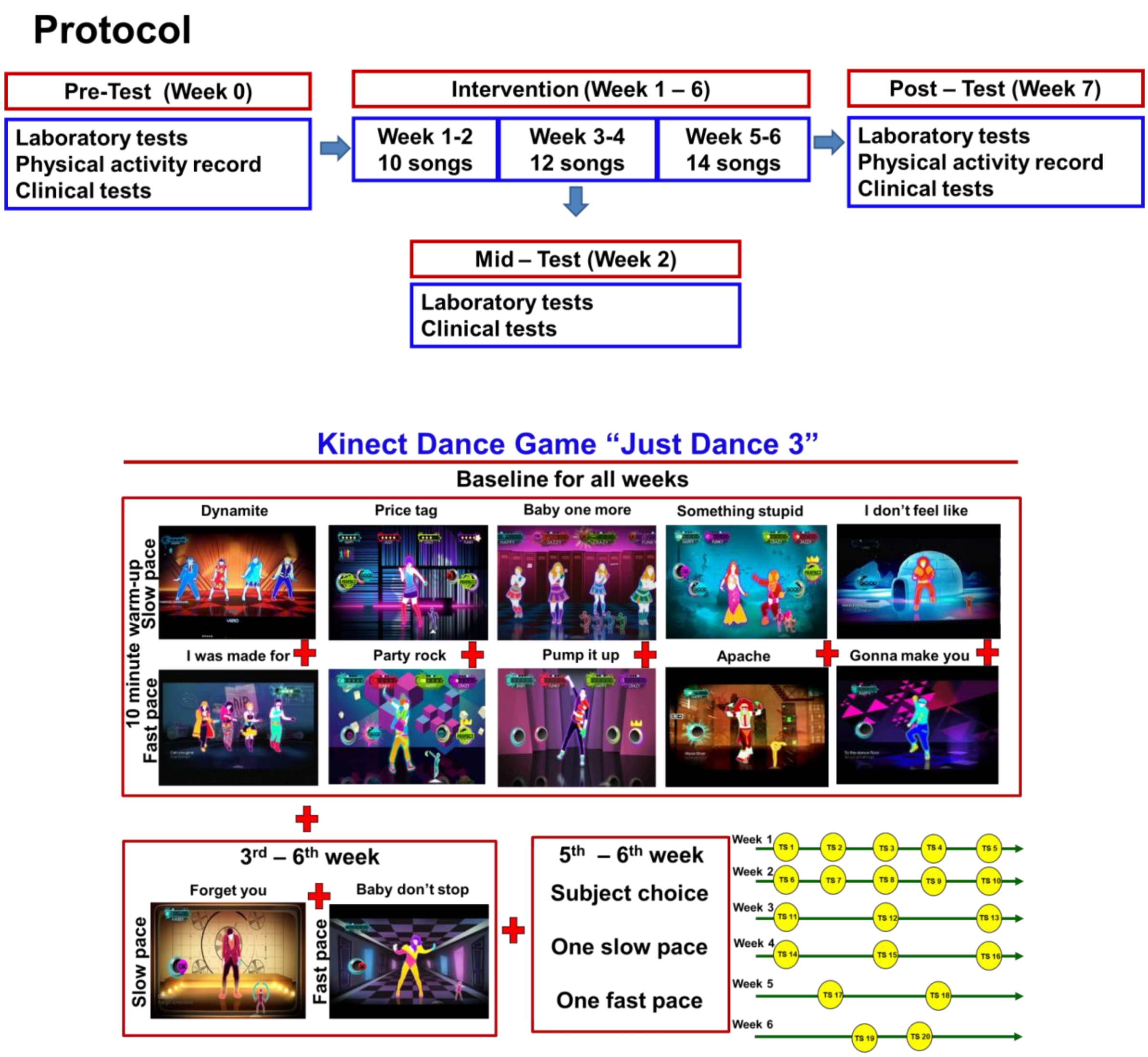

Figure 1 – Schematic representation of the study protocol

2.4 Statistical Analysis

A two way repeated measures ANOVA was performed to determine if there was any change in performance in self-initiated voluntary balance control using the LOS test to measure RT and MV. Similar analysis was conducted for reactive balance stability and step length at touchdown during slip perturbation. GaitRite measures for velocity and step length, changes in functional measures such as those measured during BBS, TUG, and 6MWT, and measures for HRV were compared between one-week pre-intervention and one-week post-intervention. These comparisons were resolved with 2*3 ANOVA followed by post hoc paired t-tests allowing comparison between both groups. A significance level (α) of 0.05 was chosen for statistical comparisons performed using SPSS software version 17.0. Any change in cognitive function was analyzed by comparing the motor and cognitive costs pre- and post-intervention on the self-initiated LOS test and other gait variables using a similar methodology to that described above. Heart rate variability measured pre- and post-training was resolved using 2*2 ANOVA followed by paired t-tests. Similarly, physical activity changes, measured by changes step count with intervention, were resolved with 2*2 ANOVA followed by paired t-test.

2.5 Results

Participant’s demographic information is shown in Table 1.

Table 1 Demographics and characteristics of community-dwelling healthy older adult participants

	Gender M/F	Age (year)	Weight (kg)	Height (cm)
Training group (n =10)	7/3	68.6±5.73	152.3±22.78	5.6±3.18
Control group (n =10)	6/4	68.6±2.14	158.9±6.15	5.8±2.18

M= *Male*; F=*Female*

The 2*2 ANOVA revealed that the DBExG training group had significant improvements in self-initiated CoP, RT [F(1,16) = 4.733 (p< 0.05)], and MV [F(1,18) = 14.801 (p< 0.05)] with no difference between the groups. Post-hoc analyses revealed additional improvement in performance of self-initiated voluntary balance control via RT and MV. Both the variables showed significant improvement post-intervention in the DBExG group in comparison to pre-intervention.

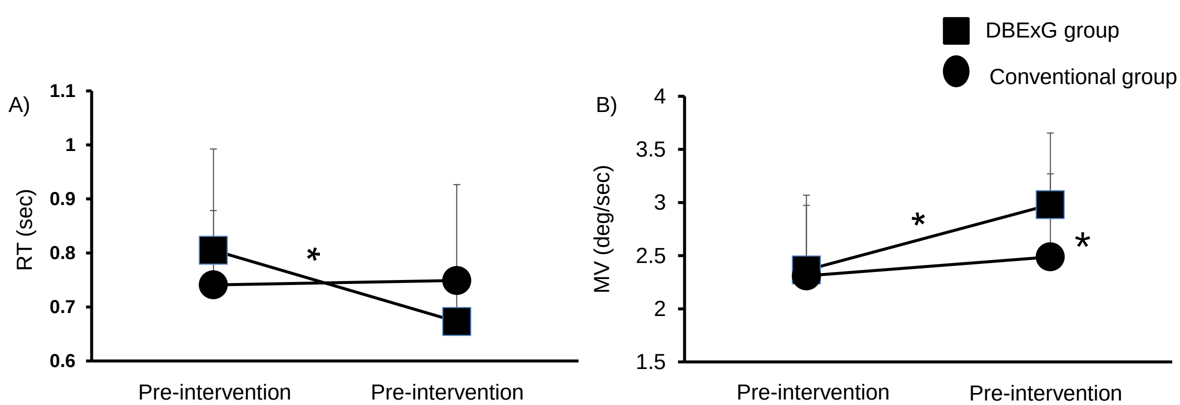

Figure 2 shows the mean ± SD limits of stability for pre-intervention and post-intervention scores of individual performance for A) Response Time (RT) in seconds B) Movement Velocity (MV) in degrees/second (d/s). As the response time was expected to decrease post-intervention, lower scores would indicate better performance. Increased scores in movement velocity were directly proportional to better performance. Significant differences ($p < 0.05$) are indicated by * .

Stance perturbation test exhibiting a main effect of intervention on step length [F(1,18) = 5.423 (p< 0.05)] with no difference between the groups (main effect of group, P> 0.05, no test*group interaction, P>0.05, and stability [F(1,18) = 7.664 (p< 0.05)] with test*group interaction, P<0.05). Post-hoc analyses showed significant improvements with intervention for step length for the DBExG training group (p < 0.05). Similarly, there was a significant difference in stability for the training group post-intervention (p < 0.05), and there was also a significant difference post-intervention between groups (p < 0.05).

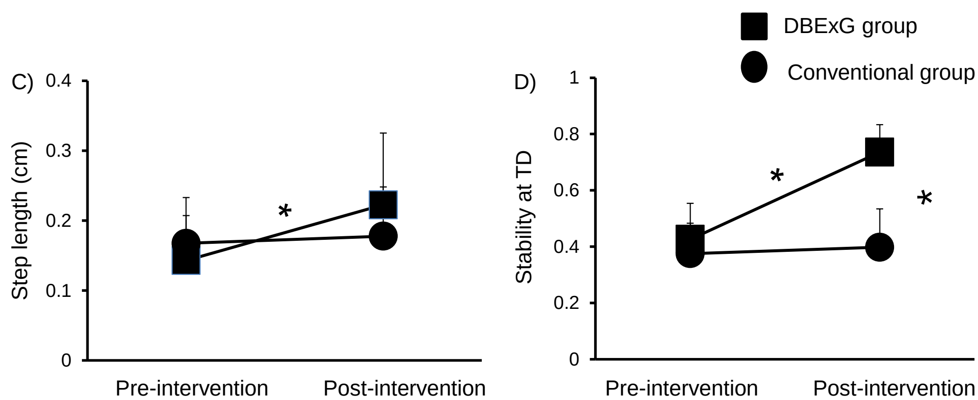

Figure 3 shows the means ± SD for the slip perturbation test for C) Compensatory step length and D) Stability at touchdown. Significant associations (p < 0.05) between the variables are denoted by *.

Gait variables were resolved with 2*3 ANOVA to resolve any pre-intervention, mid-intervention (during the10th training session), and post-intervention effects between the groups. The main effect of the task was seen in changes for both gait speed [F(2,36) = 6.554(p< 0.05)] and step length [F(2,36) = 3.295(p< 0.05)]. There was also a main effect for task*group on gait speed and step length (p <0.05). Post-hoc analysis demonstrated that there was a significant increase in both gait speed and step length for the training group both pre-intervention to mid-intervention and mid-intervention to post-intervention (p < 0.05). There was also a significant improvement in these variables in the training group pre-intervention to post-intervention (p < 0.05). Between-groups analysis revealed there was a significant difference between the groups post-intervention (p< 0.05).

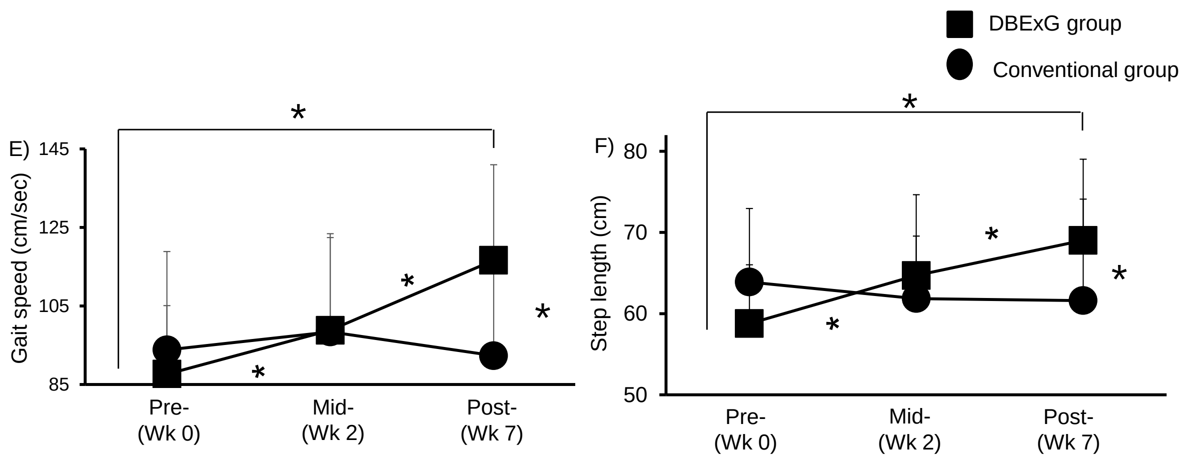

Figure 4 shows changes in E) gait speed and F) step length during preferred-speed walking for one-week pre-intervention – Wk (week) 0, (mid intervention) 10th training session – Wk (week) 2 and one-week post-intervention scores of individuals performance – Wk (week) 7.

With respect to HRV, there were significant effects of intervention on High frequency (HF)% [F(1,18) = 5.174(p< 0.05)] and Root mean square of the successive differences (RMSSD) [F(1,18) = 9.97(p< 0.05)], with no significant task*group effect for HF% but a significant task*group effect for RMSSD (p<0.05). There was also no significant between-group difference between pre-intervention and post-intervention HF%, however there was task*group effect for RMSSD (p< 0.05). Post hoc analysis revealed that HF% and RMSSD for the training group significantly improved pre-intervention to post-intervention. Furthermore, there was a significant difference in RMSSD between groups post-intervention.

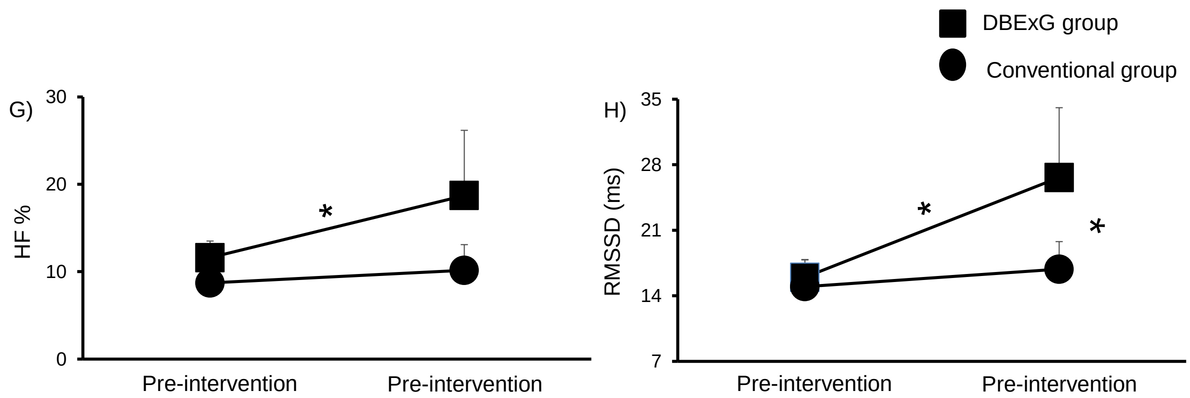

Figure 5 Means (+SD) scores on the heart rate variability test for one-week pre-intervention – Wk (week) 0 and one-week post-intervention G)HF% H) RMSSD (ms). Significant differences with intervention indicated by * represent $p < 0.05$.

For community ambulation, the mean number of steps/day increased from 6400.53 ± 1216.62 to 7029.19 ± 455.365 for the training group and increased from 6302.14 ± 1862.995 to 6378.07 ± 633.13 for the control group.

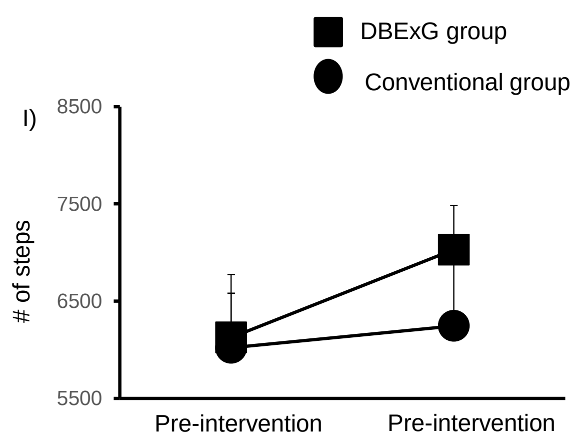

Figure 6 Means (+ SD) scores on a) Number of steps (# of steps) recorded one-week pre-intervention – Wk 0 and one week post-intervention week 7. Significant differences with intervention indicated by * represent $p < 0.05$.

Table 2 Clinical measures

	BERG		TUG		FES		ABC	
	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
DBExG Group								
Means	52.4	54.7*	10.41	9.68*	14	11.5*	87.83	93.68*
(S.D)	(1.26)	(0.82)	(0.84)	(1.18)	(3.4)	(1.43)	(6.09)	(6.39)
Control Group								
Means	52.7	52.2	10.91	10.54	13.4	12.7	88.60	89.41
(S.D)	(1.76)	(2.10)	(1.39)	(1.22)	(2.41)	(2.63)	(4.05)	(3.69)

BERG = *Berg Balance Scale*, TUG = *Timed Up and Go Test*, FES = *Fall Efficacy Scale*, ABC = *Activities of Balance Scale*. Two way repeated measures ANOVA indicated improvement in the clinical measures post-intervention for the training group. $p < 0.05$ is indicated by *. There was no significant difference between the groups ($p > 0.05$ for the main effect of group and $p > 0.05$ when comparing no test to group interaction)

2.6 Discussion

Evidence indicates that physical inactivity predisposes older adults to cardiovascular deconditioning, leading to a vicious cycle of community immobility, lack of social integration, and reduced quality of life (Avila-Funes et al., 2009; Avila-Funes et al., 2011; Tribess, Virtuoso, & de Oliveira, 2012; Virtuoso Junior, Tribess S Fau - Paulo, Paulo Tr Fau - Martins, Martins Ca Fau - Romo-Perez, & Romo-Perez, 2012). Relatively few older adults in the United States achieve recommendations for PA, and 28-34% of adults age 65 to 74 are physically inactive (Statistics). Older adults also have decreased compliance to any long-term PA regimen (Chang et al., 2004). This study evaluated the effects of DBExG on physical function, HRV, and PA. The results indicated that there was a significant effect of training on HRV, but, while there was an increased trend for community PA profiles, there was no significant effect on PA. Our findings are consistent with previous findings that PA is associated with a more favorable HRV profile for healthy older adults (Hedelin, Kentta, Wiklund, Bjerle, & Henriksson-Larsen, 2000; Stein, Ehsani, Domitrovich, Kleiger, & Rottman, 1999). These studies exhibited improvements in HRV using conventional protocols, such as stationary bicycling and walking. Recent research emphasizes the importance of PA, especially cardiovascular fitness, for older adults; however compliance with conventional methods of therapy has been lacking. Thus, the evaluation of an alternative medium, such as DBExG training, for healthy older adults is needed to compare results to conventional methods (Chang et al., 2004). Also, as cardiovascular fitness is induced by sustained PA, training paradigms that facilitate regular PA into daily life are crucial for this population. The cost for medical support for inactive adults are higher than for active adults and these increase with age (Fabre, Chamari K Fau - Mucci, Mucci P Fau - Masse-Biron, Masse-Biron J Fau - Prefaut, & Prefaut, 2002). This suggests that it could be possible to significantly reduce the health care costs by improving PA levels for older adults with alternative methods, such as the proposed DBExG training.

The results of this study also showed significant improvement for intentional and reactive balance control in the training group post-intervention. Studies have indicated that for balance training to be effective in older adults, there should be at least two or more physiotherapists present to facilitate the individual's progression of exercise and to challenge the participant (Halvarsson, Dohrn, & Stahle, 2015). Our DBExG training is the first of its kind to provide balance training using technology, and it has been established an effective methodology to train balance control while concurrently helping to provide the required PA for healthy older adults.

In addition, this protocol focuses on exploring a short-duration, high-intensity tapering method of DBExG training. A recent meta-analysis of previous studies have concurred the efficacy of a short-duration, high-intensity protocol and a few of intervention studies have exhibited that the tapering method minimizes accumulated fatigue without compromising attained gains on functional measures performance. Additionally, the tapering method reduces fatigue during the training regimen which may also increase compliance (Thompson, Arena, Riebe, Pescatello, & American College of Sports, 2013). A systematic review by Hwang (Hwang Pw Fau - Braun & Braun, 2015) observed across various dosages of intervention and also suggested that 45-minute sessions for at least once per week exhibited intervention effect on older adults physical function. The results of our study solidify the idea that a DBExG training protocol can induce effective rehabilitation for older adults, especially when using a short-duration, high-intensity tapering method.

Similar to the results in this study, and the rules evidenced by Sackett (Sackett, 1989) , other studies exhibited a relatively strong improvement in aerobic power, endurance, strength, flexibility, static and dynamic balance control, and gait speed with dancing among healthy older adults (Eyigor, Karapolat, Durmaz, Ibisoglu, & Cakir, 2009; Hackney & Earhart, 2009a; McKinley et al., 2008). Nevertheless, these studies have only assessed traditional, as well as aerobic and line, dance styles. A review by Justin et al. (Keogh, Kilding, Pidgeon, Ashley, & Gillis, 2009) have also emphasized that technical demands and movement patterns would alter the physiological and/or biomechanical requirements of the dance style in various ways, resulting in different adaptations to each dance form (Harris, Cronin, & Keogh, 2007; Schoene, 2007). Thus a standardized prescription of dance-based therapy would be twofold, one in helping older adults to improve their physical function, health, and well-being and more importantly delay the loss of these functional abilities. Secondly, such interventions can be easily accessible and tailored as required to the need of the population.

The influential changes in motor behavior with DBExG could have also been with the rhythmic auditory stimulation (RAS) provided in our study. Neuroimaging studies on dance with music in healthy adults have also exhibited shifts in cortical activation and dance-induced neuroplasticity (Brown, Martinez, & Parsons, 2006; Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005).   Previous studies have also exhibited plasticity changes induced by music training using task-based approaches(Pantev, Lappe, Herholz, & Trainor, 2009; Tabei et al., 2017). Furthermore, a bilateral network of brain regions related to motor function has also shown to be active, reinforcing that the music provided in this study in combination with physical exercise has greater beneficial effects on physical function. (Sarkamo et al., 2014).   Consequently, the intervention based improvement on motor function could be attributed to the auditory stimulus provided in this study during PA. In spite, that the above is a postulation, it would be constructive to further examine the same in future studies.

Given the importance of health and well-being, optimal participation in activities of daily living (ADL) should be considered as the ultimate goal of rehabilitation for healthy older adults (Buchman et al., 2009; Everard, Lach, Fisher, & Baum, 2000). The positive effects of DBExG on physical function improvements in this study could have stimulated community ambulation profiles, thus potentially leading to broader participation in ADL. Future work should examine the longer-term effects of the intervention and investigate the potential neurophysiological mechanisms underlying the benefits of such DBExG for healthy older adults.

Most importantly for future community application, because the training protocol was provided using an off-the-shelf, low-cost Kinect, it is highly economical and has the potential to lower long-term disability-related health care costs. Additionally, the design protocol provided increased motivation, evident in the improved intrinsic motivation scores, which is important because activity enjoyment and compliance are vital for long-term PA adherence. Thus, DBExG has the potential to be used as an at-home alternative medium for balance training while increasing the PA profile of healthy older adults and reducing the deterioration of motor and cardiovascular function for this population.

CHAPTER III

Dance-based exergaming for upper extremity rehabilitation in community-dwelling individuals with chronic stroke

3.1 Introduction

Impairment of upper extremity (UE) motor control is the most common neurological disability associated with stroke (Park, Kou, & Ward, 2016). About 75% of stroke survivors experience persistent motor deficits in the UE contralateral to the lesion, among which only 6% report satisfaction with their UE functionality (Kwakkel, Kollen Bj Fau - van der Grond, van der Grond J Fau - Prevo, & Prevo, 2003; Kwakkel et al., 2008; Nichols-Larsen, Clark Pc Fau - Zeringue, Zeringue A Fau - Greenspan, Greenspan A Fau - Blanton, & Blanton, 2005). Such motor deficits result in dependency during activities of daily living (ADL) as many require the performance of UE functional reaching movements (Jorgensen et al., 1995; Patel, Duncan Pw Fau - Lai, Lai Sm Fau - Studenski, & Studenski, 2000). Consequently, understanding how to promote motor recovery of UE function after stroke has been a significant challenge for stroke rehabilitation.

Upper- extremity rehabilitation, besides being critical for improving functional reaching and enhancing independence in ADL, could also improve its use during change-in- support strategies which are essential for preventing falls (Pijnappels, Kingma I Fau - Wezenberg, Wezenberg D Fau - Reurink, Reurink G Fau - van Dieen, & van Dieen, 2010). Change-in-support reaching movements provide the ability to prevent oneself from either falls or near-falls through responses such as protective lower extremity stepping and UE reaching and grasping an object for support. Studies have indicated that such change-in-support reaching movements are generated to change the individual's base of support to acquire a much larger degree of postural stabilization. For individuals with chronic stroke, the ability to employ rapid UE reaching for support is postulated to be a critical early defense mechanism for recovery from a balance loss, and it is shown to be an essential predictor of repeated falls (Maki & McIlroy, 1997). Because change-in-support UE reaching counterbalances postural instability, comprehensive rehabilitation strategies providing opportunities to train UE movement control and postural stability could reduce the risk of falling for individuals with chronic stroke.

Alternative therapies, such as dance could provide such a comprehensive rehabilitation, by implementing full-body movement practice. A systematic review analyzed the influence of dance on healthy older adults and found positive benefits for fall-risk reduction factors such as balance, gait, strength, and physical performance (Fernandez-Arguelles et al., 2015). Of particular interest, dancing has been shown to influence both balance control and UE functional reach among older adults (Murrock, Graor, & Sues-Mitzel, 2015; Shigematsu et al., 2002). These studies have suggested that the effects of dancing may extend beyond the context of dance to improve physical function. Similarly, a randomized controlled trial of community-based Argentine Tango dance program in people with Parkinson's disease showed a significant improvement of UE movement control in the dance-based exercise group in comparison to the control group (Duncan & Earhart, 2012). This further suggests that improved UE performance may be reflective of a global impact of dance. Given, the probability of dual benefits of improving balance control and reducing UE movement deficits, dance therapy could facilitate simultaneous improvement in UE reach kinematics while attenuating the risk of falls among chronic stroke survivors (Berrol, 1992; Decety et al., 1994; Roth et al., 1996).

Additionally, recent studies demonstrate that exergaming based rehabilitation paradigms provide opportunities for repeated physical practice and extensive bilateral UE training, incorporating audio-visual biofeedback (Laver et al., 2017). These studies shown increased recruitment of ipsilateral and contralateral motor pathways within both hemispheres and also a shift in cortical organization from contralesional (before exergaming training) to ipsilesional (after exergaming training) activation in the cerebral cortex, thereby increasing practice-induced neuroplasticity (Cauraugh & Summers, 2005; French et al., 2007; Jang et al., 2003; Jang et al., 2005). Such, cortical neuroplasticity has shown to improve the performance of paretic UE functional reaching movements (Carey et al., 2002; Cebolla et al., 2015; Johansson, 2011; Liepert et al., 2000; Wang et al., 2017). A recent Cochrane review focusing on the recovery of paretic UE function in individuals with stroke reported moderate evidence on the potential benefit of exergaming-based intervention paradigms on motor impairments (Pollock et al., 2014). Consequently, identification of a novel, cost-effective and feasible alternative forms of dance based exergaming (DBExG) could offer significant benefit for rehabilitating community-dwelling individuals with chronic stroke.

Thus, the primary purpose of the study was thus to evaluate the effect of a DBExG) training to assess paretic UE movement control. Additionally, the secondary aim of the study was to examine if improvements in UE control correlated with improvements in fall-risk measures. We hypothesized that post-training compared to pre-training participants would demonstrate increased movement control, marked by shoulder muscle activity on a functional stand-reaching task and shoulder joint kinematic on a DBExG trial. Further, there would be a positive correlation with improvement in UE movement control and clinical balance control measures.

3.2 Methods

Participants: Thirteen ambulatory adults with chronic stroke participated in the study. The Institutional Review Board of the University of Illinois approved the study, and informed consent was obtained from all of the participants. Participants were recruited by posting and distributing flyers at various stroke support groups, local neurologists' offices, outpatient clinics, and research centers.

Subject Eligibility: Participants were initially recruited in the study with a physician's confirmation of chronic (> 6 months) hemiparetic stroke. After which, participants were excluded if they self-reported active signs or symptoms of any discomfort in the shoulder, recent surgeries (< 6 months ago), or any other neurological (e.g., Parkinson's disease, vestibular deficits, peripheral neuropathy or unstable epilepsy), musculoskeletal, or cardiovascular disorders (Wade & Vergis, 1999a) during a phone screening. Participants were further excluded during the in-person screen if they were not able to stand independently for at least five minutes without the use of an assistive device so that they would be able to complete the DBExG training, had cognitive deficits (score > 10 on Short-Orientation-Memory-Concentration [SOMC] test), or with a resting heart rate of > 85% of age-predicted maximal and resting oxygen saturation < 95 during cardiovascular screening.

3.3 Outcome Measures

Data Collection and Analysis:

Functional Stand-Reaching Task

The apparatus design for the stand-reaching task used in this study has previously been thoroughly described, along with its reliability analyses (Varghese, Hui-Chan, Wang, & Bhatt, 2014). A schematic illustration of the reaching set-up is shown in figure 7. Participants were asked to stand with a shoulder-width base of support on a paper mat, after which their footprint was traced. They were asked to stand with the foot placed on the print to maintain a constant base of support throughout all of the testing conditions. For flexion reaching, participants stood to face the target, and for abduction reaching, participants stood sideways with their arms at their sides. The target was placed at 90% of the participant's maximum arm length away from them. The target was defined as the distance from the acromion to the tip of the middle finger. Participants were provided with three familiarization trials, after which they were required to perform three trial each of verbally cued forward reaching using shoulder flexion and sideways reaching using shoulder abduction. The verbal cues consisted of a first cue (preparatory), "Get Ready", given at two seconds, where participants had to visually focus their attention on the passive marker and a second, final cue, "Go", given at four seconds, at which point the participants were required to reach out and touch the target "as quickly and as accurately" as possible and then were to return to the starting position. Participants were reminded to keep their back supported against the wall between trials. If during any situation the participants missed the target or started to do the reaching task before the second verbal cue, they were asked to redo the trial. Such trial repetitions were given to reassure the precise performance of the task. Participants received a mandatory break of two to three minutes after a set of three trials to avoid fatigue.

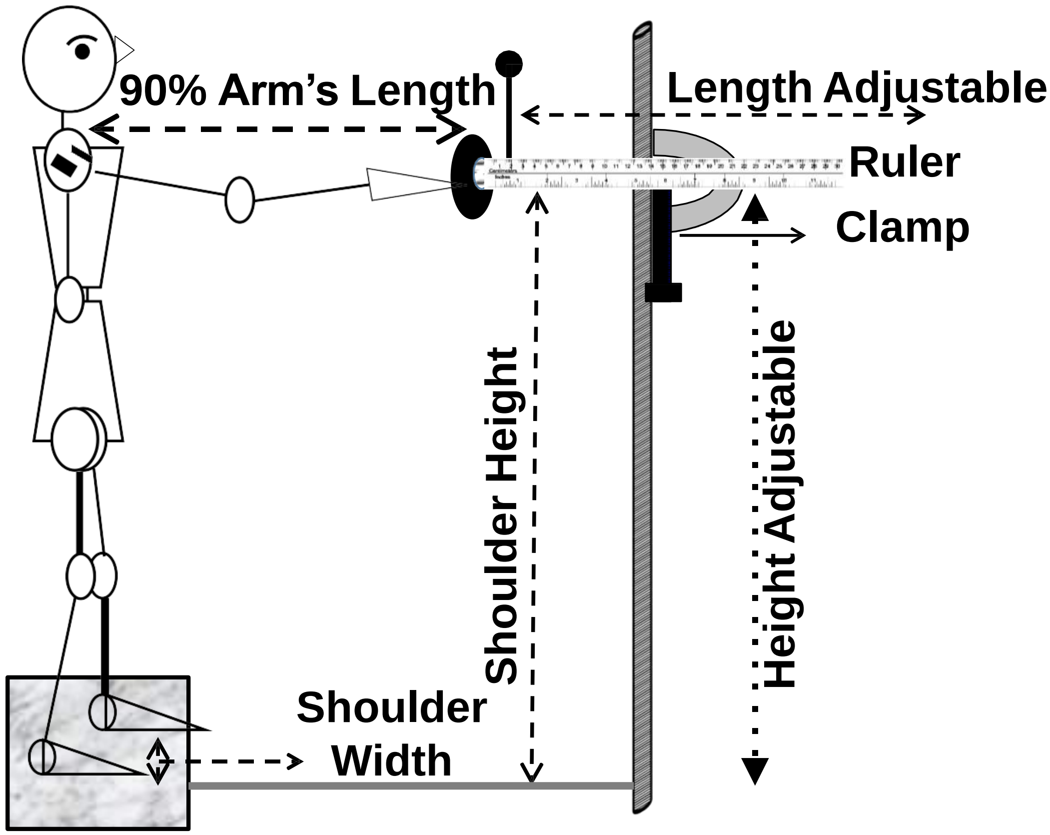

Figure 7 shows a schematic representation of the experimental set-up of a custom-made apparatus, including a ruler and eye-fixator marker held by clamp complex attached to a stationary pole which was adjustable in height and length. Participants were required to stand with shoulder width distance between feet, with a marker on a paper foot mat, and were to reach out to the target set at 90% of arm length. Participants were frequently instructed to keep the shoulder blades in contact with the wall at all times to control trunk movement. EMG sensors were affixed to the anterior and middle deltoid muscles of the dominant arm.

To record electromyography (EMG) activity, Delsys® Trigno™surface EMG sensors were used for the paretic UE (sensors placed on the anterior deltoid for shoulder flexion and the middle deltoid muscle for shoulder abduction). Using a common mode rejection ratio of >80 db, EMG signals were sampled at 2,000 Hz, and hardware band-pass was filtered over a bandwidth of 20–450 Hz. Tri-axial accelerometers embedded in these sensors rendered signals sampled at 148.1 Hz about a bandwidth of 50 Hz with an amplitude range of ±1.5 g. Signals were digitally high-pass filtered with a fourth-order zero-lag Butterworth filter (MathWorks, Inc., MATLAB) with a cut-off frequency of 20 Hz, were full-wave rectified, and then was low-pass filtered with a cut-off frequency of 50 Hz for smoothing the EMG data. Smoothing of the acceleration signals was achieved using a fourth order low-pass Butterworth filter with a cut-off frequency of 80 Hz. The acquired signal was later used to compute onset and offset to calculate movement time (MT). A total of six trials per subject was collected and analyzed from the involved prime mover, consisting of three flexion-reaching and three abduction-reaching trials. Trials were collected one-week pre-intervention, at mid-intervention during the 10th training session, and one-week post-intervention to acquire the variables of interest using a customized MATLAB code.

Performance Outcome Measures:

In the present study, reaction time (RT) was the interval between the final auditory cue "GO" at 4s and the initiation of EMG activity, measured in milliseconds (ms). Onset was defined as the time after 4s when the EMG signal exceeded two standard deviations (SD) of the ensemble average of the baseline (3s to 4s) EMG. Burst duration (BD) was defined as the time during which EMG activity was present, measured in milliseconds, and it was calculated as the interval between onset and offset latency of the EMG signal. Offset latency was defined as the time following the onset latency time point when the signal receded below two SDs of the initial resting baseline (0-4 s). Movement time was defined as the total time interval from the start to the end of UE movement, calculated as the time between the onset (> 2 + SDs) and offset of the acceleration (< - 2 S.Ds), measured in milliseconds (figure 8).

Performance Production Outcome Measures:

The maximum amplitude of the acceleration signal along the x-axis of the sensor's coordinate system was used for the peak acceleration (PA). The x-axis of the coordinate system was used for calculation because the sensor was placed relatively closer to the joint than the endpoint of the shaft. Hence, movement occurred along the sagittal axis of the sensor. The unit of measurement was g, (1g = 9.8m/s/s) (figure 8).

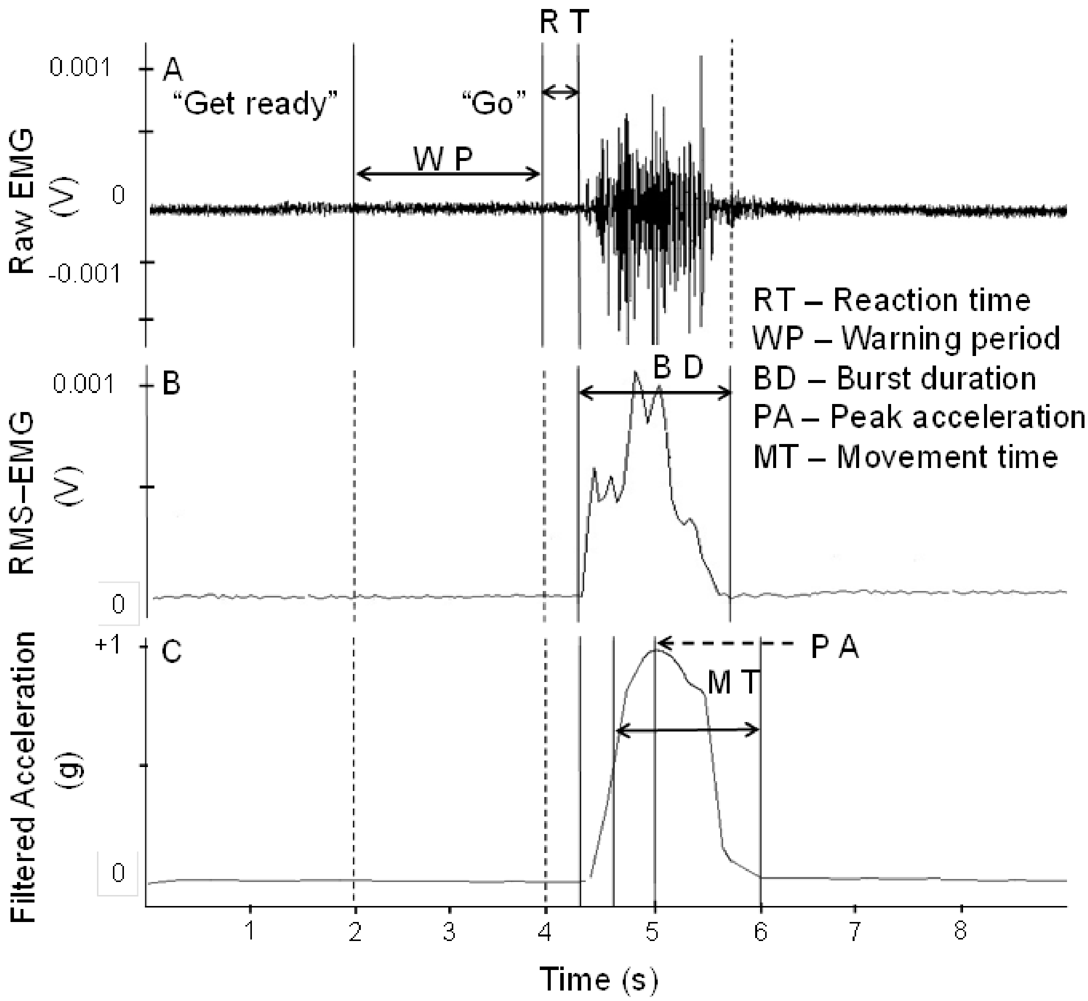

Figure 8 (A) Raw EMG, (B) Processed (filtered and rectified) EMG, and (C) Acceleration, which were sampled from the anterior deltoid during flexion-reaching, are depicted as the

variables of interest. Reaction time (RT) is the time between the final cue and EMG onset. Burst duration (BD) is the time between the beginning and end of the EMG signal. Movement time (MT) is the total time interval from the beginning to the end of the upper extremity movement. This was illustrated as the interval between the onset and offset of the acceleration signal. Peak acceleration (PA) is the maximum amplitude of the acceleration signal along the x-axis of the sensor's coordinate system.

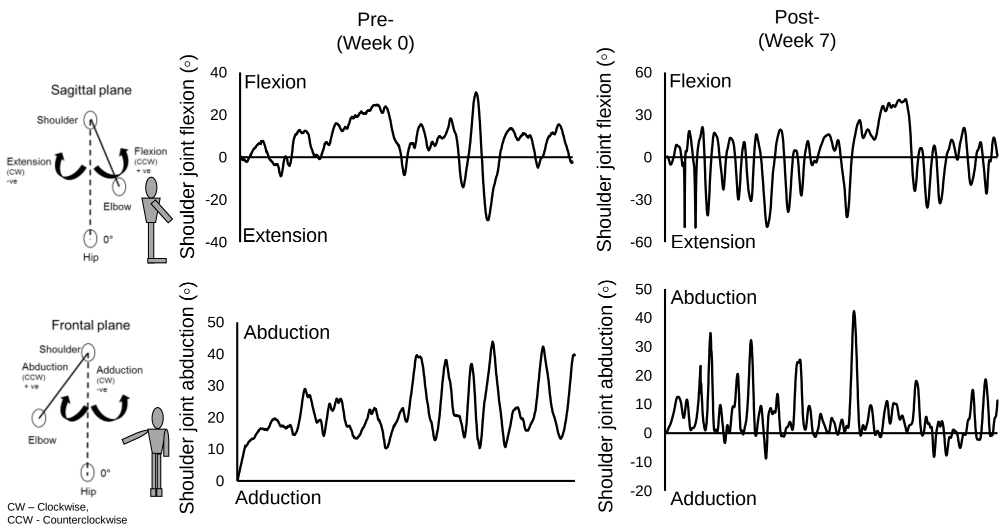

Figure 9 Free body diagram representation of flexion/extension (sagittal plane) and abduction/adduction (frontal plane) in degrees during a 30-second dance trial in the "Just Dance" Kinect gaming used in the dance-movement analysis test. CW – Clockwise, CWW – Counterclockwise. Raw plots for flexion and extension of the shoulder joint angles during a 30-second dance trial in the "Just Dance" Kinect gaming used in the dance-movement analysis test.

Dance-movement analysis test

Participants were required to perform dance movements using Microsoft Kinect "Just Dance 3" [Microsoft Inc., Redmond, WA, U.S.A.] for the song "Party Rock Anthem". Each dance trial was recorded for 30 seconds using an eight-camera motion capture system at 120 frames per second with Cortex-64 3.6.1 software [Motion Analysis, Santa Rosa, California], which recorded full-body kinematics. A Helen Hayes marker set, with 29 markers placed bilaterally on major joints, segments, and other positions on a participant's body was used to compute UE kinematics. The marker data were low-pass filtered using a fourth-order Butterworth filter with a cutoff frequency of 6 Hz. The UE shoulder joint peak angles in the sagittal and the frontal planes were computed and used for analysis. Shoulder flexion/extension angle was calculated as the angle between the vectors from the shoulder marker to the elbow marker and the vertical vector from the shoulder marker to the hip marker in the sagittal plane. Same method was used to obtain shoulder abduction/adduction in the frontal plane. In the sagittal plane, the maximum positive peak relative to the baseline value indicating maximum shoulder flexion and the negative maximum value relative to baseline indicating maximum shoulder extension were obtained. Similarly in the frontal plane, the maximum positive peak relative to baseline indicated shoulder abduction and maximum negative peak indicated adduction. Note not all subjects exhibited extension and adduction movements and stayed only in the positive movement half. Joint angle excursions were determined by calculating the difference between the maximum and the minimum peak shoulder joint angles for UE movements in both the planes. The excursion indicates the amount of free shoulder joint angulation acquired to perform the dance movement (Figure 9). All the variables were derived using a customized MATLAB code [Math Works, Natick, MA] and were manually verified (figure 9).

Functional Measures: Standardized clinical outcome measures, the Activities-Specific Balance Confidence Scale [ABC], and (Timed Up and Go Test [TUG] scales, were used to assess the risks of falls. Additionally, the stroke impact scale questionnaire, which measures changes in impairment categories, such as strength, hand function, activities of daily living (ADL), mobility, communication, emotion, memory, and thinking, was administered. All outcome measures were obtained one-week pre-intervention, (mid-intervention) 10^{th} training session and one-week post-intervention.

3.4 Statistical Analysis

Functional Stand-Reaching Task

One way repeated measures ANOVAs were performed to determine if there were any changes in functional stand-reaching task outcomes, performance-based (reaction time, burst duration, and movement time) or production-based (peak acceleration) variables and dance-movement test outcomes, peak should joint angles and excursion for pre-intervention, mid-intervention during the 10th training session, and post-intervention. Significant main effects were followed with post hoc paired t-tests. Significant main effects were followed with paired t-tests with Bonferroni corrections for controlling multiple comparisons.

A correlation analysis was conducted to evaluate pre- to post-intervention changes between functional measures and UE movement kinematics during the dance trial. Correlation analyses were performed between scores on the ABC scale and shoulder joint excursions and between TUG test scores and peak shoulder joint angles. The classification used for the correlations was < 0.49 = weak, 0.50-0.69 = moderate, and ≥ 0.70 = strong. A significance level (α) of 0.05 was chosen for statistical comparisons. Analyses were performed using the SPSS version 17.0 of the commercially available Statistical Package for the Social Sciences (SPSS).

3.5 Results

Demographics

Demographic data for the participants are presented in Table 3. Stroke impact scale found a mean of 33.41(S.D ± 5.56) for hand function, implying moderate impairment among individuals with chronic stroke (higher scores indicate a better health-related quality of life).

Table 3: Demographics and stroke characteristics for community-dwelling participants with chronic stroke

Subject	**Gender M/F**	**Age (year)**	**Weight (kg)**	**Height (cm)**	**I Side (L/R)**	**Concordant/ Discordant**	**Type (H/I)**	**Onset (year)**
n = 13	5/8				7/6	8/5	6/7	
Mean		60.75	93.48	169.27				9.72
SD		5.12	41.27	8.80				3.32

I Side = *Involved side*, L = *Left*; R= *Right*; H = *Hemorrhagic*; I = *Ischemic*; M= *Male*; F=*Female*; BMI= *Body mass index*; Concordant stroke = *dominant hand is also stroke-affected hand*; and Discordant stroke = *dominant hand is not stroke-affected*

A significant difference in RT [$F(2,89) = 8.518$, $p < 0.05$] during functional stand-reaching flexion- and abduction- tasks [$F(2,89) = 3.309$, $p < 0.05$] was noted between pre-intervention, mid-intervention during the 10th training session, and post-intervention measures. Post-hoc analysis showed significantly decreased RT for both flexion- and abduction-tasks from pre-intervention to post-intervention ($p < 0.05$), and mid-intervention to post-intervention ($p < 0.05$). There were significant changes in BD when performing the functional stand-reaching flexion- [$F(2, 89) = 1.475$, $p < 0.05$] and abduction- [$F(2, 89) = 7.931$, $p < 0.05$] tasks between pre-intervention, mid-intervention, and post-intervention measures. Post-hoc analysis revealed decreased BD from pre-intervention to post-intervention during both flexion- ($p < 0.05$) and abduction- ($p < 0.05$) tasks. Burst duration also decreased from mid-intervention to post-intervention for the abduction-task. There was also a significant change in MT during performance of both the functional stand-reaching flexion- [$F(2, 89) = 3.474$, $p < 0.05$] and abduction- [$F(2, 89) = 13.844$, $p < 0.05$] tasks between pre-intervention, mid-intervention, and post-intervention measures. Post-hoc analysis demonstrated decreased MT from pre-intervention to post-intervention during both flexion- ($p < 0.05$) and abduction- ($p < 0.05$) tasks. There was also a decrease in MT from pre-intervention to mid-intervention for the abduction-task ($p < 0.05$). Peak acceleration was significantly changed during performance of both the functional stand-reaching flexion- [$F(2, 89) = 8.522$, $p < 0.05$] and abduction- [$F(2, 89) = 5.255$, $p < 0.05$] tasks between pre-intervention, mid-intervention, and post-intervention measures. Post-hoc analysis showed a decrease from pre-intervention to post-intervention during both flexion- ($p < 0.05$) and abduction- ($p < 0.05$) tasks (figure 10).

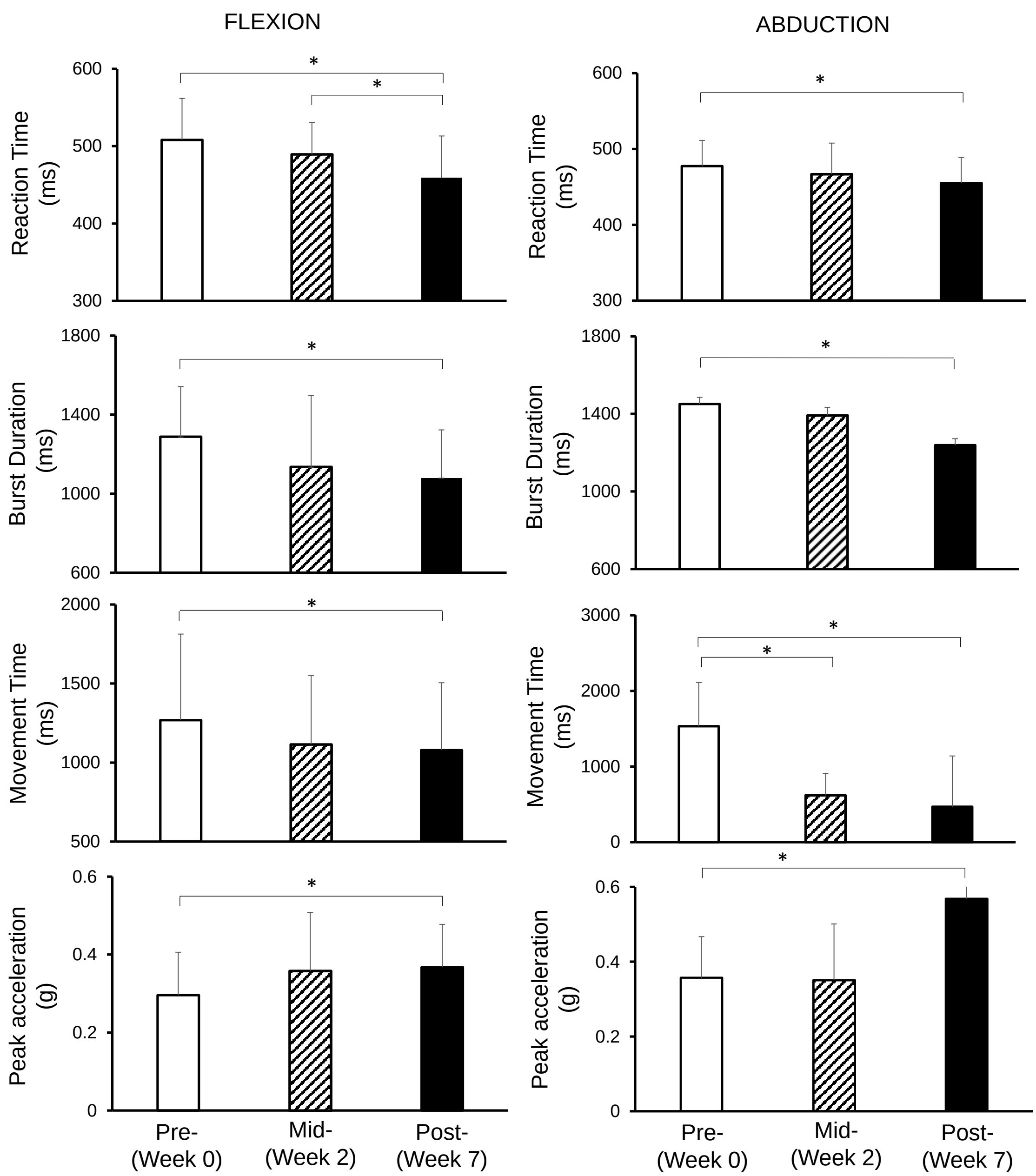

Figure 10 The data shows the effect of DBExG training on the paretic UE movement control for (A) Reaction Time (ms), (B) Burst Duration (ms), (C) Movement Time (ms), and (D) Peak Acceleration (g), with * indicating $p < 0.05$ for both flexion- and abduction-reaching movements

There was a significant change in the maximum shoulder joint angle for the dance-movement analysis test during UE movements in the sagittal plane – flexion/extension [$F(2,32) = 4.843$, $p < 0.05$] and in the frontal plane-abduction/adduction [$F(2,35) = 1.557$, $p < 0.05$]. Post-hoc analysis showed increased maximum shoulder joint angle during shoulder joint movements in both the planes from pre-intervention to post-intervention ($p < 0.05$). There was also a significant increase from mid-intervention to post-intervention ($p < 0.05$) during sagittal plane ROM. There was additionally a significant change observed in shoulder joint excursion for the kinematic dance test during both sagittal [$F(2,32) = 3.809$, $p < 0.05$] and frontal [$F(2,35) = 8.127$, $p < 0.001$] plane ROM. Post-hoc analysis showed maximum shoulder joint angle increased during both sagittal ($p < 0.05$) and frontal ($p < 0.001$) plane of ROM from pre-intervention to post-intervention (figure 11).

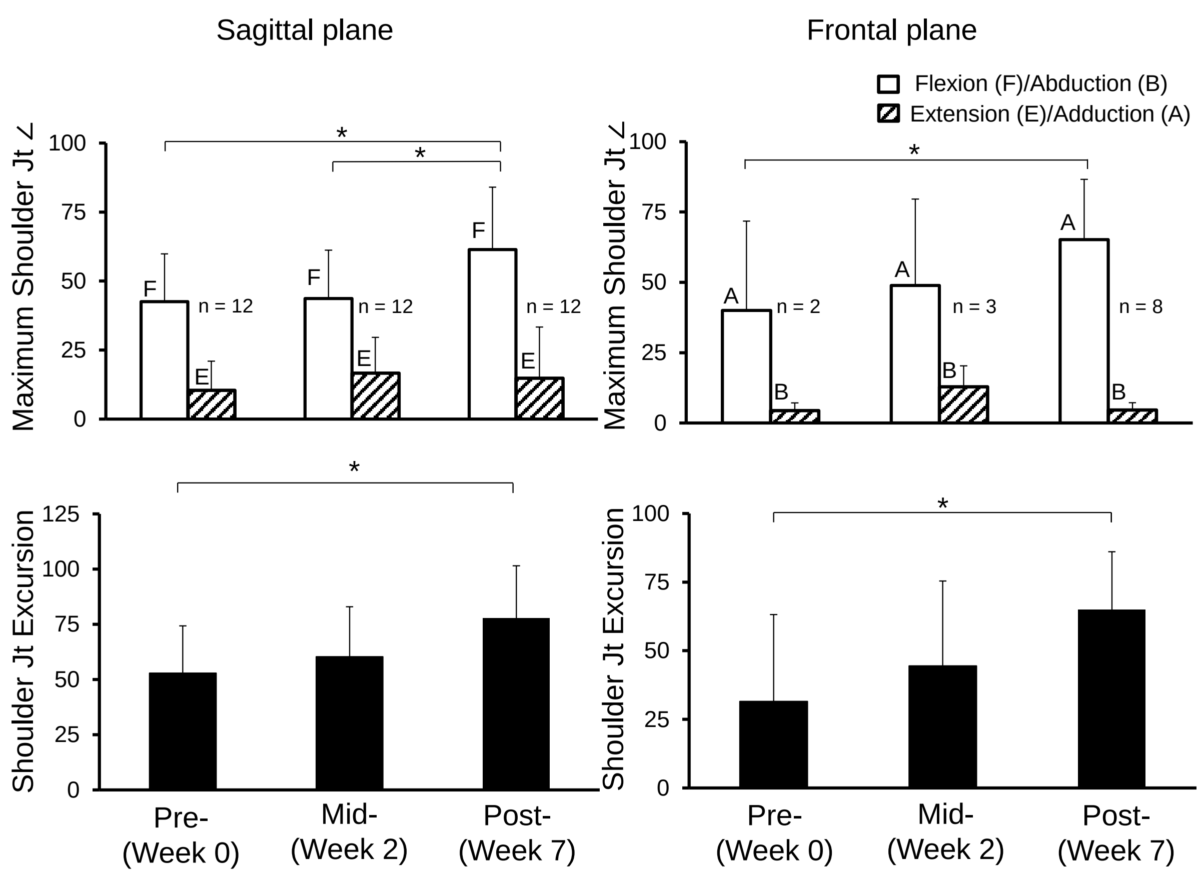

Figure 11 depicts post-intervention changes from pre-intervention measures of flexion- and abduction-reaching movements for A) Maximum Shoulder Joint Angle (Max Sh Jt ∠) and (B) Shoulder Joint Excursion (Sh Joint Ex), with * indicating $p < 0.05$.

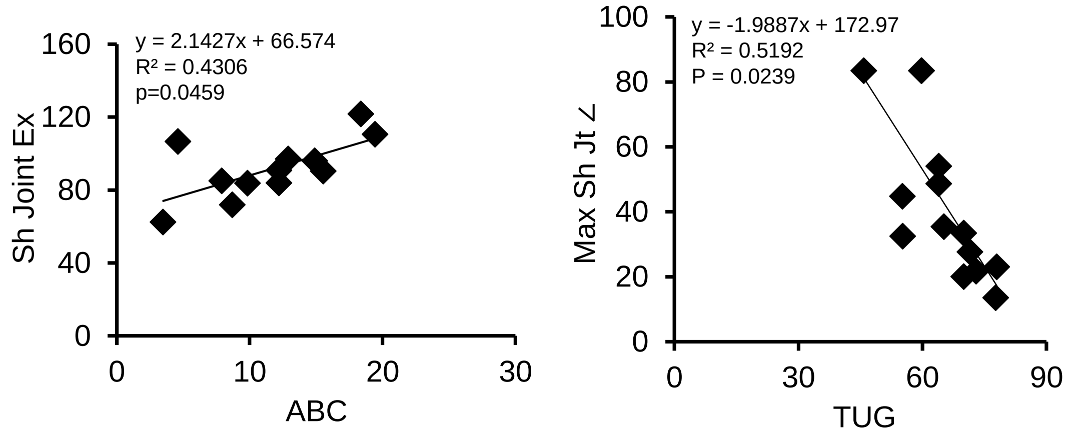

Figure 12 shows the mean (± SD) results for the clinical measures of: Balance Control (Activities-Specific Balance Confidence Scale [ABC]) linearly regressed with shoulder joint excursion (Sh Joint Ex) (R^2 = 0.4306, p = 0.0459, y = 2.1427x + 66.574), and risk of falls (Timed Up and Go Test [TUG]) linearly regressed with maximum shoulder joint angle (Max Sh Jt ∠) (R^2 = 0.5192, p = 0.0239 y = 1.9887x + 172.97) from pre- to post-intervention.

The ABC scores were significantly correlated with post-intervention changes in shoulder flexion excursion [R^2 of .43 ($p < 0.05$)]. Similarly, the TUG results were significantly correlated with post-intervention changes in peak flexion joint angle [R^2 of .52 ($p < 0.05$)] (figure 12).

3.6 Discussion

The dance-based exergaming (DBExG) resulted in significant improvements in paretic UE movement control as indicated by a significant change in outcome variables for both the stand-reaching test as well as the dance-movement analysis test. There were significant improvements in both performance-outcome and performance-production measures on the functional stand-reaching task. Furthermore, participants showed increased shoulder joint excursions and peak shoulder joint angles on the dance-movement analysis test.

While to the best of our knowledge there are no similar DBExG studies for chronic stroke survivors with which to compare our results, many exergaming-based intervention studies have focused on paretic UE training for functional reaching, lifting, and grasping motor skills (Askin, Atar, Kocyigit, & Tosun, 2018; Perez-Marcos et al., 2017; Warland et al., 2018). These studies have also found significant improvements in paretic UE clinical outcomes. The DBExG provided in this study improved UE motor function, along with improving its underlying neural control, as measured by the performance-outcome and performance-production measures respectively. Several beneficial strategies provided by the exergaming-based training could be responsible for such improvements. Studies have proven exergaming-based interventions enhance motor function through problem-solving-based learning and promote the performance of multiple repetitions of movement (Levin, Weiss, & Keshner, 2015). Recent evidence has also indicated that intensive, repetitive practice of movements can facilitate neural reorganization and efficient recovery of functional motor skills (Arya, Pandian, Verma, & Garg, 2011; Dimyan & Cohen, 2011). Specifically, studies have shown that post-stroke individuals who exhibited paretic UE motor function have also developed use-dependent plasticity changes via changed cortical activation patterns in response to exergaming-based training (Ekman et al., 2018; Schuster-Amft et al.). Additionally, exergaming technologies can also be applied to lend performance feedback in real time to yield the maximum benefit during rehabilitation. Such feedback-based training paradigms have been deemed crucial for motor task learning and skill acquisition, while also increasing stroke individuals' motivation to participate in therapy. Thus, it could be postulated that the exergaming-based training strategies, , could have resulted in cortical plasticity via a shift in cortical organization from contralesional to ipsilesional activation in the cerebral cortex, thus enabling individuals with chronic stroke to gain UE motor control (French et al., 2007; Wolf, Blanton, Baer, Breshears, & Butler, 2002).

As the study also intended to make the results obtainable to clinicians and determine if the participants are improving on functional UE movements, we divided shoulder joint movement kinematics into flexion/extension and abduction/adduction for further analysis. The significant increase in sagittal – flexion and frontal – abduction in comparison to extension and abduction respectively pre- to post-intervention could be attributed to the task-oriented training provided with the DBExG training. The DBExG encompassed multiple repetition of flexion and abduction during training in contrast to the other UE movements. Such significant benefits with DBExG could also be attributed to the bilateral UE movement training provided in this study. Prior studies have demonstrated that bilateral UE movement training is more efficacious than unilateral paretic UE training for individuals with chronic stroke (Coupar, Pollock, van Wijck, Morris, & Langhorne; Ekman et al., 2018). Studies from the last decade using bilateral movement training suggest that the use of intact UE promotes functional recovery of the impaired limb through the facilitation of the coupling effects of bilaterally distributed neural networks between both paretic and non-paretic UEs. Specifically, investigators with neurophysiological background found strong evidence that during symmetircal movement of both impaired and non-impaired UE, crossed facilitatory drive from the intact hemisphere produces increased excitability in homologous motor pathways in the impaired UE (Ackerley, Stinear, & Byblow, 2007). Such increased excitability could provide optimal conditions for functional gains and possible increased neural plasticity. Based on these findings, the bilateral UE training provided using DBExG in this study could also have accounted for the translation of the training effect to paretic UE movement control.

Furthermore, the results of this study support a positive correlation between intervention-induced improvements in UE movement kinematics (shoulder joint excursions and peak shoulder joint angles) and improved fall efficacy (ABC and TUG scores respectively). Change-in-support UE reactions, involving grasping or touching an object for support and rapid UE movements during self-induced or external perturbation, induce anticipatory feed-forward mechanisms. Such mechanisms promote recovery of equilibrium (postural stability) by regulating the relationship between the body's CoM and base of support. Stroke-related neuromuscular deficits can deteriorate change-in-support UE reactions, resulting in reduced fall self-efficacy. Additionally, studies which evaluated change-in-support or functional arm movements in young adults found increased involvement of shoulder joint motor control. Our study is one of the few studies incorporating UE movement control training along with lower extremity and balance control, in addition to training one to voluntarily shift one's center of mass to different spatial locations to maintain postural stability. Given that postural stability and UE, motor control is postulated to be controlled by independent and convergent parallel signals from the pontomedullary reticular formation (Schepens & Drew, 2004), it could be beneficial to train UE and postural stability control together. In support of our postulation, research on stroke rehabilitation has also indicated that these parallel control mechanisms need to be integrated for effective completion of ADL tasks without incurring a loss of balance or a fall (Kusoffsky, Apel, & Hirschfeld, 2001). The dance component of our study could have facilitated the integration of UE motor control with postural stability control.

The DBExG paradigm used in this study was designed to provide a short- duration, a high-intensity tapering method of training for six weeks, with each session being 1.5 hours long, for a total of 20 sessions. Study results show that the prescribed protocol intensity was appropriate and effective in rehabilitating chronic stroke survivors. Systemic reviews on post-stroke rehabilitation have recommended that the efficacy of post-stroke UE motor control training is associated with the intensity and dosage to which the neuromuscular system is challenged, suggesting that an intensity of twenty to sixty minutes per session of exercise per day for a total dosage of fifteen hours of training is ideal (Barreca, Wolf Sl Fau - Fasoli, Fasoli S Fau - Bohannon, & Bohannon, 2003). Recently, a few intervention studies have demonstrated that a tapering method increases compliance (Hackney & Earhart, 2009b). Because of this, our study used a tapering method of reducing the number of days to bring about compliance in the participants, and we provided an average of 30 hours of DBExGduring the six weeks. Given the results of this pilot study, future randomized control trials can evaluate the appropriate intensity and dosage needed for post-stroke UE rehabilitation with the proposed DBExG paradigm (Lang et al., 2009; Schweighofer, Han, Wolf, Arbib, & Winstein, 2009),

In conclusion, this study lends support to the possibility that DBExG could be a potential intervention to successfully address paretic UE movement control, while also reducing fall-risk for chronic stroke survivors. Future studies could strategically incorporate this DBExG paradigm as adjuvant therapy for a clinical treatment program to address the multi-faced requirement of stroke rehabilitation. Additionally, because individuals with stroke suffer external barriers to long-term rehabilitation such as the cost of, access to, transportation to, and caregiver support of therapy, future studies should consider examining the translation of such DBExG into a home-based exercise program.

CHAPTER IV

Effect of a dance-based exergaming training paradigm on movement kinematics and community ambulation among individuals with chronic stroke

4.1 Introduction

Stroke is the fifth leading cause of morbidity in the United States, affecting approximately 7 million people who exhibit a spectrum of sensory, motor, and cardiorespiratory deficits (Roger Vl Fau - Go et al., 2011). Of these, postural instability and gait deficits have been found to be present in nearly 80% of community-dwelling chronic stroke survivors, and these are responsible for approximately 40-70% of falls annually (Wei, Ke, Na, Cuiping, & Shouwei, 2017). In non-fatal circumstances, in addition to the risk of experiencing a fracture, these falls contribute to difficulty with ADL and severely impact health-related quality of life, both of which contribute to repeated falls (Carod-Artal, Egido, Gonzalez, & de Seijas, 2000; Mutai, Furukawa, Nakanishi, & Hanihara, 2016). Additionally, the average cost of managing a non-fatal fall is approximately $20,450 to $51,000l, creating an economic burden of $34 billion each year, which is expected to increase to $185 billion by 2030 (Hickenbottom et al., 2002; Joo, Wang, Yee, Zhang, & Sleet, 2017).

Post-stroke, individuals exhibit reduced ability to control their CoM motion and regulate their body's momentum (Yu et al., 2008). Such inability to control CoM directions has been shown to be associated with postural instability, thus leading to falls (Corriveau, Hebert, Raiche, & Prince, 2004; Niam, Cheung, Sullivan, Kent, & Gu, 1999). Furthermore, studies have shown that chronic stroke individuals have a general reduction in lower extremity joint movements, such as hip, knee, and ankle flexion during the different phases of gait. The ultimate result of these paretic lower extremity biomechanical alterations is a challenge to successful foot clearance (Corriveau et al., 2004; Cruz, Lewek, & Dhaher, 2009). Such ineffective foot clearance during gait is important because this has been associated with an increased risk of falls (Matsuda et al., 2017). Additionally, researchers evaluated community ambulation gait patterns and determined that a velocity less than 0.8 m/s is not safe for community ambulation as this is correlated with decreased fall self-efficacy and increased incidence of falls (S. E. Lord & Rochester, 2005). The combined effect of impaired ambulatory function, reduced fall self-efficacy, and an increased risk of falls predisposes this population group to sedentary behaviors, which in turn leads to reduced community integration and quality of life. This causes cardiovascular deconditioning, which in turns leads to an increased risk of secondary stroke and mortality (C. D. Lee, Folsom, & Blair, 2003). Given such vast consequences of postural and gait instability, the establishment of defenses against falls for community-dwelling adults, while concurrently improving their ambulatory capacity, is crucial for improving their quality of life.

Interventions to address postural instability and gait challenges for chronic stroke individuals, including methods such as lower extremity strengthening, electrical stimulation of lower extremity musculature, and gait training with body weight support on a treadmill, have been proven to be efficacious in outpatient rehabilitation centers (Dickstein, 2008; Ernst, 1990). But, free-living ambulatory activity patterns still have not been reported for the chronic hemiparetic stroke population (Michael, Allen, & Macko, 2005). A recent review by Lubetzky et al. (2010) assessed the current conventional training methods for stroke survivors and reported high attrition rates and a lack of long-term participation in the intervention programs. Based on the current research, it is imperative that alternative rehabilitation methodologies are identified, and these should incorporate enhancement of postural stability, gait function, and lower extremity kinematics, while also focusing on increasing motivation to ensure intervention compliance in an effort to restore community ambulation for this population group.

Dance movements, in particular, may facilitate continuous CoM displacements within the individual's stability limits, by which one could train rapid anterior-posterior and medio-lateral CoM displacements (Fernandez-Arguelles et al., 2015; Keogh et al., 2009). Such rapid CoM shifting is postulated to improve dynamic activities, such as gait, and could potentially be associated with decreased fall-risk. Although no other study evaluates the efficacy of dance on movement kinematics post-intervention for chronic stroke survivors, studies with younger adults have proposed that dance training facilitates postural stability (Rein, Fabian, Zwipp, Rammelt, & Weindel, 2011; Wilson & Kwon, 2008). Similarly, previous cross-sectional studies with young adults have also found that dancers had significantly greater lower extremity joint angles (hip, knee, and ankle) in comparison with non-dancers. Additionally, few studies have evaluated the effect of dance therapy on gait, but those that have shown improvement in mobility measures such as cadence, fast-swing percent, and fast-double support percent which exceed those of conventional training (Liederbach, 2010; Wilson & Kwon, 2008) . Specifically, McKinley et al. (McKinley et al., 2008) reported greater postural and gait stability in older adults who participated in Argentine tango compared with those who walked for exercise.

Furthermore, a recent review indicated that DBExG has an added advantage over non-exergaming-based interventions for the recovery of postural stability and gait function (Laver et al., 2015; Lohse, Hilderman, Cheung, Tatla, & Van der Loos, 2014). The authors propose that some factors such as repetitive variable practice, enhanced engagement, increased motivation, and added feedback which are associated with the exergaming systems and the new training paradigms could be important for this additional improvement. Based on the beneficial characteristics of the intervention methodologies, integrating dance with exergaming could potentially facilitate gait function for individuals with chronic stroke.

Thus the purpose of this pilot study was to examine the effect of a custom-designed, DBExG paradigm for improving full-body kinematics and gait function, thereby increasing fall self-efficacy and community-ambulation profiles for chronic stroke survivors. Based on conceptual postulation of the advantages of dance and exergaming-based rehabilitation, we hypothesized that participants would exhibit increased CoM excursion, lower extremity joint kinematics (full-body motion analysis), and improved gait function (GaitRite) post-training compared to pre-training. Such motor function improvements will also translate to increased activity profiles (number of steps in community ambulation) for community-dwelling stroke survivors.

4.2 Methods

Participants: Thirteen community-dwelling individuals with chronic hemiparetic stroke participated in this study after first providing informed consent. The presence of chronic hemiparetic stroke (for > 6 months) was confirmed by the participant's physician prior to enrollment in the study. Individuals were recruited by posting and handing out flyers at various stroke support groups, local neurologist's offices, outpatient rehabilitation clinics, and research centers. This study protocol was approved by the Institutional Review Board of the University of Illinois. Participant eligibility included the ability to stand independently for at least five minutes without the use of an assistive device. Participants' degree of disability or their dependence in daily activities status was quantified using the Modified Rankin Scale (Quinn Tj Fau - Dawson, Dawson J Fau - Walters, Walters Mr Fau - Lees, & Lees, 2009) and they were ranging from mild-to-moderate disability. Participants with surgeries (< 6 months ago), or any other neurological (e.g., Parkinson's disease, vestibular deficits, peripheral neuropathy or unstable epilepsy), musculoskeletal, or cardiovascular conditions were excluded from the study. Cardiovascular health were again identified at the lab screening by a resting heart rate > 85 % of age-predicted maximal or a resting oxygen saturation < 95% and these individuals were also excluded from this study. Additionally, individuals with cognitive deficits (score > 10 on the SOMCT of cognitive impairment were excluded(Wade & Vergis, 1999b)

Intervention protocol: Information on the DBExG intervention is provided in Chapter II.

4.3 Outcome measures

Biomechanical Analysis of Dance Movement

Data Collection and Instrumentation

Participants in the study were exposed to dance movements using Microsoft Kinect "Just Dance 3" [Microsoft Inc., Redmond, WA, U.S.A.] for a medium-paced song, "Party Rock Anthem", with specific dance patterns at 130 beats per minute (bpm) in both the AP and ML directions (Figure 12). The song "Party Rock Anthem" was classified medium-paced based on its bpm and it was chosen to match the aerobic exercise equivalent of brisk walking (3.5 – 4.5 mph), light elliptical use, or stair climbing (database., 2003-2017. [accessed].). All participants were instructed to imitate the exact dance movement patterns shown in front of them. One familiarization trial was provided, after which data was collected for three trials, each of which were for the duration of thirty seconds. Kinematic data was collected using an eight-camera motion capture system at 120 Hz with Cortex-64 3.6.1 software [Motion Analysis, Santa Rosa, CA]. Markers from the Helen Hayes marker set which included twenty-nine reflective markers were placed on bilateral bony landmarks, the head, and the trunk to collect full body kinematics values and to compute participants' CoM position and their joint angles. Following the trials, the processing and extraction of the variables of interest was performed using a customized MATLAB code [Math Works, Natick, MA] which generated CoM excursion, number of CoM peaks, maximum, minimum, and baseline peak CoM positions, number of joint angle peaks, and maximum, minimum, and baseline peak joint angles. Dance movements were recorded three times, and the average values for the outcome measures were then used for further analysis. The one-time data collection session lasted for 45 minutes.

Biomechanical Analysis of Dance Movement Outcome Measures

Postural Stability: Post-intervention changes in postural stability where determined by calculating the CoM excursions, number of CoM peaks, and the magnitude of the minimum, maximum, and baseline CoM Peaks in both the AP and ML directions. To acquire the CoM excursion, one CoM peak was identified as a complete cycle of an upward and downward displacement of CoM. The baseline peak was recorded as the mean of the CoM peaks for the first five frames before initiation of the dance movement, and the magnitudes of the minimum and maximum peaks during dancing were defined as the lowest and highest peaks for CoM movement, respectively (Figure 13).

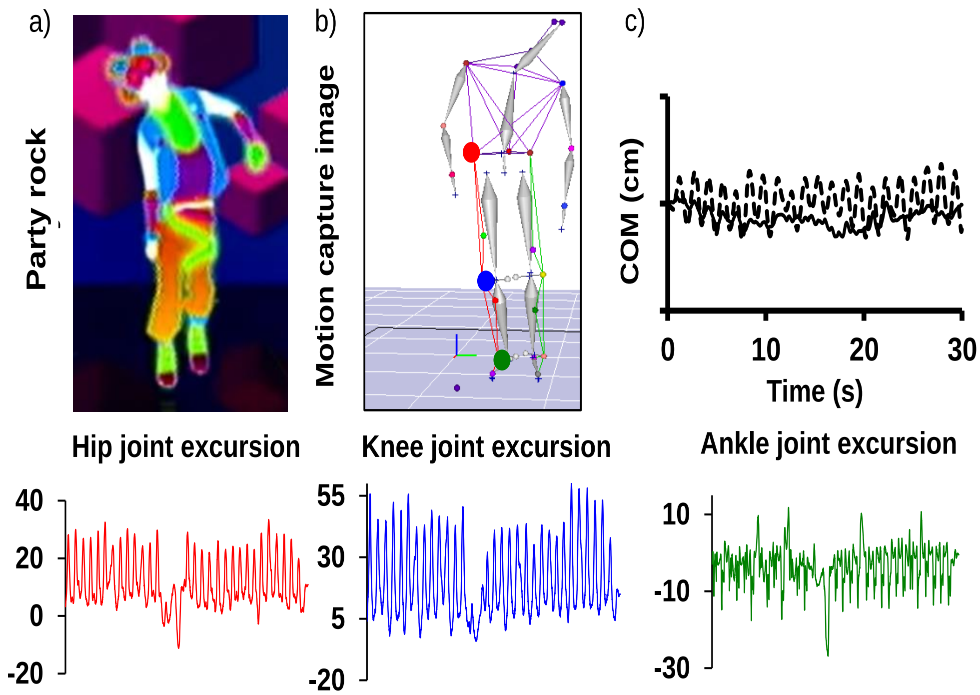

Figure 13 shows a) Dance routines in the Just Dance 3 gaming system that will be used in the study, b) A 3-D data view of a subject performing DBExG, c) Anterior-posterior (AP) and Medio-lateral (ML) CoM excursion for the song “Party Rock”, and d) Peak hip, knee, and ankle joint excursions for the song “Party Rock”.

Lower Extremity Joint Kinematics: Changes in mobility post-intervention were evaluated by determining the absolute number of peak joint angles and the magnitude of the peak joint angles for the hip, knee, and ankle. Body segment parameters and the joint angles were calculated according to the methods of Vaughan et al. (Vaughan, Davis, & Jeremy, 1999). The joint angles in the sagittal plane were then generated using three-dimensional trajectories of segmental markers by a custom-made MATLAB code. To evaluate joint excursion, one joint peak was defined as a complete cycle with the lowest and highest displacement of the joint. The baseline peak was the mean of the peaks from the first five frames before the start of the dance movement, and the magnitude of the minimum and maximum peaks was identified as the lowest and highest height of joint movement during the dance. Each joint excursion was also then assessed during dance movement by calculating the difference between all corresponding maximum and minimum peak joint angles.

Gait: Speed and cadence during walking were assessed using an electronic GaitRite® (CIR Systems, Inc., Sparta, NJ, USA). High reliability and validity have been recorded for the GaitRite® in comparison to other instrumented gait assessment systems (Roche et al., 2018). GaitRite® is a 12 foot by 2-foot mat which has sensors embedded to help measure both spatial and temporal gait parameters using the accompanying GaitRite Software (GaitRite Gold, Version 3.2). To document self-selected comfortable gait speed and cadence, participants were asked to begin walking about 1 m prior to stepping on the mat and were told to keep walking until about 2 m beyond the mat, with three trials recorded. These variables were selected to evaluate the change in motor function, and they are consistently linked to functional outcomes.

Community Ambulation: Changes in the physical activity profile during community ambulation (one week before and after intervention start) were recorded using Omran HJ-321 Tri-Axis Pedometer. Evaluation of free-living PA measures supports that the simple and inexpensive pedometer, which measures step count, is an efficient option for assessing PA both in research and in practice (Schneider, Crouter, & Bassett, 2004). The Omron pedometer procures advanced Tri-axis sensor technology, which enables accurate assessment of PA. In this study, we asked participants to wear the pedometer on an adjustable elastic waist belt perpendicular to the ground. This placement was chosen, instead of the other four mounting options proposed by the manufacturer (Omron healthcare, INC., Made in China), because it was previously reported to provide a precise assessment. To assure appropriate application, a research assistant demonstrated the mounting of the pedometer on the waist and asked the participants to execute the same procedure.

4.4 Statistical Analysis

A 2 × 2 repeated measures analysis of variance (ANOVA) was performed to determine post-intervention changes for each of the postural stability variables recorded during the dance movement, including changes in CoM amplitude and CoM excursion in the AP and ML directions during dance movement. Significant interaction was resolved with post-hoc paired t-tests. A 2 × 3 repeated measures ANOVA was conducted to analyze the effect of the intervention on hip, knee, and ankle joint angle excursions. Significant main effects were followed with post hoc paired t-tests. Similarly, to determine post-intervention changes in community ambulation (one week before and after intervention start), a paired t-test was performed. A significance level (α) of 0.05 was chosen for statistical comparisons performed using SPSS software version 17.0 for analysis.

4.5 Results

Participants' demographics and their performance on clinical performance are presented in Chapter III, Table 3. Fifteen participants underwent training, of which two were excluded and thirteen were included for the biomechanical analysis of dance movement due to error in the data collection for two individuals.

The 2 × 2 ANOVA revealed that there was a main effect of intervention on CoM amplitude [F(1,18) = 14.424, $p < 0.05$)] as well as a significant effect from pre- to post-intervention measure of CoM amplitude in the anterior-posterior and medio-lateral directions [F(1,18) = 4.351; $p < 0.05$]. However, there was no interaction between CoM amplitude in the anterior-posterior and medio-lateral directions for both pre- and post-intervention ($P > 0.05$). Post-hoc analysis of the main effects of intervention using paired t-test showed that there was a significant increase in CoM amplitude in both the anterior-posterior and medio-lateral directions during dance movement post-intervention ($p < 0.05$) (Figure 14).

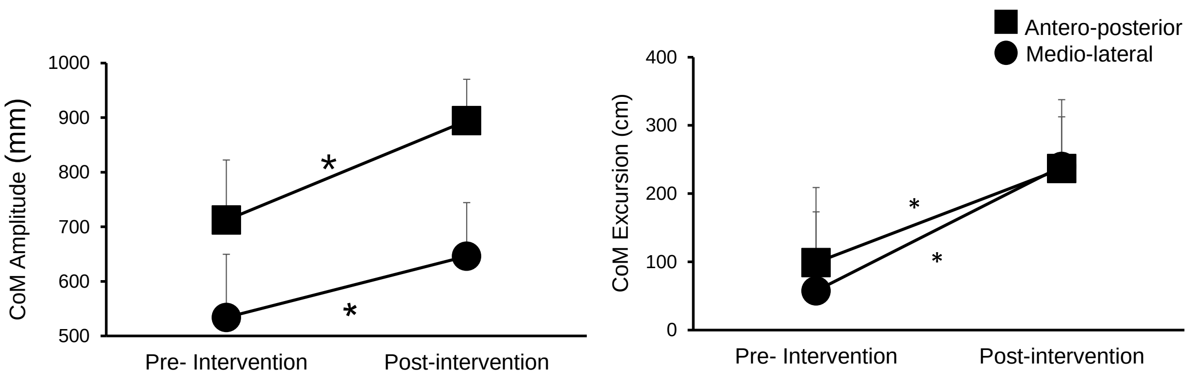

Figure 14 shows the AP and ML CoM (a) Amplitude and (b) Excursion. Significant associations ($p < 0.05$) between the variables are denoted by *.

For CoM excursion, there was a significant main effect of intervention on CoM excursion [F(1,18) = 1.79, $p < 0.05$)] with a significant effect from pre- to post-intervention measure of CoM excursion in the anterior-posterior and medio-lateral directions [F(1,18) = 48.062; $p < 0.01$]. There was no interaction between CoM excursion in the anterior-posterior and medio-lateral directions for both pre- and post-intervention ($P > 0.05$). Post-hoc analysis of the main effect of intervention using paired t-test showed improved CoM excursion during dance movements in both the anterior-posterior and medio-lateral directions post-intervention ($p < 0.05$) (Figure 14).

Results from the 2 × 3 ANOVA showed a significant main effect of intervention on joint angle excursion [$F(1,18) = 23.786$; $p < 0.05$] and a significant effect from pre- to post-intervention on the hip, knee, and ankle pre- and post-intervention [$F(1,18) = 59.481$; $p < 0.01$]. There was also an interaction between joint angles in the anterior-posterior and medio-lateral directions for both pre- and post-intervention [$F(2,36) = 4.968$; $p < 0.05$). Post-hoc analysis showed a significant increase in hip, knee, and ankle joint excursions pre- to post-intervention ($p < 0.05$). There was a significant difference between hip joint excursion and both the knee and ankle joint excursions pre- and post-intervention ($p < 0.05$). A similar difference was also seen between knee and ankle joint excursions for pre- and post-intervention ($p < 0.05$) (Figure 15). There was additionally a significant post-intervention effect on community ambulation and gait ($p < 0.05$) (Figures 16 and 17).

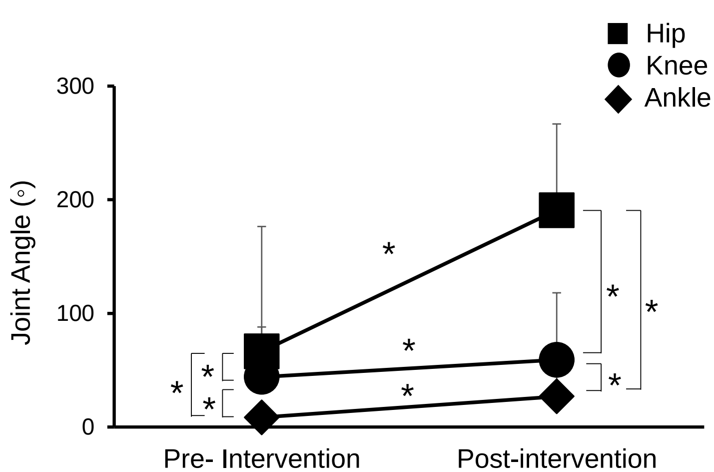

Figure 15 shows the hip, knee, and ankle joint angle excursions pre- and post-intervention. Significant associations ($p < 0.05$) between the variables are denoted by *.

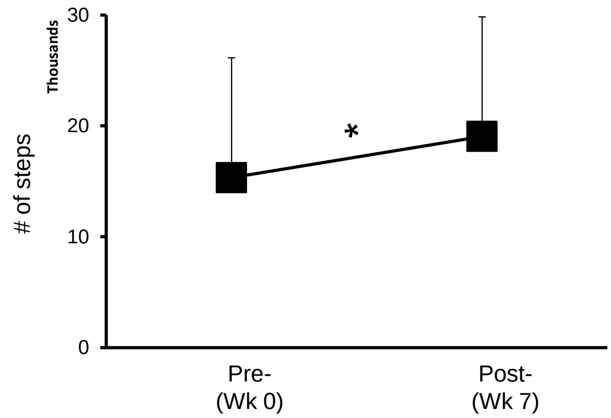

Figure 16 shows the number of steps during community ambulation (one week before training started and after training ended), where a greater number of steps indicates improvement in performance. Significant associations ($p < 0.05$) between the variables are denoted by *.

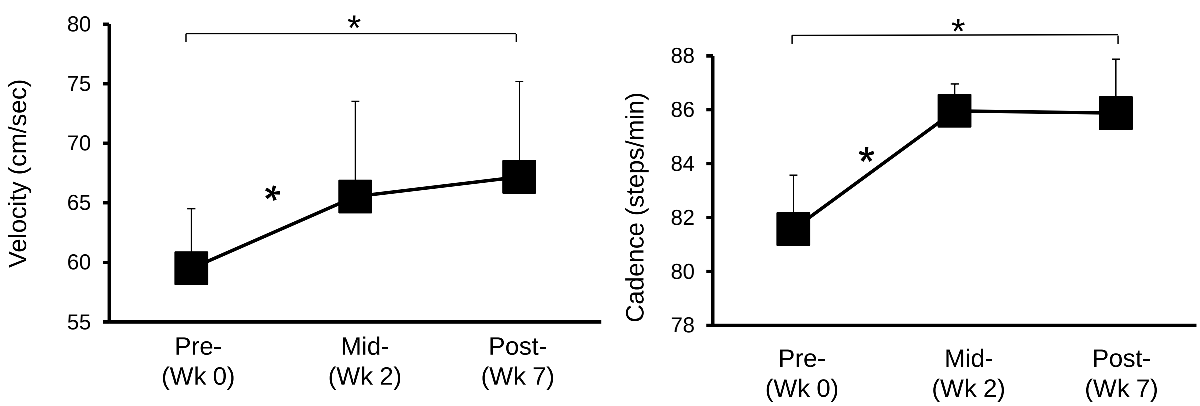

Figure 17 shows individual velocity and cadence pre-, during-, and post-training using data from an electronic mat GaitRite. Significance ($p < 0.05$) is denoted by *.

4.6 Discussion

The present study assessed the full-body kinematics of a custom-designed DBExG protocol for improving lower extremity joint kinematics, reactive balance control, gait function, and fall self-efficacy. It also evaluated participants' compliance to therapy, along with evaluating their accomplishment of recommended levels of community ambulation. The results supported the hypothesis that participants would exhibit increased CoM excursion, lower extremity joint kinematics (full-body motion analysis), improved reactive balance control, and improved gait function (on GaitRite), in addition to improvement in functional measures and motivation post-intervention. As postulated, such motor function improvements also translated to increased activity profiles (number of steps during community ambulation) for community-dwelling stroke survivors.

The results from this study also indicated that there was a training-induced effect on both AP and ML CoM excursions between pre- and post-intervention. Despite this study being among the pioneer studies for evaluating DBExG training stroke patients, other studies employing dance training for older adults have shown more efficient increased CoM excursions post-intervention (Hwang Pw Fau - Braun & Braun, 2015; Keogh et al., 2009). Studies have also indicated that the capacity for increased CoM excursion may reflect movement efficiency without incurring a loss of balance (Rogers, Rogers, Takeshima, & Islam, 2003). Ojofeitimi evaluated ML CoM excursions and found that skilled dancers maintained more vertical trunk alignment than beginners during weight shift tasks(Tsaklis, Grooten, & Franzen, 2012). A post-stroke, vertical trunk alignment deficit while standing has been associated with deteriorated motor functions like postural stability and other gait functions (S. W. Kim, Shim, Zatsiorsky, & Latash, 2006). Hence, the dance training component provided in this study could have facilitated augmented CoM excursion training and thus indirectly addressed both motor functions in individuals with chronic stroke. Additionally, this improvement in CoM excursions could have been due to the DBExG training provided in our study, which has been shown to provide proprioceptive feedback. Such feedback modes are fundamental for motor learning by stroke survivors and these are well known to improve CoM excursions for older and neurologically impaired populations (S. Cho et al., 2014).

Numerous studies have indicated that dancers exhibit greater peak joint angles in comparison to non-dancers (Khan et al., 1997; Steinberg et al., 2006). Dance training incorporates specific movements that require precise spatial and temporal coordination of postural control with multi-joint lower extremity movements.

All of these actions require precise lower extremity joint control and appropriate postural stability. Sofianidis et al. (Sofianidis, Hatzitaki, Douka, & Grouios, 2009) demonstrated that dance training could improve multi-joint and single-joint lower extremity motor control and proprioception in young adults. While previous studies have focused on the beneficial impacts of dance, including its feasibility, increased compliance, and impact on balance control, for chronic stroke survivors (Demers & McKinley, 2015; S. Subramaniam, & Bhatt, T., 2015), in this study we showed increased lower extremity joint angle peaks in the hip, knee, and ankle. However, to our knowledge, few studies have investigated the effect of DBExG training on gait joint-kinematics including joint excursion angles and dynamic range of motion for individuals with chronic stroke (Darekar, McFadyen, Lamontagne, & Fung, 2015b; J. H. Kim, Jang, Kim, Jung, & You, 2009). These studies demonstrated an increase in knee joint maximum excursion during both the swing and stance gait phases. These results support earlier findings that DBExG training can improve joint angle peaks for individuals with chronic stroke, however, the research findings also further support the idea that coupling dance with DBExG training can be additionally beneficial.

Furthermore, gait training paradigms, which implement preferred speed mobility training via treadmill training in isolation or using body weight support, lead to greater improvements in gait speed compared to conventional gait training (da Cunha et al., 2002; Fung, Richards, Malouin, McFadyen, & Lamontagne, 2006). However, more recently, new training paradigms incorporating fast walking (85% of the fastest comfortable speed) and high-intensity training regiments (30-second bursts at maximum-tolerated treadmill speed alternated with 30 to 60-second rest periods) have been proposed (Lamontagne & Fung, 2004; Pohl, Mehrholz, Ritschel, & Ruckriem, 2002). These paradigms, incorporating principles, such as task-specificity and repetition, have been suggested to promote accelerated improvements in walking speed using short duration training in as little as three times/week during a four-week period. The DBExG training provided in this study also provided high-intensity factors, and the repetitive variable practice could also have been responsible for the improvements in gait speed seen in individuals with chronic stroke.

Additionally, a comprehensive, participant-centered, goal-oriented approach to lifestyle modification is required for rehabilitation paradigms that address both the ability of stroke survivors to be both PA and motivated to be compliant with therapy (French et al., 2010; Rensink, Schuurmans, Lindeman, & Hafsteinsdottir, 2009). Maintaining high levels of PA via improved walking ability and ongoing cardiorespiratory fitness should also lead to a range of benefits, including improved fall self-efficacy, increased participation in therapy, improved health-related quality of life, and increased community ambulation. Our results support the idea that the DBExG rehabilitation methodology implemented in this study can improve motor function for chronic stroke survivors, and the increased gait speed did indeed translate to improved community ambulation.

CHAPTER V

The purpose of this study was to examine the feasibility, compliance and effectiveness of a dance-based exergaming training paradigm in improving voluntary and reactive (response to slip-like treadmill perturbations) balance control, falls self-efficacy along with achieving recommended levels of physical activity in community-dwelling individuals with hemiparetic stroke.

Partial data is published

Subramaniam, S., & Bhatt, T. (2015). Does a virtual reality-based dance training paradigm increase balance control in chronic stroke survivors? A preliminary study. Int J Neurorehabil, 2, 1-10.

5.1 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/year (Grimby G Fau - Andren, Andren E Fau - Daving, Daving Y Fau - Wright, & Wright). A stroke event causes a number of deficits that contribute towards impaired balance control, and loss of balance has been determined as a major risk factor for falls in individuals with stroke (Gresham et al., 1975). Forty to 70% of community-dwelling stroke survivors experience detrimental falls every year (Belgen, Beninato, Sullivan, & Narielwalla, 2006). The consequences of falling include hip fracture, soft tissue injuries, fear of falling, hospitalization, increased immobility, and disability (Batchelor, 2012) . Among these consequences, reduced falls self-efficacy has been highly correlated to recurrent falls in stroke survivors (Belgen et al., 2006). 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 (Baseman, Fisher, Ward, & Bhattacharya, 2010; Ryan, Dobrovolny, Silver, Smith, & Macko, 2000).

Balance training for chronic stroke survivors shown to be efficacious in outpatient rehabilitation centers, includes methods, such as sit-to-stand training, weight bearing and postural symmetry training and agility exercises (Langhorne, Coupar, & Pollock, 2009). Albeit falls at a rate of 40% are still occurring, among the high functioning community-dwelling stroke survivors, with the risk of falling being twice than that of age similar healthy adults (Belgen et al., 2006). Further, the reduced motivation and compliance towards the conventional interventions in comparison to exergaming-based rehabilitation exhibited amongst community-dwelling stroke survivors makes it difficult to receive the maximum benefits from these methods (Celinder & Peoples, 2012; Moreira, de Amorim Lima, Ferraz, & Benedetti Rodrigues, 2013).

The 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 (Langhorne et al., 2009). While 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, while simultaneously increasing motivation and compliance to intervention might improve rehabilitation gains targeted towards fall-risk prevention.

To enhance the level of biofeedback, an alternative medium, such as exergaming has been applied to rehabilitate chronic stroke survivors. Recent studies demonstrate exergaming rehabilitation, being largely used in addressing balance control deficits in this population (Darekar, McFadyen, Lamontagne, & Fung, 2015a; Lange, Flynn, Proffitt, Chang, & Rizzo, 2010). A recent review recently evaluated the efficacy of exergaming-based rehabilitation on balance and mobility disorders in stroke rehabilitation (Darekar et al., 2015a). Findings from this review indicate that exergaming-based rehabilitation has an added advantage over non-exergaming-based interventions in the recovery of balance control while performing functional tasks. The authors suggest that some of the factors, such as repetitive variable practice, enhanced engagement, motivation, feedback are associated with the exergaming systems and the training paradigms used could be responsible for this additional improvement.

Another alternative form of intervention being increasingly used in rehabilitation settings for improving balance control in people with neurological disorders is 'dance therapy' (Fernandez-Arguelles et al., 2015; Hecox et al., 1976).

Dance movements may be particularly helpful for individuals with stroke, as it facilitates continuous CoP displacements within the individual's stability limits.

Recent research has shown that such training strategies implementing continuous CoP displacements would provide the potential for weight shift training towards the paretic limb, resulting in an improved symmetry in weight distribution (Ding, 2013). Such symmetrical weight distribution during standing and walking is associated with improved performance on voluntary balance control and reduce fall risk among chronic stroke survivors (Cheng et al., 1998; Cheng, Wu, Liaw, Wong, & Tang, 2001). Dance steps would also require practicing of 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 improve dynamic stability very rapidly (in about 4 weeks) (Husemann, Muller, Krewer, Heller, & Koenig, 2007). Additionally, dancing would involve fast repetitive full- body movements. Such rapid movement training has been previously shown to decrease the response time of self-initiated postural weigh shifts (decreased time to initiate CoP excursion on the limits of stability test) while performing functional tasks in older adults (Bisson, Contant, Sveistrup, & Lajoie, 2007). Increased RT in hemiparetic stroke has been indicated to be among the main predictors for the decline in movement initiation and performance (Goh, Chua, Hong, & Ng, 2013). Thus dance could have a 'holistic' practice approach, which can be used as a complementary therapy to reduce 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 (Fernandez-Arguelles et al., 2015; Foster, Golden, Duncan, & Earhart, 2013a; Mandelbaum et al., 2015; Sharp & Hewitt, 2014b), 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 (BBS and TUG test), gait and endurance measures (6-Minute Walk Test) (Hackney, Hall, Echt, & Wolf, 2012).

Recent studies have also demonstrated that increasing PA in stroke survivors improves balance control and could reduce their fall-risk (Marigold et al., 2005). The suggested frequency of PA is $\geq$ 3 days per week for stroke survivors, with duration of 20 to 60 minutes per session depending on the individual's functional capacity (Billinger et al., 2014; Gordon et al., 2004). Despite the positive effect of PA on balance control in this population, the average number of steps walked per day is approximately 2800 to 3000 steps/day, which is far below the daily step counts documented from age-matched sedentary healthy older adults (5000–6000 steps/day) (Haeuber, Shaughnessy, Forrester, Coleman, & Macko, 2004; Michael et al., 2005). 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 PA into the daily life of community-dwelling stroke survivors.

In regards to the above mentioned, off-the-shelf, lower-cost exergaming gaming systems like Kinect (Microsoft Inc.) have shown improvements in posturography, functional balance and gait performance in chronic stroke survivors (Celinder & Peoples, 2012; Lange et al., 2010; Saposnik et al., 2010). Some studies have also demonstrated the transition of these exergaming training-induced balance and gait improvements to functional mobility, thus suggesting it to be an effective tool for enhancing PA in this population group (K. H. Cho et al., 2012; H. Y. Lee, Kim, & Lee, 2015) . Given the preliminary evidence of exergaming and dance for improving balance control, this study would like to propose, a novel cost-effective DBExG training intervention using the commercially available off the shelf Kinect gaming system, in order to provide a more holistic intervention while addressing the recommended frequency of PA.

The purpose of this pilot study was to examine the feasibility, compliance, and effectiveness of a DBExG training paradigm in improving balance control, falls self-efficacy along with achieving recommended levels of PA in community-dwelling individuals with hemiparetic stroke. We hypothesized that post-training compared to pre-training participants would demonstrate increased balance control and functional measures, along with greater scores on FES scale and IMI 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.

5.2 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 ± 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. Cardiovascular health was also 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 and the details of the intervention for 6 weeks is represented in chapter II.

5.3 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 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 pre-intervention, (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

Intentional balance control task: Voluntary balance control was assessed using the Limits of Stability (LOS) test protocol of the Equitest (Computerized Dynamic Posturography) (Koozekanani, Stockwell, McGhee, & Firoozmand, 1980). 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. Participants were asked to transfer their center of pressure, while standing on stable force plates, towards the forward direction spaced at 45° interval around the body's CoP, as displayed on a monitor in real time and 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 vital to mobility tasks such as reaching for objects, progressing 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 determined as the distance of the first movement toward the designated target, conveyed 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: i) 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 linked to a computer, which could independently allow measurement of vertical forces between the surface of the platforms and the lower extremity. 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.

ii) Reactive balance was also assessed with slip-like perturbation test in stance. Kinematic data were collected using an eight-camera motion capture system at 120 Hz with Cortex-64 3.6.1 software [Motion Analysis, Santa Rosa, CA]. The Helen Hayes marker set with twenty-nine reflective markers on bilateral bony landmarks, head, and trunk were used to collect full body kinematics values and compute the CoM position and joint angles of the participants. Following which, the processing and extracting the variables of interest, was done using a customized MATLAB code [Math Works, Natick, MA]. To identify perturbation onset, one marker was placed at the treadmill belt. The obtained data from the marker was low pass filtered using a fourth-order Butterworth filter with a cutoff frequency of 6 Hz. The load cell data were sampled at 1200 Hz and were synchronized with the motion capture system using an analog-to-digit converter. A single-slip like support surface perturbation was induced in the standing position, in the forward direction was induced using a motorized treadmill (ActiveStep, Simbex, Lebanon, New Hampshire). Participants were instructed to stand in a comfortable position with feet shoulder width apart before the onset of the slip. A safety harness system attached via ropes prevented the participant's knees from touching the treadmill belt in circumstances of a fall. Participants were exposed to a single, large magnitude forward perturbation at 0.67 m/s for 0.19 m with the acceleration of 16.75 m/s^2. They were asked to execute a natural response to maintain their balance and prevent them from falling.

Reactive Balance control outcome measures: The CoM position in the anteroposterior direction was illustrated relative to the most posterior heel position ($X_{CoM/BoS}$) and was normalized to the foot length. The CoM velocity was computed by the first order differentiation of the CoM position and was normalized to a dimensionless fraction of g × h, g is the acceleration due to gravity and has the body height. The CoM velocity was taken relative to the velocity of the most posterior heel marker of the BOS ($\dot{X}_{COM/BOS}$). Postural stability was computed as CoM position ($X_{CoM/BoS}$) and velocity ($\dot{X}_{COM/BOS}$) relative to the BoS at first step lift-off (LO). A more negative $X_{CoM/BoS}$ and $\dot{X}_{COM/BOS}$ imply the CoM is posterior to the BoS with a slower velocity contributing toward instability in the backward direction.

Physical activity measure: Changes in the physical activity during the 20 sessions of dance training were recorded using the Omran HJ – 321 Tri-Axis 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 PA in research and practice (Fabre, Chamari, et al.; Rand et al., 2009). The Omron pedometer features advanced Tri-axis sensor technology, which allows accurate measurement of PA. The pedometer had to be worn on an adjustable elastic waist belt perpendicular to the ground. This was proclaimed to be the most precise mounting position out of four mounting positions recommended 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", "Somethin" 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 such as BBS, TUG and 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 (Berg, Wood-Dauphinee, & Williams, 1995; Fabre, Chamari, et al.). Timed Up and Go Test, is an objective measure of basic mobility and balance maneuvers that assesses the risk of falls (Boulgarides, McGinty, Willett, & Barnes, 2003; Fabre, Chamari, et al.). Similarly, the FES has been used extensively for evaluating fall-related self-efficacy and higher activity avoidance (McAuley, Duncan, & Tammen, 1989; Tinetti, Richman, & Powell, 1990).

Motivation: In addition to the functional outcome measures, motivation to rehabilitation was measured with IMI Scale (Fabre, Chamari, et al.; Medalia A, 2011; Plant RW, 1985). It has been used in several experiments related to intrinsic motivation, self-regulation and has good evidence of being reliable (Fabre, Chamari, et al.).

5.4 Statistical Analysis

A one way repeated measures ANOVA was performed to determine, if there was any change in performance in self-initiated CoP RT, MV, MXE and WS, along with changes in functional measures, such as BBS, TUG test and FES and IMI between one week pre-intervention, (mid-intervention) 10th training session and one week post-intervention followed by post hoc paired t-tests. Since the RT was expected to decrease post-intervention, lower scores would indicate a higher performance. While, increased scores in MV and MXE were directly proportional to better performance. Equal symmetry of body-weight 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. T-test revealed significant improvement in stability during slip perturbation test. 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. Greater values in IMI indicate higher compliance to training. To determine the changes in PA 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) 10^{th} training session and one-week post-intervention scores followed by post hoc paired t-tests . To determine the changes in PA 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 PA over the intervention period (number of steps during 1^{st} and 20^{th} training session). The classification used for correlation was: < 0.49, weak; 0.50 to 0.69, moderate; and ≥ 0.70, strong. A significance level (α) of 0.05 was chosen for statistical comparisons performed using SPSS software version 17.0 for analysis.

5.5 Results

Demographic data for the participants are presented in Table 4. 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.

Table 4: Demographics and stroke characteristics of study participants

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
S D		5.12	41.27	8.80			3.32

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

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 and last two weeks of 2 sessions/week) with the feasibility to reschedule their training days.

Balance Outcomes

Significant differences in self-initiated CoP RT [F(2, 20) = 6.659, (p <0.05)], MV [F(2, 20) = 15.913, (p <0.01)] and MXE [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 RT 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 to post-intervention ($p < 0.05$). There was also a significant increase of MXE 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 18). All the participants demonstrated a backward compensatory stepping response upon a sudden forward perturbation. Post-intervention participants showed improvement in postural stability ($X_{CoM/BoS}$ and $\dot{X}_{COM/BOS}$) at lift-off and increased step length ($p < 0.05$). Similarly, community ambulation recorded one week prior and post-intervention exhibited a significant increase in a number of steps with training ($p < 0.05$) (figure 19 and 20).

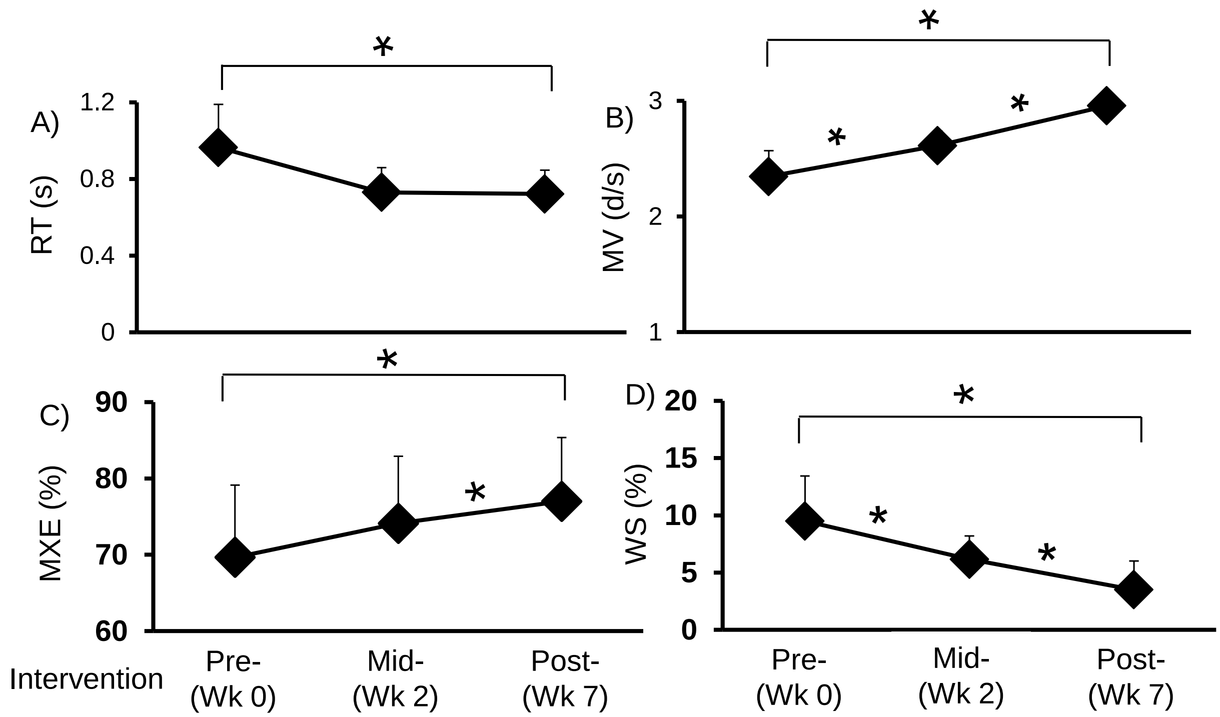

Figure 18 Means (+SD) scores on the limits of stability and motor control test respectively for one week pre-intervention – Week (Wk) 0 , (mid intervention) 10th training session – Week 2 and one week post-intervention scores of individuals performance – Week 7: a) Response Time (RT) in seconds b) Movement velocity (MV) in degrees/second (d/s) c) Maximum Excursion (MXE) in (%) d) Weight symmetry in (%). As the response time was expected to decrease post-intervention, lower scores would indicate a higher performance (s). Increased scores in movement velocity and maximum excursion were directly proportional to better performance A score of 0 indicates symmetrical body-weight distribution on both legs, while a score of > 0 indicate more weight bearing on the non-paretic side, and a score of < 0 indicated increased weight bearing on the paretic side. Significant differences with intervention indicated by * represent $p < 0.05$.

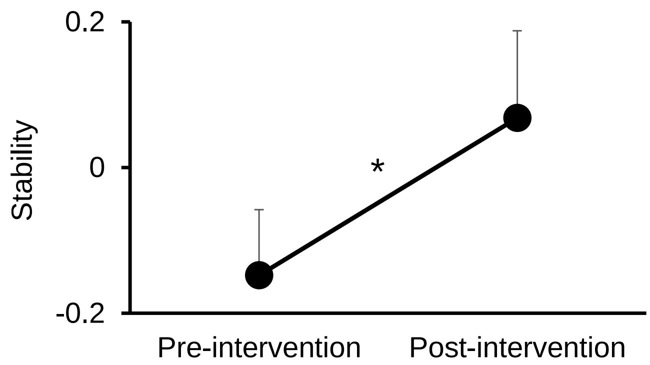

Figure 19 Post-training changes of individual's performance on slip perturbation test demonstrating stability at touchdown. Significant differences with intervention indicated by * represent $p < 0.05$.

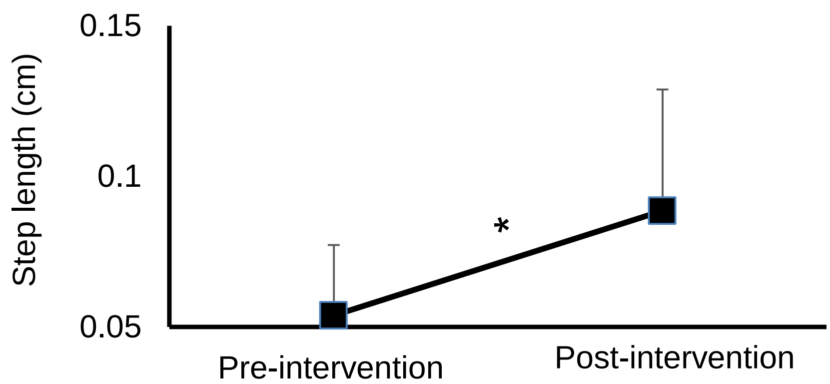

Figure 20 Post-training changes of individual's performance on slip perturbation test demonstrating compensatory step length. Significant differences with intervention indicated by * represent $p < 0.05$.

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 ± 489 on 1st session to 2375 ± 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 ± 785 steps recorded at 20th session ($p < 0.05$) (Figure 21) Further there was a significant linear increase in total number of steps across sessions [y = 1490.3e0.0335x, R^2 of .5208 ($p < 0.05$)].

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 ± 8071.74 on 1st session to 22138 ± 7351.37 on the (mid intervention) 10th training session. Participant continued to increase the gaming scores taken from (mid intervention) 10th training session to the 20th training session with 26950 ± 6660.399 recorded at 20th session. There was a significant increase of the gaming scores between the 1st and 20th session ($p < 0.05$) (Figure 3b). Further a significant linear increase in gaming scores was noted across sessions [y = 327.29x+21771, R^2 of .5407 ($p < 0.05$)] (Figure 21).

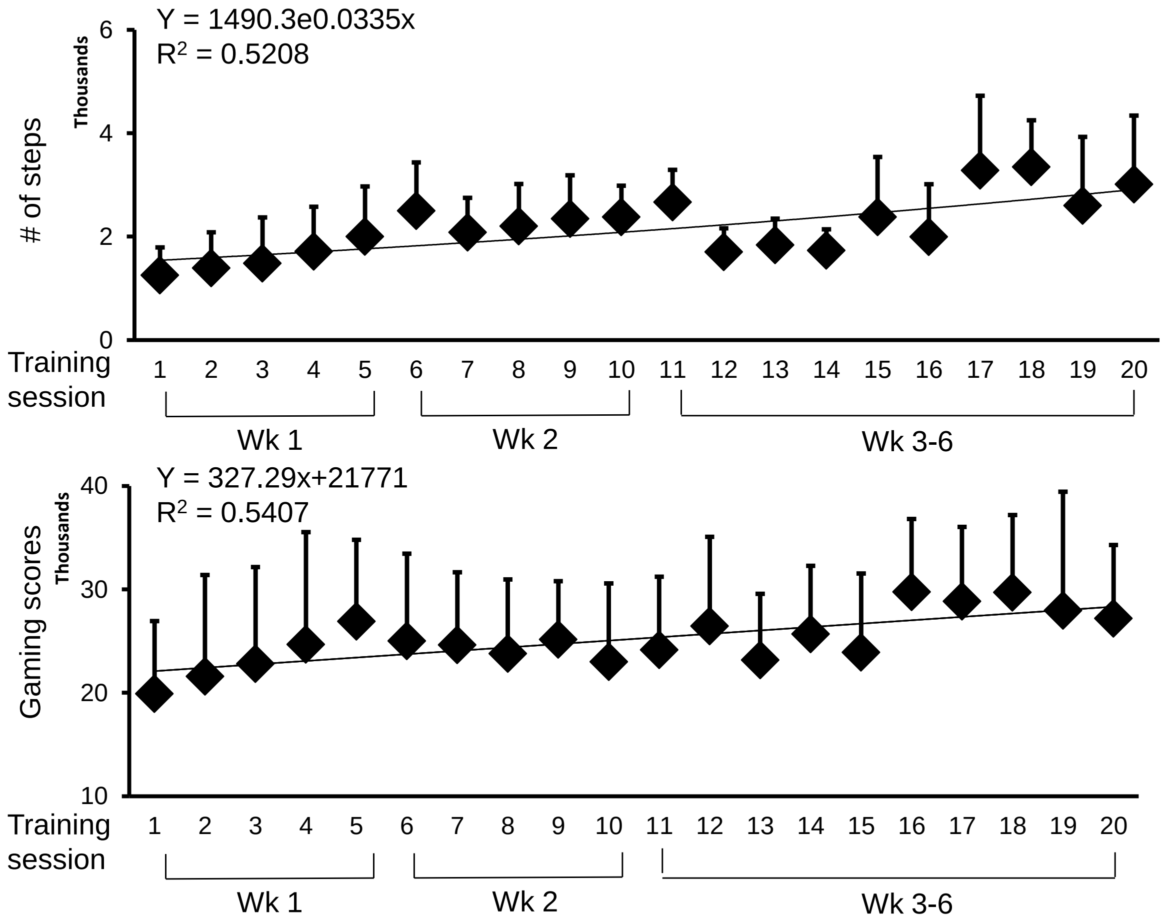

Figure 21 Means (±SD) results for the total number of steps (# of steps) and scores recorded for each session linearly regressed with the number of training sessions (1st through 20th) for: physical activity ($R^2 = 0.5208$ and $y = 1490.3e^{0.0335x}$) and, gaming scores ($R^2 = 0.5407$ and $y = 327.29x + 21771$). R^2=Pearson correlation coefficient.

Functional outcome measures

A significant main effect of training among pre-intervention, (mid intervention) 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 10th training session ($p < 0.05$) and from the (mid intervention) 10th training session to post-intervention ($p < 0.05$).

A significant main effect of training among pre-intervention, (mid intervention) 10th training and post-intervention sessions was observed in TUG with [$F(2, 20) = 44.763$, ($p < 0.01$)]. Post hoc analysis showed that the TUG the scores significantly decreased from pre-intervention to the 10th training session ($p < 0.01$). There was difference in TUG scores between the (mid intervention) 10th session and post-intervention ($p > 0.05$) and scores on the post-intervention session were significantly lower than the pre-intervention session ($p < 0.05$). Significant differences in FES was 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 FES increased significantly pre- to (mid intervention) 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 22).

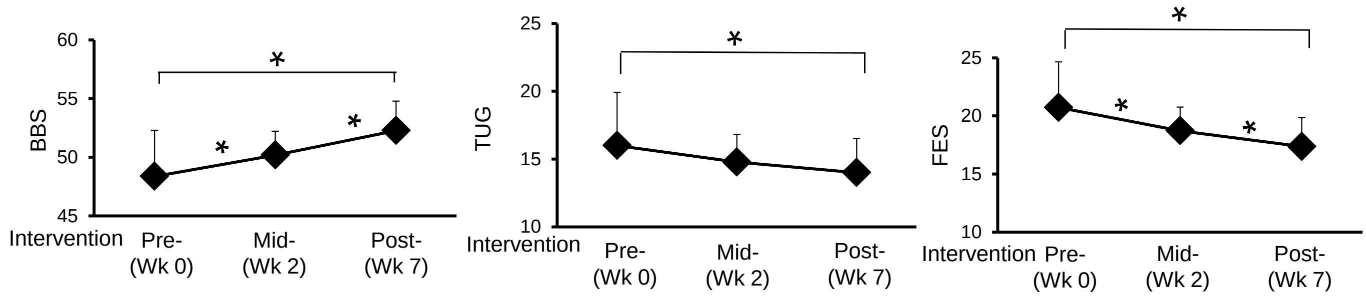

Figure 22 Means (±SD) changes in one-week pre-intervention, (mid intervention) 10th training session and one-week post-intervention scores of individuals performance on function measures, such as: Berg Balance Scale (BBS), Timed Up and Go Test (TUG), and Falls Efficacy Scale (FES). As the BBS score was 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 $p < 0.05$.

Motivation

Overall, there was a significant main effect of training on motivation with [$F(2, 20) = 36.677$, ($p < 0.01$). Post-hoc analyzes showed that there was 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).

Correlation between balance control and physical activity

The participant's number of steps from the 1st and 20th training session correlated with the pre-post intervention scores for response time [R^2 of .5089 ($p < 0.05$)] and movement velocity [R^2 of 0.5488 ($p < 0.05$)] showing a moderate correlation (figure 23).

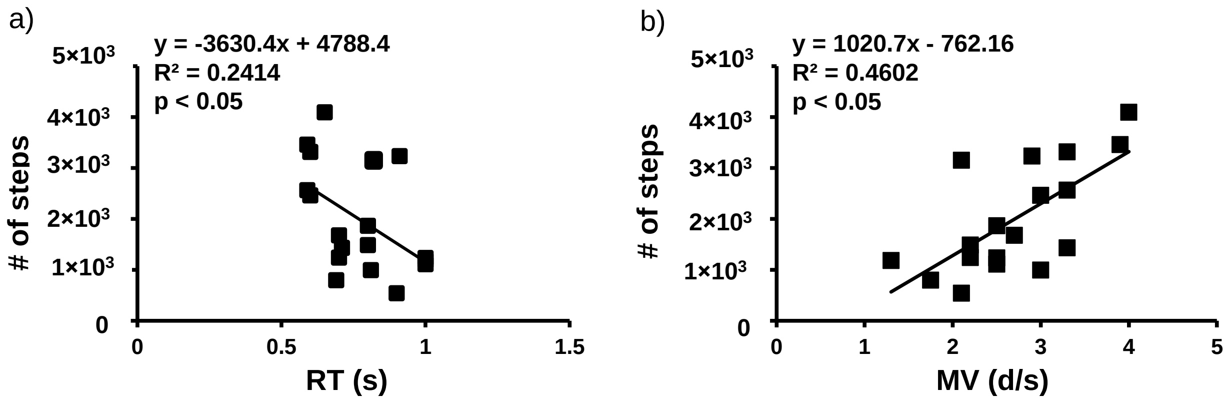

Figure 23 Correlation between physical activity (number of steps (# of steps) during 1st and 20th training session) and balance control measures (pre-intervention and post-intervention a) Response time (RT) in seconds (s) and b) Movement velocity (MV) in degrees/second (d/s).

5.6 Discussion

The present study evaluated the feasibility and effect of a DBExG 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 PA, 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 (RT) and spatial (MV and MXE) 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 DBExG 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 and respond to the next sequence of movement strategies that appear on the screen (S. Subramaniam, Wan-Ying Hui-Chan, & Bhatt, 2014). 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 exergaming environment also provides real-time visual, auditory, and proprioceptive feedback, which are fundamental in motor learning in stroke survivors (Todorov, Shadmehr, & Bizzi, 1997). Such feedback modes can lead to improvement of motor abilities in the gaming environment, and are transferable to activities of daily living in the real environment (Fabre, Chamari K Fau - Mucci, et al., 2002; Moreira, de Amorim Lima Am Fau - Ferraz, Ferraz Km Fau - Benedetti Rodrigues, & Benedetti Rodrigues, 2013). 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 (Dimyan & Cohen, 2011; Fabre, Chamari K Fau - Mucci, et al., 2002). Lastly, the exergaming 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 RT and MV. 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 (Fabre, Chamari K Fau - Mucci, et al., 2002; C. D. Lee et al., 2003). 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 (Thompson et al., 2013). Most of the participants were 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 exergaming-based rehabilitation, in comparison with conventional methods, provides the subject with high levels of motivation and compliance and a strong sense of presence in the gaming environment (Celinder & Peoples, 2012; Moreira, de Amorim Lima Am Fau - Ferraz, et al., 2013). Recent studies have also exhibited that people with neurological disorders are motivated to attend regular dance classes, have a greater degree of compliance with a lesser dropout rate, and often endure with the activity after the study phase (Hackney & Earhart, 2009a, 2009b). Immersion in the exergaming environment has been demonstrated as a critical component to positive gaming experience (Fabre, Chamari K Fau - Mucci, et al., 2002; Gatica-Rojas & Mendez-Rebolledo, 2014). Significantly, improved score on the IMI scale 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 (Deconinck et al., 2015; Iacoboni & Mazziotta, 2007). It is also indicated that training or activation of AON could result in cortical plasticity (Carvalho D Fau - Teixeira et al., 2013). Furthermore, recent studies have also shown that dance based training activates both AON system and other brain centers that help in balance control (Cynthia F.BerrolPh.D., 2006). Exergaming-based dance training provided in this study, facilitated subjects to observe the dance steps in the game providing an 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 BBS, which was very close to the minimal detectable change of 4.13 points for individuals with chronic stroke (Fabre, Chamari K Fau - Mucci, et al., 2002; Franchignoni, Martignoni, Ferriero, & Pasetti, 2005). For the TUG the participants improved by 3 seconds, which exceeds the minimal detectable change of 2.9 seconds (Flansbjer, Holmback, Downham, Patten, & Lexell, 2005). Fall Efficacy Scale also improved by two points. These positive changes in functional outcome measures indicate that exergaming-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. (2009a) and Bronner et al. (Bronner, Pinsker, Naik, & Noah, 2016) evaluated similarly structured protocols for subjects with Parkinson's disease and healthy young adults respectively. Hackley et al. (Hackney & Earhart, 2009a) 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 BBS and percentage of time spent in stance during forward walking. Bronner et al. (Bronner, Pinsker, & Noah, 2013) 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 gaming scores with no improvement on kinematic data for sagittal plane mean peak angular displacement of hip and knee. Study by Bronner et al. (Bronner et al., 2013), 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 an elderly population (Hardy, Perera, Roumani, Chandler, & Studenski, 2007). 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. (Hackney & Earhart, 2009b) 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 (Mujika & Padilla, 2003). 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. 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 exergaming-based dance training, their results similar to ours have found improvements in balance control (BBS), mobility (TUG), and falls self-efficacy (FES) in older adults and Parkinson's disease (Earhart, 2009; Fernandez-Arguelles et al., 2015). 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 (Fabre, Chamari K Fau - Mucci, et al., 2002; Sharp & Hewitt, 2014a). Additionally, other studies done with older adults and Parkinson's disease have reported greater compliance with dance rehabilitation due to it being more enjoyable and satisfying experience (Eyigor et al., 2009; Hackney & Earhart, 2009a; Hawkins, Kramer, & Capaldi, 1992). 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 PA were retained post-intervention. However, the feasibility and compliance to the protocol along with the improvements in balance control and PA is shown in this study lend 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 a 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 DBExG training paradigm in improving balance control along with PA levels. Several clinical guidelines now recommend incorporating PA and a structured exercise program after stroke for achieving an increase in functional mobility and decreasing risk of a second cardiovascular accident. Given the results of this study, exergaming-based dance gaming using an off-the-shelf gaming could be integrated as a clinical intervention to address community ambulation PA profile and reduce fall risk in chronic stroke survivors.

CHAPTER VI

Compare the effect of dance-based exergaming training paradigm for increasing motor function, and PA levels between healthy aging and aging with stroke

6.1 Introduction

Deficits in the neuromuscular control of balance post-stroke are among the main cause of increased risk of falls among individuals with chronic stroke (Sommerfeld & von Arbin, 2004). Stroke-associated balance deficits include impaired ability to perform coordinated responses to intentional (self-generated) and reactive (external perturbation) balance control (Marigold & Eng, 2006). Likewise, aging has also been identified with decline in physiological function, leading to reduced muscle mass, strength, endurance, balance, and aerobic power (Keogh et al., 2009) in comparison to younger adults. Such physiological decline causes postural and balance problems with aging (Laufer, Barak, & Chemel, 2006). Aging has also been shown to be associated with increased incidence of falls (S. R. Lord, 2007).

Given the overload of fall incidence in these populations and the economic impact of hospitalizations, and rehabilitation in outpatient settings, there is need of care for the elderly for maintenance therapy and rehabilitation for individuals with chronic stroke. Evaluation of various intervention paradigms have suggested that balance control is achieved via a unique, complex combination of systems, and as such requires task-specific training (Schaefer, Haaland, & Sainburg, 2007).

In general, rehabilitation interventions for older adults and stroke would require therapist-assisted daily practice. Nonetheless, the demand requirement for the physical therapists makes it logistically impractical and expensive, suggesting the need for alternative therapies that facilitate rehabilitation methods which addresses decline in balance control and also reduce the dependence on therapist for training. Studies have indicated that exergaming-based training have been beneficial in both elderly and individuals with chronic stroke (Molina, Ricci Na Fau - de Moraes, de Moraes Sa Fau - Perracini, & Perracini, 2014). Specifically, dance could be performed in a various environments, and does not require expensive equipment, and it has been shown to appeal both these population groups (Studenski et al., 2010). Moreover, gaming-based rehabilitation methods would hold great potential for providing task-specific training with increasing motivational levels and augmented feedback in real-time (performance feedback) (Molina et al., 2014). The current thesis has provided insight on the effect of DBExG training for older adults and community-dwelling individuals with chronic stroke.

However, as the motor and cognitive control are independently affected due to stroke and aging, understanding the effect of such dance-based exergaming interventions between healthy aging and aging with stroke is crucial to understand therapy-induced improvements in these groups. Thus the purpose of this study was to evaluate the effect of a dance-based exergaming training paradigm for improving PA profiles, while also assessing its translation to increased motor functioning, increased community ambulation, and decreased falls between healthy aging and aging with stroke. We had hypothesized that the effect of dance-based exergaming training post-training between both the groups would be identical demonstrating increased voluntary control on posturography, increased reactive balance control on CoM position (XCoM/BoS) and velocity (XCoM/BoS) relative to the base of support (BoS) at compensatory touchdown, gait improvement, resulting in an equal significant change in PA profiles and community ambulation for healthy aging and aging with stroke groups

6.2 Methods

Design, Participants, and Recruitment: The study used healthy older adults (n = 10) and individuals with chronic stroke (n = 13). Both the groups received DBExG training.

Subject Screening: For the older adults group, participants were excluded with neurological, musculoskeletal, cardiovascular, or any other systemic disorders. Participants with any drug usage and uncorrected vision problems were excluded. Participants ≥ 65 years of age were included in the study. They had to answer a general health questionnaire, and achieve a minimum score of 8 on the SOMCT which would prove "normal" cognitive performance.

For the stroke group, participants with hemiparetic stroke (> 6 months), as confirmed by the participant's physician were included. Participants mean ± SD disability status quantified using the Modified Rankin Scale, ranged from mild to moderate disability. Those participants with other neurological (e.g., Parkinson's disease, vestibular deficits, peripheral neuropathy or unstable epilepsy) and musculoskeletal disorders were excluded.

For both groups, participants did not proceed in the study if their resting HR > 85% of age-predicted maximal heart rate, and if they were unable to stand for at least 5 minutes without an assistive device (length of dance game), or if they had history of spine or long bone fracture in the last 6 months. They were also required to have the ability to stand independently for at least 5 minutes without the use of an assistive device. Additionally, participants had to give informed consent, which was approved by the Institutional Review Board.

Protocol: A schematic diagram of the study protocol, demonstrating the chronological sequence of intervention for 6 weeks is represented in chapter II.

The participants completed assessments for balance control, physical activity, and functional measures, which were performed three times (one-week pre-intervention, mid intervention during the 10th training session, and one-week post-intervention). The details of each of these tests are described in the previous chapters.

6.3 Outcome Measures

Balance Control Measures

Both the groups of participants were assessed on **Intentional Balance Control, community ambulation (physical activity), gait parameters, and reactive balance.** The details of all the above-mentioned assessments are described in detail in previous chapters.

Intervention: Both the groups received high-intensity tapering intervention five days/week for two weeks, followed by three days/week for two weeks, and ending with two days/week for two weeks for a total of 20 sessions with each session lasting about 1 hour and 40 minutes, including rest breaks and warm-up and cool-down time. Chapter II includes the full details of the training protocol.

6.4 Statistical Analysis

A 2*3 ANOVA was conducted with groups (healthy aging and stroke) and time (one week pre-intervention, mid-intervention and one week post-intervention) as independent factors and balance control variables, such as reaction time, movement velocity (Limits of stability test), and gait variables, such as gait velocity and gait cadence (GaitRite test) as dependent variables. Similarly, a 2*2 ANOVA, was used with groups (healthy aging and stroke) and time (one-week pre-intervention and one-week post-intervention) as independent variables and reactive balance control measures, such as reactive balance stability, step length (slip perturbation test) as dependent variables. Significant interactions were resolved with post hoc paired *t*-tests for within-subject factors and independent *t*-tests for between-subject factors. A significance level (α) of 0.05 was chosen for statistical comparisons performed using SPSS software version 17.0.

6.5 Results

Limits of stability test exhibited a main effect of time on reaction time [F(2,42) = 3.730 ($p < 0.05$)] with no difference between the groups (main effect of group, $p > 0.05$), no time*group interaction, $p > 0.05$, and movement velocity [F(2,42) = 18.890 ($p < 0.05$)] with no difference between the groups (main effect of group, $p > 0.05$), no time*group interaction, $p > 0.05$. Post-hoc within group analysis for both groups demonstrated a significant increase in reaction time and movement velocity from pre-intervention to post-intervention ($p < 0.05$). There was also a significant improvement in these variables in both the groups from pre- to mind-intervention. For the movement velocity the training group also had a significant increase from mid- to post-intervention ($p < 0.05$) (Figure 24).

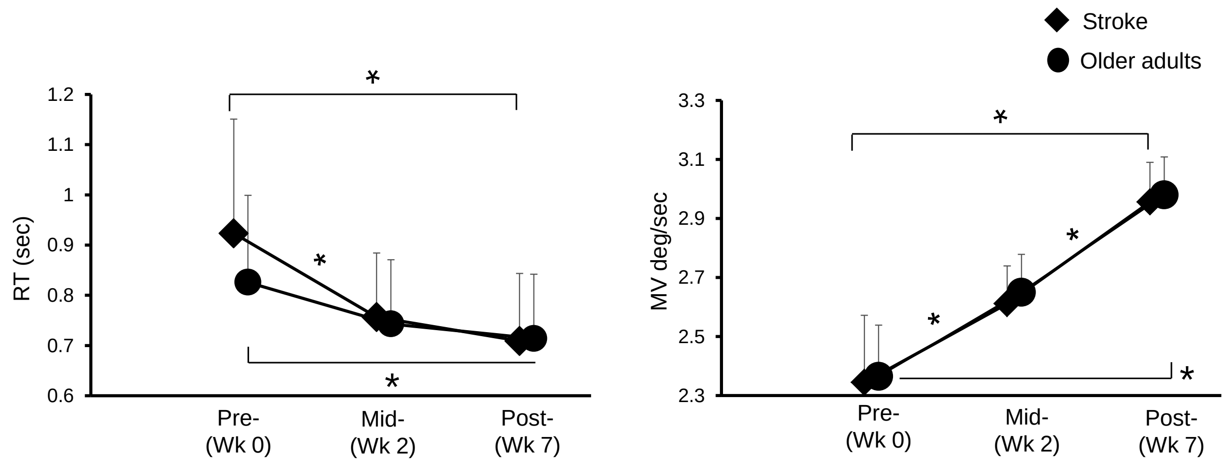

Figure 24 shows the mean ± SD limits of stability for pre-intervention and post-intervention scores of individual performance for Response Time (RT) in seconds, Movement Velocity (MV) in degrees/second (d/s). As the response time was expected to decrease post-intervention, lower scores would indicate better performance. Increased scores in movement velocity were directly proportional to better performance. Significant differences ($p < 0.05$) are indicated by * .

GaitRite test exhibited a main effect of intervention on velocity [$F(2,46) = 169.125$ ($p < 0.05$)] with between-group difference (main effect of group, $p < 0.05$), time*group interaction, $p < 0.05$. There was also a main effect of time on cadence [$F(2,42) = 59.342$ ($p < 0.05$)] with no difference between the groups (main effect of group, $P > 0.05$, notime*group interaction, $P > 0.05$. Post hoc analysis revealed that there was a significant increase in velocity pre- to mid intervention and also mid- to post-intervention for the stroke group. The older adults group exhibited significant increase in velocity pre – to mid-intervention, and also pre- to post-intervention ($p < 0.05$). For the cadence the stroke group exhibited increase from pre- to mid-intervention and, also pre- to post-intervention. The older adults showed a significant increase from mid- to post-intervention and also pre- to post-intervention (Figure 25).

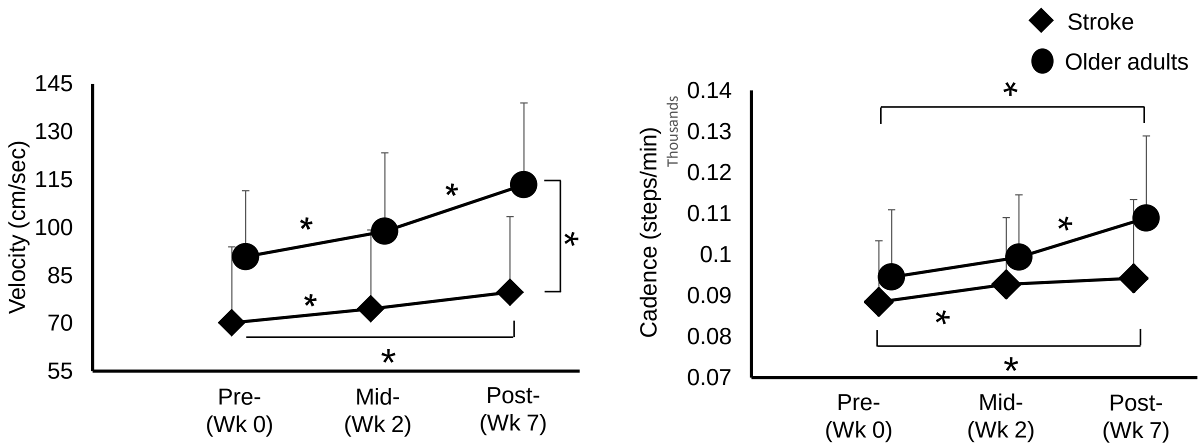

Figure 25 shows changes in gait speed during preferred-speed walking for one-week pre-intervention – Wk (week) 0, (mid intervention) 10th training session – Wk (week) 2 and one-week post-intervention scores of individuals performance – Wk (week) 7.

Community ambulation profile assessment indicated a main effect of time on PA [$F(1,21) = 5.288$ ($p < 0.05$)] with between-group difference (main effect of group, $p < 0.05$), time*group interaction, $p < 0.05$. Post hoc analysis revealed an increase in number of steps ($p < 0.05$) in stroke group with no difference in the older adults groups. The groups also exhibited a significant difference between them post-intervention ($p < 0.05$) (Figure 26).

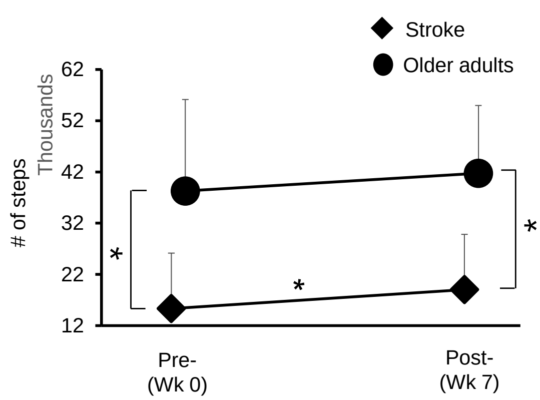

Figure 26 Means (+ SD) scores on a) Number of steps (# of steps) recorded one-week pre-intervention – Wk 0 and one week post-intervention week 7. Significant differences with intervention indicated by * represent $p < 0.05$.

With respect to the slip perturbation test there was a significant main effect of intervention on stability at touchdown [F(1,18) = 8.170 ($p < 0.05$)] with between-group difference (main effect of group, $p < 0.05$), time*group interaction, $p < 0.05$, and step length [F(1,18) = 9.026 ($p < 0.05$)] with between-group difference (main effect of group, $p < 0.05$), time*group interaction, $p < 0.05$. Post-hoc analyses showed significant improvements with intervention for stability for the dance-based exergaming group ($p < 0.05$) for both groups. Similarly, there was a significant difference in stability between groups post-intervention ($p < 0.05$). Both groups showed a significant improvement in step length pre- to post-intervention ($p < 0.05$). There was also a group difference between the groups post-intervention (Figure 27).

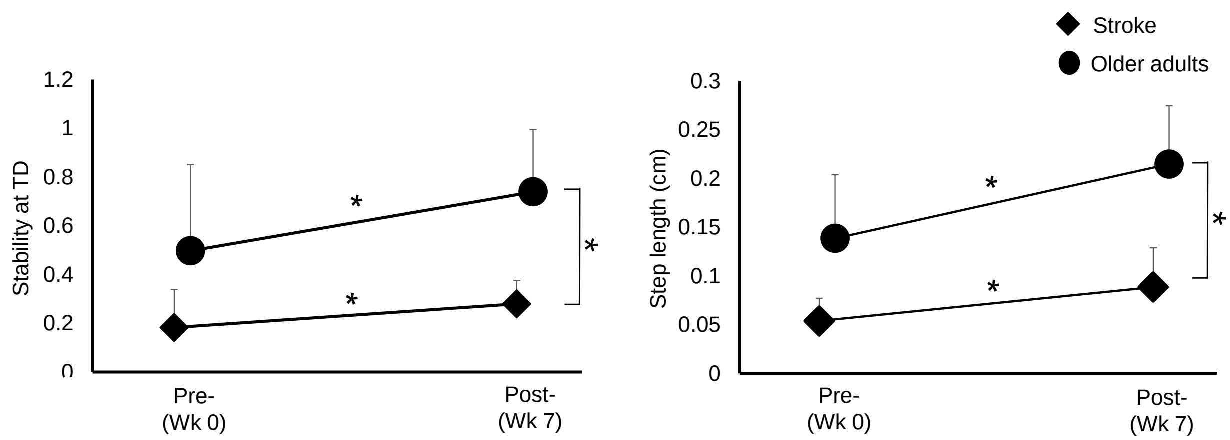

Figure 27 shows the means ± SD for the slip perturbation test for: Compensatory step length and Stability at touchdown. Significant associations ($p < 0.05$) between the variables are denoted by *.

6.6 Discussion

The comparison of both groups with the six-weeks high-intensity tapering DBExG training indicate that alternative therapies could provide improvement in physical function in both older adults and individuals with chronic stroke. Dance has been indicated as a less threatening intervention in comparison to other conventions methods (Keogh et al., 2009). It has also been shown to promote successful and healthy aging, along with promoting continued health, physical activity and mobility (Hwang & Braun, 2015). The above factors, along adherence to dance-based intervention protocols, would suggest that the proposed study design in this thesis could appear to be a form of physical activity that may be more likely to be adapted as part of many older adults exercise programs.

The results though promising indicate the necessity to further develop and evaluate the dosage plan for such alternative therapy based physical activity for different populations. The preliminary results indicate appropriate dosage for community-dwelling stroke survivors. The reason being the DBExG could improve physical function and also translate the acquired improvement to community-based PA profiles. For the older adults, though there was a significant increase in the overall physical function, the intervention protocol was not able to be translated to community ambulation. Thus, future studies should focus on tailoring the dosage requirement based on the chronic conditions and activity limitations, risk of falls, individual abilities and fitness, strategies for exercise adherence, and individual preferences.

Albeit, the prescribed dosage is consistent with the recommendation for balance exercises with the clinical practice guideline published for healthy older adults (Nelson et al., 2007). Further, studies have indicated that interventions that include increasing PA are effective in community-living older adults to reduce the risk for falls (Taylor et al., 2004). Additionally, given that physical activity, by itself, could reduce falls and fall-related injuries as much as 35-45%, dance-based PA focusing on dynamic balance control could potentially be beneficial to improve physical function and also as a maintenance therapy to decline age-associated decline.

CHAPTER VII

7.1 Conclusion and future direction

The limited success in engaging healthy older and individuals with stroke in PA demonstrates a critical need to design and implement rehabilitation paradigms targeted towards achieving the recommended levels of PA, along with concurrently addressing cardio-vascular conditioning, and ensuring that the positive effects are translated to the community physical activity profiles (Billinger Sa Fau - Arena et al., 2014; Gordon Nf Fau - Gulanick et al., 2004; Matthew J. Field, 2013). Dance is a universal form of PA, which involves sensorimotor rhythmic body movements integrating motor, cognitive and social elements with the potential to slow aging and reduce stroke-related deficits (Hackney et al., 2012; Hwang Pw Fau - Braun & Braun, 2015). Further, exergaming environment provides highly customizable, controllable, multimodal simulation, ensuring high levels of motivation and compliance towards intervention (Iruthayarajah, McIntyre, Cotoi, Macaluso, & Teasell, 2017; Lohse et al., 2014). Integrating dance with exergaming – **DBExG training**, could potentially facilitate cardio-vascular conditioning, along with addressing functional mobility leading to a better quality of life. This thesis aimed to evaluate the efficacy of alternative DBExG therapy in healthy older adults and individuals with chronic stroke via the commercially available and cost-effective Kinect dance video game "Just Dance 3".

The studies in this dissertation demonstrated the feasibility and effectiveness of a novel DBExG training paradigm and validated the same. Such paradigms have the potential to be easily translated into home settings, where community-dwelling healthy older and individuals with chronic stroke can safely address the challenges of linking multiple domains of the ICF (International Classification of Functioning, Disability and Health), particularly in the context of negating the impairment at the body function/structure level (e.g., CV fitness, CMI), at the activity level (eg, increase PA), and community participation level (e.g., increased community integration). The results of this dissertation would hold good for translating the DBExG training programme to be used either in clinical practice/ home-based setting as an alternative to conventional and maintenance therapy. The underlying goal of this line of research is to form the basis for launching and establishing a compliant and effective multidimensional training regimen, later to be translated to minimal caregiver supervised home-based training using Kinect, which, without doubt, have vast implications for healthcare in community-dwelling stroke population.

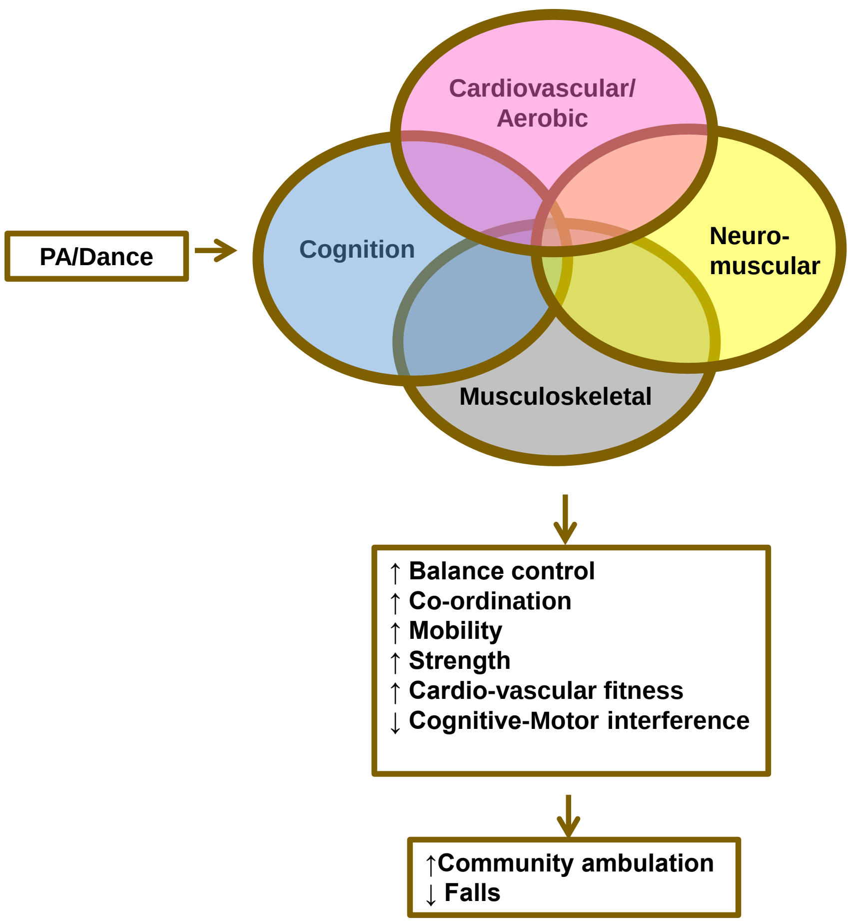

Figure 28 Conceptual effects on the effects of PA/Dance

Conventional and emerging alternative forms of rehabilitation methods are primarily directed towards incorporating improvement in physical function. This thesis proposed a holistic approach, to focus on motor, cognitive and cardiovascular function in an attempt to increase PA and community ambulation in chronic stroke survivors and older adults. Potentially, integrating dance with low-cost exergaming could potentially increase executive functioning processes, and provide physical activities with decision-making opportunities to facilitate complex cognitive processing required for community-living and at the same time address balance control, functional mobility, cardiovascular fitness and reduce fall risk, leading to a better quality of life.

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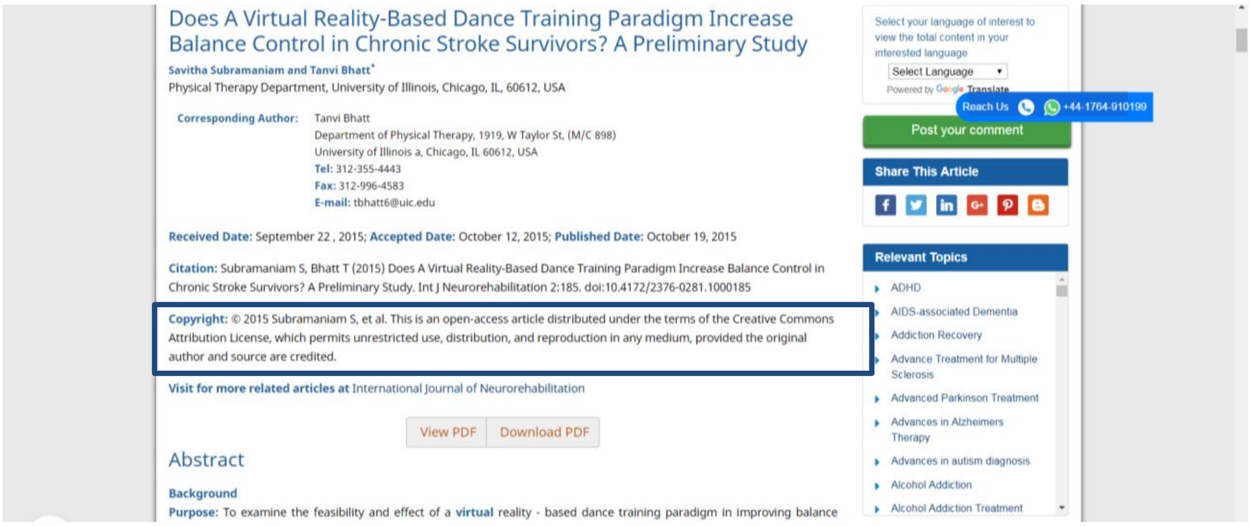
Appendix A



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

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Received Date: September 22 , 2015; Accepted Date: October 12, 2015; Published Date: October 19, 2015

Citation: Subramaniam S, Bhatt T (2015) Does A Virtual Reality-Based Dance Training Paradigm Increase Balance Control in Chronic Stroke Survivors? A Preliminary Study. Int J Neurorehabilitation 2:185. doi:10.4172/2376-0281.1000185

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Abstract

Background

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

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- Advances in autism diagnosis
- Alcohol Addiction
- Alcohol Addiction Treatment

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Jan 2014- Present — ***Research Assistant***, Cognitive, Motor & Balance Rehabilitation (CogMoBal) Laboratory, University of Illinois, Chicago

Jun 2005- Oct 2005 — ***Physical Therapist***, Satya Physiotherapy Center, Chennai, TN, India,

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Honors and Awards

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2012 ***Tuition Waiver for Fall***, College of Applied Health Sciences, University of Illinois at Chicago

2004 ***Best Student of the Year,*** **Tamil Nadu DR. MGR Medical University, India**

2003 ***Best Student of the Year,*** **Tamil Nadu DR. MGR Medical University, India**

Contributions to Science

1. **My first and primary research line focuses on investigating and understanding the effect of cognitive-motor interference with the semantic cognitive domain on intentional vs. reactive balance control in people with hemiparetic stroke. The findings of these studies demonstrated that the individuals with stroke showed deteriorated balance and cognitive performance (semantic) under dual-task compared with single-task during intentional balance control and only cognitive task during the reactive balance task. Later, to understand the effect of cognitive-motor interference, between healthy aging and aging due to stroke, I explored the impact of both semantic and working memory cognitive domains when each was concurrently performed with a voluntary balance task to evaluate the differences in the resulting cognitive-motor interference between healthy aging and aging with stroke. In this study, I found that young adults showed the least cognitive-motor interference, with a similar performance on both semantic and working memory tasks. On the other hand, healthy aging and stroke impacted both semantic and working memory. Stroke-related cognitive deficits may further significantly decrease working memory function. Additionally, I also evaluated the reliance on the ipsilesional upper extremity for activities of daily living and maintenance of functional independence and postulated that it is essential to integrate ipsilesional UE training with cognitive-motor training into stroke rehabilitation interventions as it might aid in functional reaching activities of daily living and maintain independent living among community-dwelling stroke survivors.**

1. **Bhatt, T., <u>Subramaniam, S.,</u> & Varghese, R. (2016). Examining interference of different cognitive tasks on voluntary balance control in aging and stroke. Experimental brain research, 234(9), 2575-2584.**
2. **<u>Subramaniam, S.,</u> Hui-Chan, C. W. Y., & Bhatt, T. (2014). Effect of dual tasking on intentional vs. reactive balance control in people with hemiparetic stroke. Journal of Neurophysiology, 112(5), 1152-1158.**
3. **Bhatt, T., <u>Subramaniam, S.,</u> & Varghese, R. (2018).** Influence of chronic stroke on functional arm reaching: Quantifying deficits in the ipsilesional upper extremity? Experimental Brain Research (In review).

2. **Determining cognitive-motor interference plays a critical part in balance control among people with hemiparetic stroke, and understanding rehabilitation paradigms that address the same are essential. I firstly, integrated cognitive-motor rehabilitation and examined a novel and cost-effective cognitive-motor training paradigm comprising WiiFit gaming performed in conjunction with various higher-cognitive tasks. I explored the above paradigm based on recent literature that demonstrated that** virtual reality rehabilitation, in comparison with conventional methods, provides enhanced sensory feedback about movement characteristics and improves both motor task learning and execution. Additionally, virtual reality rehabilitation methods offer highly customizable, controllable, multimodal simulations that give the high subject levels of motivation and adherence and a strong sense of presence in the virtual environment. Secondly, I also explored to understand effects of alternative therapies, such as Yoga to reduce **cognitive-motor interference** for maintaining balance control during various balance tasks and found that Yoga practitioners showed better balance cognitive performance than non-practitioners during DT.
    1. <u>Subramaniam, S</u>., Hui-Chan, C. W. Y., & Bhatt, T. (2014). A cognitive-balance control training paradigm using Wii fit to reduce fall risk in chronic stroke survivors. Journal of neurologic physical therapy, 38(4), 216-225.
    2. <u>Subramaniam, S</u>., & Bhatt, T. (2017). Effect of Yoga practice on reducing cognitive-motor interference for improving dynamic balance control in healthy adults. Complementary therapies in medicine, 30, 30-35.

3. Additionally, research from the last decade has reported that the combined effect of impaired cognitive-motor control, fall incidence and reduced falls self-efficacy dispose of chronic stroke survivors to sedentary behaviors, which in turn reduces physical activity levels, community reintegration and quality of life, thus increasing cardiovascular deconditioning, the risk of secondary stroke and mortality. Only in Illinois, in 2010, more than 200,000 hospitalizations were due to stroke. For 2016, the estimated cost was $ 3 billion for health care and productivity loss for stroke, with nearly 50% incurred on long-term disabilities. This cost is expected to triple from 2016 to 2030. Given the potential financial and functional implications, I explored piloting cardiac autonomic modulation in individuals with chronic stroke post-training using virtual reality-based aerobic dance training paradigm**.** A**dditionally, contributed to science by helping in finding out virtual-reality full-body kinematics evaluated through continuous motion capture system during dance**

movement in healthy young adults in an attempt to provide a normative data set of movement kinematics, which could be comparable to older and stroke population.

1. Sampaio, L. M. M., Subramaniam, S., Arena, R., & Bhatt, T. (2016). Does virtual reality-based Kinect dance training paradigm improve autonomic nervous system modulation in individuals with chronic stroke? Journal of vascular and interventional neurology, 9(2), 21.
2. Subramaniam, S., & Bhatt, T. (2015). Does a virtual reality-based dance training paradigm increase balance control in chronic stroke survivors? A preliminary study. Int J Neurorehabil, 2, 1-10.
3. Subramaniam, S., & Bhatt, T. Virtual reality-based dance for upper extremity rehabilitation in community-dwelling individuals with chronic stroke. A preliminary study (In preparation).
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Additional Information: Research Support and Scholastic Performance

Ongoing Research Support

1) 5 P30 AG 022849 **Principal Investigator** - Savitha Subramaniam
09/26/2016 – Present
Mentor – Dr. Tanvi Bhatt

Midwest Roybal Center for Health Promotion and Translation – Pre-Doctoral pilot grant