Dance-Based Exergaming in Older Adults: Examining Effect on Movement Kinematics and Physical Function

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Dedication

This dissertation is dedicated to my parents, family (especially to my sister, Mrs. Angela Ofori and her husband) and to my wife, without whom this work would have never been accomplished.

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Contribution of Authors

Chapter 1 is a brief literature review of research questions of this dissertation. Ms. Julia Lerman assisted to edit this chapter. Chapter 2 represents a published manuscript (Ofori, E. K., Subramaniam, S., Wang, S., & Bhatt, T. (2019). Kinematic analysis of dance-based exergaming: effect of song pace on center of mass and joint mobility. *Journal of physical therapy science, 31*(9), 708-716) for which I was the primary author. I was also involved in all aspects of this study, which included recruitment, data collection, analysis and writing the manuscript. Dr. Tanvi Bhatt and I contributed to research design, coming up with research question and by reviewing and providing valuable input to the manuscript. Also, Drs. Shuaijie Wang and Savitha Subramaniam contributed to data collection, data analysis, write-up and reviewing of the manuscript. Ms. Julia Lerman and Alison Schenone assisted with editing this chapter. Chapter 3 represents an unpublished manuscript (Ofori, E. K., Subramaniam, S., Wang, S., & Bhatt, T. Kinematic analysis of dance-based exergaming: a cross-sectional study) for which I was the primary author. I was also involved in all aspects of this study, which included recruitment, data collection, analysis and writing the manuscript. My research mentor, Dr. Bhatt and I contributed to research design, coming up with the research question as well as reviewing and writing the manuscript. Ms. Julia Lerman assisted by editing this chapter. Chapter 4 represents unpublished manuscript (Ofori, E. K & Bhatt, T. Effectiveness of a dance-based exergaming intervention for older adults with mild cognitive deficits) for which I was the primary author. This research was mainly funded by the Roybal predoctoral grant from the National Institute of Aging (NIA) and by Dr. Bhatt's departmental funds. I was also involved in all aspects of this study, which included seeking IRB approval, recruitment, data collection, analysis and writing the manuscript. Dr. Bhatt and I contributed to research design, coming up with research question and by reviewing and providing valuable input to the manuscript. Drs. Savitha Subramaniam and Shuaijie Wang and contributed to data collection and data analysis, respectively. Ms. Julia Lerman assisted with editing this chapter. Chapter 5 represents an unpublished manuscript (Ofori, E. K & Bhatt, T. Validity of inertial sensors for assessing balance kinematics of mobility during dance training) for which I was the primary author. I was also involved in all aspects of this study, which included recruitment, data collection, analysis and writing the manuscript. My research mentors, Dr. Bhatt and I contributed to research design, coming up with the research question and by reviewing and providing valuable input to the manuscript. Drs. Shuaijie Wang and Savitha Subramaniam contributed to data collection, data analysis, write-up and reviewing of the manuscript. Ms. Julia Lerman assisted with editing this chapter. Chapter 6 represents my synthesis, conclusion and future directions of the research presented in this dissertation. Ms. Julia Lerman assisted with editing this chapter.

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List of Abbreviations

MCI	-	Mild cognitive impairments
ST	-	Single task
DT	-	Dual task
DBExG	-	Dance-based exergaming
bh	-	Body height
CoM/COM	-	Center of Mass
TUG	-	Timed-up and Go
BBS	-	Berg Balance Scale
RSME	-	Root mean square error
RT	-	Reaction time
SIT	-	Step initiation time
MVL	-	Movement velocity
MXE	-	Reaction time
DCL	-	Directional control
Ex (s)/exc	-	Excursion (s)
SP	-	Slow-paced song
MP	-	Medium-paced song
FP	-	Fast-paced song
AP	-	Anteroposterior
ML	-	Mediolateral
3D	-	Three (3) dimensional
CoV	-	Coefficient of variation/variability
LE	-	Lower extremity
s/sec	-	Second (s)
deg	-	Degree
BOS	-	Base of support
AD	-	Alzheimer's disease
SBP	-	Systolic blood pressure
DBP	-	Diastolic blood pressure
HR	-	Heart rate
SPO_2	-	Oxygen saturation
bpm	-	beats per minute

Lt	-	Left
Rt	-	Right
LE	-	Lower extremity

Chapter 1: Background

1.1. Falls and epidemiology of falls

A fall is an accidental event, in which the body comes into contact with the ground or a supporting surface such as a chair or wall, occasioning from either an internal or any external environmental force (Masud & Morris, 2001). As humans age, there is reduced balance control, gait instability and increased frequency of falls (Dionyssiotis, 2012; Rubenstein, 2006). Frequent falls in the aging population results in perilous injuries and increased hospitalizations (Dionyssiotis, 2012). Falls are an outcome of increased loss of stability, with stability defined as the ability to keep the center of mass within the base of support during walking (Shumway-Cook & Woollacott, 2007). An incidence of at least one fall per year is reported by 30% of individual over 65 years and 50% of those over 80 years report of at least one incidence of falls every year. Walking results in over half of these falls (Barak et al., 2006; Hausdorff et al., 2001; Kerrigan et al., 2000), resulting in varying degrees of injuries. Thus, falls in older adults over 65 years of age is the leading cause of fatal injuries and accidental deaths in this population (Barak et al., 2006; Hausdorff et al., 2001). Imperatively, therapeutic interventions should be implemented in order to curtail the increasing trend of falls and its consequences in older adults.

1.2. Consequences of falls

Falls result in varying degrees of injuries ranging from fractures of the hip and wrist to head injuries, which can lead to prolonged hospitalization and death (Stevens et al., 2006). A consequence of frequent falls and injuries is the occurrence of the fear of falls, which leads to reduced physical activity, cardiovascular deconditioning, and less participation in community or social activities (Wagner et al., 1992). The fear of falling is a mental effect of frequent falls, which plays a key role in reduced physical activity and poor quality of life (Bertera & Bertera, 2008).

Furthermore, the reduced physical activity in aging then leads to increasing comorbidities such as high blood pressure and diabetes. The treatment and management of fall-related injuries and comorbidities culminate into huge financial burden of medical cost (Burns et al., 2016). Considering the above-mentioned physical, psychological and economic impact of fall-related injuries that occur in old age, it is necessary to understand the age-related changes that occur in aging and to implement physical rehabilitation strategies in order to reduce fall risk and improve physical conditioning of older adults.

1.3. Age-related changes contributing to balance and falls

Aging results in increased fall risk due to reduced balance control, which is controlled by interactions between intrinsic and extrinsic factors (Campbell et al., 1989; Lipsitz et al., 1991; Tinetti et al., 1988; Woollacott, 2000). Intrinsic factors contributing to reduced balance control are reduced muscle strength, poor vision and inferior somatosensory systems resulting in gait instability and imbalance, thereby leading to increased fall risk (Plaksin, 2014; Rubenstein, 2006). Aging results in changes in the nervous system, which includes motor cortex atrophy, deterioration of the transmission of sensory inputs to motor units and reduction of nerve endings (Prince et al., 1997). Due to the deterioration of the sensorimotor system, there is reduced speed and accuracy of transmission of sensory inputs, as well as reduced coordination of leg muscles in aging. Because of these intrinsic factors, there is slowness of reaction to a slip or trip event, which contributes to increased fall risk (Pannese, 2011; Plaksin, 2014; Rubenstein, 2006; Seidler et al., 2010).

Additionally, extrinsic factors play a critical role in increasing fall risk during aging. Factors such as availability of stair railings, bath rails or bars, poor stair designs, dim lights, slippery surfaces and obstacles are regarded as factors, which can cause falls (Plaksin, 2014; Rubenstein, 2006). A major extrinsic factor which increases fall risk in aging is perturbation-like events such as slips and trips in the community (Courtney et al., 2001; Luukinen et al., 2000). In aging, the inefficiency of maneuvering around the extrinsic factors because of the deteriorating intrinsic events leads to the inability to maintain or regain balance during a slip or trip event, resulting in increased fall risk. Since slips and trips during gait results in increased rate of falls, it is imperative to understand the mechanisms of balance control and age-related gait changes in older population (Li et al., 2006).

Balance control is attained by the interaction between proactive (anticipatory) and reactive (compensatory) balance systems of the nervous system, which controls the center of mass (CoM) position by activation of muscles of the trunk and legs (Aruin, 2002; Maki & McIlroy, 2006). Anticipatory postural adjustments occur before a perturbation event, while the compensatory postural adjustments occur soon after perturbation. Studies have shown that age-related deficits in anticipatory postural adjustments are depicted in the slowness of volitional stepping in order to reestablish the center of mass (CoM) within the base of support (BOS) (McCrum et al., 2016; Süptitz et al., 2013; Takeshima et al., 2014). Efficient stepping mechanism with regards to quick voluntary stepping is a major requirement for increased balance and prevent falls during the occurrence of perturbation (Maki & McIlroy, 2006). Younger adults exhibit this efficient mechanism than older adults and this results in the increased fall risks in older adults (Luchies et al., 2002; Rogers & Mille, 2003). In effect, aging results in slower proactive step initiation time due to the slowness of activation of postural muscles (Frank, 1987).

While proactive balance control is mediated by feed-forward mechanism, the reactive or compensatory balance control is regulated by the feedback mechanism of the nervous system in order to maintain the CoM within the BOS. The reactive balance control is controlled by somatosensory, visual and vestibular systems of the nervous system (Shumway-Cook & Woollacott, 2007). Following a disturbance of balance, an individual must utilize hip and ankle strategies as well as a rapid reactive stepping response in order to prevent falls (McIlroy & Maki, 1996; Rogers & Mille, 2003). To prevent falls, there should be a well-timed execution of a coordinated response to sensory stimuli. Aging results in slowness and poor coordination of stepping response due to inefficient activation of muscles, leading to frequent falls in older population (Prince et al., 1997; Sawers et al., 2016; Süptitz et al., 2013). The inefficient proactive and reactive balance control mechanisms in aging are shown to result in the inability to recover from a novel slip-like perturbation. As such, older adults are twice more likely to fall than younger adults (Pai et al., 2010). Additionally, older adults are twice as probable to fall after experiencing perturbations in the forward, backward and mediolateral directions and take more recovery steps than young adults (McIlroy & Maki, 1996). With knowledge of the age-related balance control deficits leading to increased fall risks in aging, it is important to better understand these factors and implement new and alternative paradigms to ameliorate these balance deficiencies.

1.4. Aging and cognition

Recently, the increase in fall risk during aging has been attributed to worsening cognitive function in domains such as memory and executive functions (Beurskens & Bock, 2012; Shumway-Cook et al., 1997; Tinetti et al., 1988; Y Tseng et al., 2014). Thus, an individual with less cognitive ability will be predisposed to an increased number of falls in a year. As such, older adults with mild cognitive impairments (MCI) will experience falls by two-fold and detrimental effects of fall risk such as fracture and head trauma than older adults without MCI (Beurskens & Bock, 2012). Around 60% of cognitively-impaired older adults fall every year and this occurrence is twice that of the aged with normal cognitive functions (Liu-Ambrose et al., 2008). Another study has stated that the odds of falling are five times greater in older adults with cognitive impairment

(Tinetti et al., 1988). Though there are numerous studies on falls in the elderly with dementia and Alzheimer disease (AD) (Buchner & Larson, 1987; Shaw, 2002), limited research is concentrated on older adults with MCI. Thus, the incidence of falls and determinants of fall risk in older adults with MCI are not clearly understood.

Mild cognitive impairment (MCI) is defined as a transitional clinical condition between normal aging and AD consisting of reduced cognitive functions, which exceeds ones anticipated for an individual's age and educational level. However, this condition does not affect ADLs of individuals affected (Feldman & Jacova, 2005; Petersen et al., 2001). As a transitional stage to AD, older adults with MCI are 5 to 30 times more likely to develop AD than non-MCI counterparts (Liu-Ambrose et al., 2008). The prevalence of MCI is higher than dementia. A study conducted in Canada reported that MCI is prevalent in 16.8% of Canadians aged 65 years and older, while 8% had dementia (Graham et al., 1997). Consequently, older adults with MCI present with poor balance and gait instability in addition to impaired executive functions. The above-mentioned impairments are associated with frequent falls in older adults with MCI (Liu-Ambrose et al., 2008; Rapport et al., 1998). In an assessment study with Physiological Profile Assessment (PPA), older adults with MCI had higher composite PPA score and greater postural sway than their counterparts without MCI. Additionally, MCI older adults performed worse on executive function tests than their non-MCI counterparts (Liu-Ambrose et al., 2008). Thus, the assessment cognitive functions and the management of fall risk should be a major constituent of health care for adults with MCI.

1.5. Age-related changes to gait

Gait is complexly mediated by interaction between the nervous, musculoskeletal and the cardiopulmonary systems (Ferrucci et al., 2000; Moon et al., 2016; Prince et al., 1997). The reduction in the performance of these systems in aging results in the decrease of step length, gait speed and cadence. There is also a reduction in single-stance time and an increase in double support time, stride width and stride length variability during aging (JudgeRoy et al., 1996; Riley et al., 2001; Winter et al., 1990). Nevertheless, gait speed is considered as a major predictor of fall risk and a key measure of general wellbeing and physical function (Pasma et al., 2014 224; Verghese et al., 2009). Research has shown that the reduced step length and slowness of gait speed are a result of the reduction of power generation of the plantarflexors during push-off (Franz, 2016). Other studies have also shown that decline in performance of activity such as walking as well as the inability to prevent falls during a slip-like perturbation leads to a reduction in the CoM velocity in aging. Attributes such as faster horizontal heel contact velocity, shorter step length, and faster CoM acceleration predispose one to slip-related falls. Such age-related gait changes in aging depicted as reduction in gait speed results in the inability to maintain CoM within BOS, and these factors are highly associated with increased fall risk in older adults (Bhatt et al., 2011; Bhatt et al., 2006).

1.6. Aging and physical function

Physical function is the ability to perform activities of daily living (ADLs) with the requisite mobility, strength and endurance required for maintaining independence (Shah et al., 2017). Aging results in decline in physical function, which has been shown to increase fall risk, hospitalization, admissions to nursing homes, dependence and reduced quality of life. Hence, it is important to promote different components of physical function in order to prevent comorbidities for an increased quality of life during aging. Some of these components of physical function are physical activity (PA) and cardiovascular fitness or endurance.

Physical inactivity is highly prevalent in the older population 65 years and over (DiPIETRO, 1996). This leads to the development of comorbidities such as hypertension, cardiovascular disease, diabetes mellitus and over-dependency on others for ADLs (Tudor-Locke & Bassett, 2004). In fact, the World Health Organization (WHO) reports that physical inactivity accounts for 3.5 million deaths annually (Organization, 2013). With the aging population projected to increase to 2 billion in the year 2050, the physical inactivity trend is also expected to increase (Bauman et al., 2016). As a result, the Health Department of United States has recommended an increase in physical activity levels for the aging population. It is reported that walking is the most prevalent and convenient physical activity for the older adults to maintain increased quality of life. However, older adults are unable to attain the daily count of 10,000 steps. Therefore, a moderately paced walking for 30 minutes is a recommended activity for older adults to attain at least 5,000 steps per day in order to achieve the optimal level of physical functioning (Tudor-Locke & Bassett, 2004). In order for older adults to execute the optimal daily step count, there is the need to improve cardiovascular fitness through aerobic training. With increased cardiovascular fitness or endurance, older adults can reach their daily step count, normalize blood pressure, reduce resting heart rate and increase or improve heart rate variability indices (Hsu et al., 2015) for an enhanced quality of life and increased physical functioning such as the reduction or prevention of falls as a result of increasing PA levels (Sherrington et al., 2004). This will assist in reducing the ascending trend of comorbidities in the aging population. Since, older adults are unable to even attain the daily count of at least 5,000 steps, it is imperative to develop other physical activity interventions (such as dance-based exergaming) to increase the PA levels in the aging population.

1.7. Interventions for fall risk with conventional vs alternative therapies

Over the years, conventional therapies that include task-oriented movements and balance training have been implemented to curtail the increasing fall risk in the geriatric population and in those with neurological conditions such as stroke and Parkinson’s disease. These conventional balance training programs delivered with the required dosage are effective in improving balance and prevent falls by placing an optimal challenge to the balance systems (Sherrington et al., 2011). It is also known that balance training improves balance, gait and physical conditioning of older adults through motor learning because of increased plasticity in brain centers for balance and movements (Berrol, 2006). However, these conventional balance training programs improve the anticipatory or volitional balance only and may not be translatable to the community of older adults, since it fails to train the reactive balance and reduce falls (Grabiner et al., 2014). Also, motivation and adherence to therapy are hampered as conventional training programs are monotonous and require multiple visits to clinics or training sites in order to attain any improvement in balance (Lee et al., 2014). In order to train the reactive balance to prevent falls in daily activities by older adults and to increase adherence and participation in balance training, alternative balance interventions such as perturbation training, dance and exergaming have been highly recommended for community-based older adults.

Perturbation training is a growing alternative balance training paradigm that induces adaptive changes by challenging the balance systems with simulated unexpected, repeated disturbance of balance similar to an accidental slip or trip (Gerards et al., 2017; Patel & Bhatt, 2015). This novel mechanism improves both proactive and reactive balance (Patel & Bhatt, 2015) and translates to fall prevention in older adults in the community (Pai et al., 2010; Pai et al., 2014). Mechanistically, the central nervous system (CNS) uses trial-error information from repeated exposure to perturbation to adapt reactively and proactively through the feedback and feed-forward systems of the CNS. The CNS then adapts to produce protective and reactive response to prevent falls through effective stepping strategies in order maintain the CoM within the BOS (Bhatt et al., 2006; Yang et al., 2009). However, as an emerging therapy, there is no information on the adherence rate of participation in the perturbation training.

Nevertheless, dance as an alternative therapy is known to facilitate positive exercise-related behaviors, such as motivation and adherence, towards interventions (Burkhardt & Brennan, 2012; Shigematsu et al., 2002). Recently, dance as a sensorimotor physical activity has been reported to increase cognitive functions, improve balance and enhance physical functioning in older adults (Hamacher et al., 2015; Rehfeld et al., 2017). The improved cognitive functions with dance also have positive effect on fall risk as a result of plastic changes that occur in the cortex of brain (Berrol, 2006). The use of dance may therefore play a critical role in improving the quality of life of older adults. However, in order to increase the practice sessions, repetitions and adherence to dance therapy for improved results, it will be appropriate to implement the therapy at home for patients.

The home-based dance therapy could be executed with the use of exergaming tools such as Wii, PlayStation or Xbox Kinect. The implementation of dance-based exergaming in older adults and in individuals with stroke is feasible and effective in improving balance, cardiovascular and physical functioning (Subramaniam & Bhatt, 2015). However, dance-based exergaming currently lacks baseline data on biomechanical or kinematic measures of balance control (center of mass position, postural sway), motor learning (stepping speed) and physical activity (step count) for comparison of the progression of goals of dance therapy. It is therefore imperative to generate this data using song inputs of variable intensities or paces ranging from slow to fast-paced songs. Additionally, generating baseline or normative data of balance control for young and older individuals, as well individuals with neurological conditions will provide an objective data of balance for an accurate assessment of the effectiveness of dance therapy in different populations.

With no study on dance-based exergaming for older adults with MCI, this dissertation proposes a dance-based exergaming for improvement of cognitive function in older adults with MCI, which will in turn improve balance, reduce fall risk and improve physical and cardiovascular function. In order to conduct a study with dance-based exergaming for older adults with MCI, it will be advisable to determine its feasibility in a controlled laboratory setting before its implementation at the home-based or community-based setting. The translation of benefits of dance-based exergaming to clinics, homes and community could be executed by assisting in examination of kinematics of postural stability and mobility with accelerometer-based, miniature and portable motion capture system known as inertial sensors.

1.8. Translation of therapies to home or community setting with inertial sensors

To transfer the gains of dance therapy to the community setting and into the activities of daily living for older adults with mild cognitive impairments (MCI), there is a need to continually assess its effectiveness in the home or community setting. However, the assessment of the effectiveness of dance can only be accomplished by the use of activity monitoring sensors or inertial sensors. Inertial sensors are low-weight motion analysis systems, which has the capability of providing data on gait, balance, stability fall risk as well as joint mobility outside the laboratory setting. The ability of inertial sensors in providing these quantitative objective data are due to the infusion of accelerometers, gyroscope, magnetometers, pressure sensors and goniometers in their construction. Inertial sensors are less expensive, miniature in size and portable for easy transfer to different locations outside the laboratory. These wearable inertial sensors make data collection less cumbersome for both patients and therapist (Qiu et al., 2018). Inertial sensors are reliable in collecting data on balance, mobility and fall risk during the performance of balance and gait tasks. However, to date, there is no data indicating the use of inertial sensors in collecting data on balance, stability, fall risk and joint mobility during stance perturbation training and dance therapy. Therefore, this dissertation proposed the validity of inertial sensors for obtaining data on stability and fall risk during dancing with different song paces. With proven validity of inertial sensors, we can confidently design home-based dance therapy and assess variables of interest in future studies.

1.9. Statement of the problem

Recent knowledge of the association between cognition and fall risk has not been widely studied. But it is common knowledge that older adults with MCI are faced with increased fall risk than those without MCI, due to increased deficits in cognitive functions such as working memory, learning and spatial navigation (Hamacher et al., 2015; Rehfeld et al., 2017). Reduction in fall risk can be tackled with exercise that incorporates the use of memorization and physical activity. Dance, as a multisensory activity, has been reported to have positive effect cognitive function of healthy older adults and those with AD due to the plastic changes that occur in the hippocampus. The increased plasticity necessitated by performance of dance mediates spatial orientation, working memory, balance and motor learning (Hamacher et al., 2015; Rehfeld et al., 2017). However, there is no data on the effectiveness of dance therapy for enhancing cognition, which has the potential to improve balance, reduce fall risk and increase physical functioning in older adults with MCI.

1.10. Significance of the study

Results of this study will have the potential to add more information to the alternative rehabilitation field and contribute to the design of more comprehensive studies with dance therapy and other adjunctive therapies. Additionally, with a proven validity of inertial sensors for objective data collection during dance therapy, therapists can confidently assess the progress of performance of dance therapy at home or in the community setting. With current advocacy on the transfer of laboratory-based research to daily activities of older adults in the community or home settings, data from this dissertation study will assist in designing dance and other studies in the home or community setting for older adults with MCI.

1.11. Summary of aims and hypotheses

This dissertation consists of four individual studies addressing a unique research question. These individual studies have been described in four major chapters. Study 1 in chapter 2 examines and compare the balance and movement kinematics of dance movements to different song paces during dance-based exergaming (DBExG) in young adults, while study 2 in chapter 3 compares these kinematic variables between healthy young and older adults. Specifically, the ultimate goal is to establish a quantitative kinematic assessment method for examining postural control and joint kinematics using a commercially available dance-based exergaming Microsoft Kinect ‘Just Dance’ platform.

It was hypothesized that normative kinematic data during DBExG would be established for health young adults and determine the differences between the kinematics of dancing with slow, medium and fast-paced songs. Additionally, the normative data of kinematics of dance would be developed for healthy older adults. The comparison with young adults would depict a better performance in younger than older adults during dance with the three paces of songs.

Additionally, study 3 in chapter 4 proposes to examine feasibility, adherence and effectiveness of a dance-based exergaming (DBExG) paradigm on cognitive function, motor function and physical fitness of community-based older adults with mild-cognitive impairment (MCI).

It was hypothesized that this protocol will prove to be feasible with adherence rate comparable or as good as those obtained in other studies involving older adults. Also, post-training will demonstrate improvements in cognitive and motor functions as well as increases in physical fitness of older adults with MCI. This will provide the older population with reduced fear of falling and the confidence in participation in community-based activities of daily living.

Study 4 in chapter 5 examines the validity of inertial sensors in measuring kinematics of balance and mobility during the performance of dance-based exergaming.

It was hypothesized that inertial sensors would show high validity for data collection and assessment of balance and mobility kinematics during perturbation training and dance. It would therefore provide a strong proposition for the translation of benefits of rehabilitation paradigms to the clinical, home and community settings.

1.12. Organization of dissertation

This dissertation involves six main chapters, which includes four main research topics that are connected to each other. Chapter 1 provides the background, aims and hypotheses of this dissertation. Chapter 2-5 are made of research topics that are all aimed at determining the baseline kinematic data, effectiveness of dance-based exergaming and validity of inertial sensors in young and older adults. The last chapter involves concluding remarks and future directions of all the studies in this dissertation.

Chapter 2

Kinematic analysis of dance-based exergaming: effect of song pace on center of mass and joint mobility (Previously published as: Ofori, E. K., Subramaniam, S., Wang, S., & Bhatt, T. (2019). Kinematic analysis of dance-based exergaming: effect of song pace on center of mass and joint mobility. *Journal of physical therapy science, 31*(9), 708-716)

2.1. Introduction

Dance uses full-body movement practice, which provides comprehensive rehabilitation by addressing physical functioning in healthy and neurologically impaired populations (Hackney & Earhart, 2009; Krampe, 2013; Lee et al., 2015; Pichierri et al., 2012; Subramaniam & Bhatt, 2015). Dance has been shown stimulate productive exercise-related attributes, such as motivation and adherence, towards interventions using dance therapy (Burkhardt & Brennan, 2012; Shigematsu et al., 2002). Dance involves coordination of movement of multiple limb segments, synchronized with a rhythmic stimulus, over many degrees of movement (Sofianidis et al., 2009). Dancing involves repeated, self-generated internal perturbations. Such repeated self-induced perturbations require individuals to rapidly shift their center of mass (CoM) to different spatial locations while preventing loss of balance and this facilitates improvements in balance control, which leads to reduction in the risk of falls (Federici et al., 2005; Keogh et al., 2009). Recently, dance has demonstrated to be successful in improving balance control and mobility deficits in various populations including healthy young adults, aging individuals and people with disabilities (Betker et al., 2007; da Silva Borges et al., 2014; Lohse et al., 2014; Veronese et al., 2017). A systematic review found dance to be clinically beneficial for improving on factors of fall-risk such as balance, gait, strength and physical function in older adults (Fernández-Argüelles et al., 2015). Additional systematic review and meta-analysis showed dance to be an effective intervention in improving clinical measures of balance control and quality of life for people with neurological deficits (Hwang & Braun, 2015; Keogh et al., 2009; Sharp & Hewitt, 2014).

However, it is pertinent to note that many studies have been conducted with wide variety of different dance styles, including Korean, Ballroom, Argentine, Tango, Turkish folkloristic, Greek, Caribbean and Aerobic dance (Granacher et al., 2012; Keogh et al., 2009; Sofianidis et al., 2009). These dance types consist of variety of movement patterns in the anteroposterior (AP) and mediolateral (ML) direction. They are also made of different song paces, which alter the biomechanical demands, resulting in specific adjustments for each dance form (Harris et al., 2007; Schoene, 2007). Still, there is limited evidence of how different dance forms with varying song paces affect the quality of movement and postural control. Therefore, the quantification of clinical improvements movement and postural control, which may be important for rehabilitation in aging and neurologically-impaired populations. Additionally, although dance as a community-based activity has several benefits on quality of life, it also possesses barriers to dance activity including cost, accessibility, availability of transportation to therapy site and caregiver support of therapy. Some of these barriers to dance of either structured or semi-structured dance sessions could be assuaged by dance-based exergaming using platforms such as the Kinect (Microsoft Inc., Redmond, WA, USA).

A laboratory-based pilot study with dance-based exergaming have shown improvements in balance control assessed by the Limits of Stability test (NeuroCom International Inc., Clackaman, OR, USA), and enhancement in functional clinical measures for individuals with chronic stroke (Subramaniam, 2015) and Parkinson's disease (Lee et al., 2015; Šumec et al., 2015). These studies on contemporary dance have use tools such as electromyography (EMG), force plates, motion analysis to evaluate variables of mobility and balance (Hackney & Earhart, 2009; Pichierri et al., 2012). However, although these studies have shown the positive effects of dance-based exergaming, they did not quantitatively assess the kinematic parameters of motor control to demonstrate any improvements during dance training. Moreover, till date, no study on dance has used a continuous motion capture system to depict how different song paces used in dance-based exergaming impact movement kinematics of the body. By examining the kinematic changes related to dancing with different song paces, the understanding of motor control and learning during dance-based exergaming will be enhanced, which could play a major role in determining the effectiveness and subsequent recommendation of dance-training protocols. For instance, evaluating the effect of dance performance on kinematic variables such as postural sway and joint range of motion (ROM) could provide critical information to clinicians in the prescription of a particular song pace to achieve a specific goal of dance training. Also, the determination of the effect of dance songs on kinematics of dance is because these important movement control variables are norm-referenced measures of postural stability and mobility.

Thus, the purpose of the present study was to develop a method for quantitative kinematic assessment postural control and joint kinematics during dance-based exergaming using a commercially available Microsoft Kinect 'Just Dance' platform. Specifically, this study sought to establish normative values for postural stability (CoM sway area and excursions in both AP and ML directions) and physical mobility (joint angles excursions in the sagittal plane) during the performance of dance by healthy young adults to selected segments of slow-paced (SP), medium-paced (MP) and fast-paced (FP) songs. Since there is no study of this kind and to examine the feasibility of this paradigm, the young population was chosen to serve as a baseline assessment for examining improvements in future dance-based intervention. Subsequently, there will be a replication of a similar protocol in other populations, including aging individuals and those with neurological disorders. The generation of objective baseline data over subjective data, could assist in the unbiased assessment of dance-based exergaming for rehabilitation.

2.2. Participants and methods

Fifteen nonprofessional dancers young adults with no previous participation in any choreographed dance program for at least one year (via prescreening interview) provided consent to participate (Table 1). For recruitment of participants, flyers were posted across various notice boards on the University of Illinois Chicago (UIC) campus. An approval of the study was sought from the Institutional Review Board (IRB) and the study was conducted in the Cognitive Motor and Balance Rehabilitation Laboratory (CogMoBal) at UIC.

Table 1: Demographic data of participants

Participants (N=15)	Gender (M/F)	Age (years)	Weight (kg)	Height (cm)
Mean	5/10	26.1	63.4	166.1
SD		4.0	8.3	8.3

2.2.1. Participant eligibility

In order to evaluate their health status and family history, participants completed a general health questionnaire. Exclusion from the study included participants' report of any recent surgery (less than six months ago) or musculoskeletal or cardiovascular conditions, which may hinder their performance of dance movements.

2.2.2. Protocol

Exergaming tool, Microsoft Kinect 'Just Dance 3' (Microsoft Inc., Redmond, WA, USA) was used to deliver segments of dance videos to participants. Three songs, which were selected for this study were of slow, medium and fast pace and of the hip-hop genre (Figure 1). A 30-second segment from each song with similar dance movement sequences were selected in order to control for variance in choreography. Generally, dance movements of all three songs included forward, backward and lateral stepping, composing of rhythmic forward and lateral single- and double-step touches, sidekicks and stepping in-place, hip-hop bounces to front and back, along with in-place and forward marching. These dance pattern necessitated anteroposterior and mediolateral movements of the upper and lower extremities. As such, all dance encouraged flexion and extension of the hip, knee and ankle joints, and with flexion and abduction of the shoulder joints. The dance songs only differed by their pace and number of repetitions of a movement sequence. Specifically, the three-song paces were slow-paced (SP- "Dynamite"), medium-paced (MP- "Party Rock Anthem") and fast-paced (FP- "Price Tag"). Due to the hip-hop genre's wide availability, popularity and enjoyment in both the United States and worldwide, songs chosen were of the hip-hop genre. The BPM database (BPM, 2003-2017) was used to verify the beats per minute (bpm) and to classify them as slow (120 bpm), medium (130 bpm) or fast (138 bpm). Before the beginning of each test, two familiarization trials of each dance song were provided in order for participants to learn the dance steps and sequences. In order to elicit their natural response and performance of the dance steps, the three dance songs were randomly delivered to participants. This dance testing session lasted for 60 minutes.

2.2.3. Data collection and processing

Twenty-nine reflective markers (Helen Hayes marker set) were placed on specific joints of upper and lower limb extremities of all participants. Dance testing for dance to each song was recorded for 30 seconds with an eight-camera motion capture system at 120 frames per second with Cortex-64 3.6.1 software (Motion Analysis, Santa Rosa, CA, USA). The software is able to provide full body kinematic values and determine raw CoM positions and joint angles for each participant. A highly reliable tractivity motion sensor (Kineteks Corporation, Vancouver, Canada) was attached to the ankles of each participant in order to record the number of dance steps for each song. The motion analysis software via digitization and an in-house MATLAB code (Math Works, Natick, MA, USA) were then used to perform initial processing and analysis of data.

2.2.4. Outcome variables

Postural stability measures of interest were absolute postural sway area, CoM excursions, number of CoM peaks and the magnitude of the maximum and minimum CoM peaks in the AP and ML directions. To determine the CoM excursion, one CoM peak was defined by a complete cycle of upward and downward CoM displacement. The magnitude of the maximum and minimum peaks was measured as the highest and lowest peak heights of the CoM movement, respectively, during a dance performance. Total sway area was defined by the combined AP and ML ellipse area and the total CoM excursion was defined by the displacement of the CoM in the transverse plane. These primary outcome measures computed using segmental method formulas (shown below) which were proposed by Prieto and colleagues (Prieto et al., 1996).

$$\text{Total Sway Area} - \text{CE} = \pi ab = 2\pi F_{0.05[2,N-2]}\left[s^2\text{CoM}_{AP}s^2\text{CoM}_{ML} - s^2\text{CoM}_{AP}\text{CoM}_{ML}\right]^{1/2}$$

$$\text{Total CoM Ex} = \sum_{n=1}^{N-1}\left((\text{CoM}_{AP}[n+1] - \text{CoM}_{AP}[n])^2 + (\text{CoM}_{ML}[n+1] - \text{CoM}_{ML}[n])^2\right)^{1/2},$$

where CE=95% confidence ellipse, N=sample size, CoM_{AP}=CoM in AP direction, CoM_{ML}=CoM in ML direction, s=standard deviation and $s\text{CoM}_{AP}\text{CoM}_{ML}$=covariance.

Secondary outcome measures were physical activity and mobility variables, which included the absolute number of peak joint angles and the magnitude of the peak joint angles for the hip, knee and ankle in the sagittal plane. These joint angles were calculated by a model created by Vaughan et al. (Vaughan et al., 1999). In this model, joint angle is determined by defining a reference frame in the proximal and distal segments. For example, the hip joint has a reference point of where the pelvis and thigh meet, for the knee joint it is at the thigh and shank, and that for the ankle joint is at the shank and foot. A customized MATLAB code was used to generate the joint angles in the sagittal plane (Figure 2) through 3-dimensional trajectories of the segmental markers (from the Helen Hayes Marker set). To calculate joint angle excursions the differences between the maximum and minimum joint angles were determined. After the elimination of one participant's data due to a missing marker data, statistical analysis was conducted using data from the remaining 14 participants.

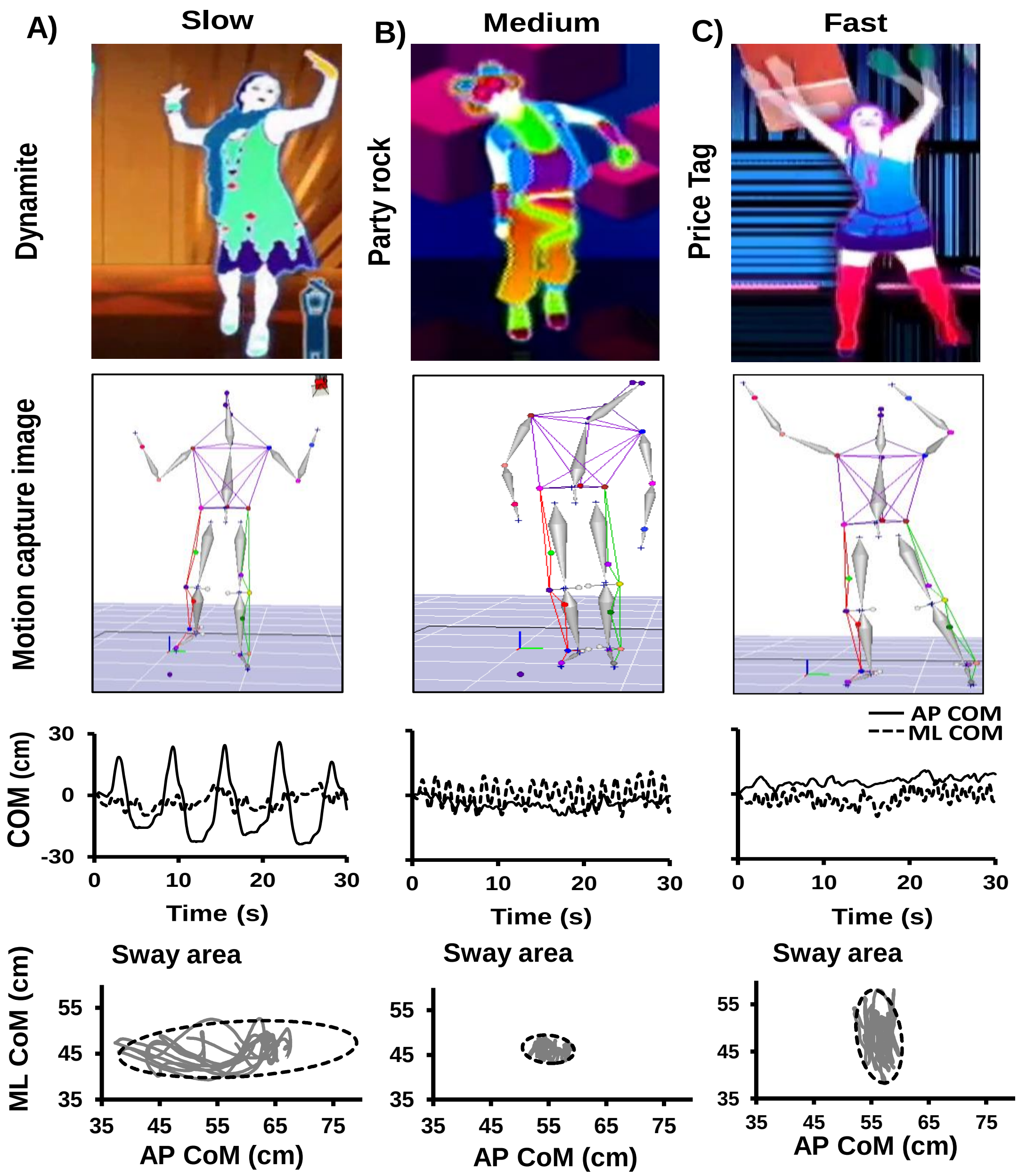

Figure 1: Frontal view of dance video images, motion capture images, anteroposterior (AP) and mediolateral (ML) center of mass (CoM) movement, as well as postural sway area plots representative of participants during dance-based exergaming. The CoM plots were normalized to zero in order for the peaks to begin from zero. Titles for the hip-hop songs used for this study include A) slow- ("Dynamite"), B) medium- ("Party Rock") and C) fast-paced ("Price Tag") songs.

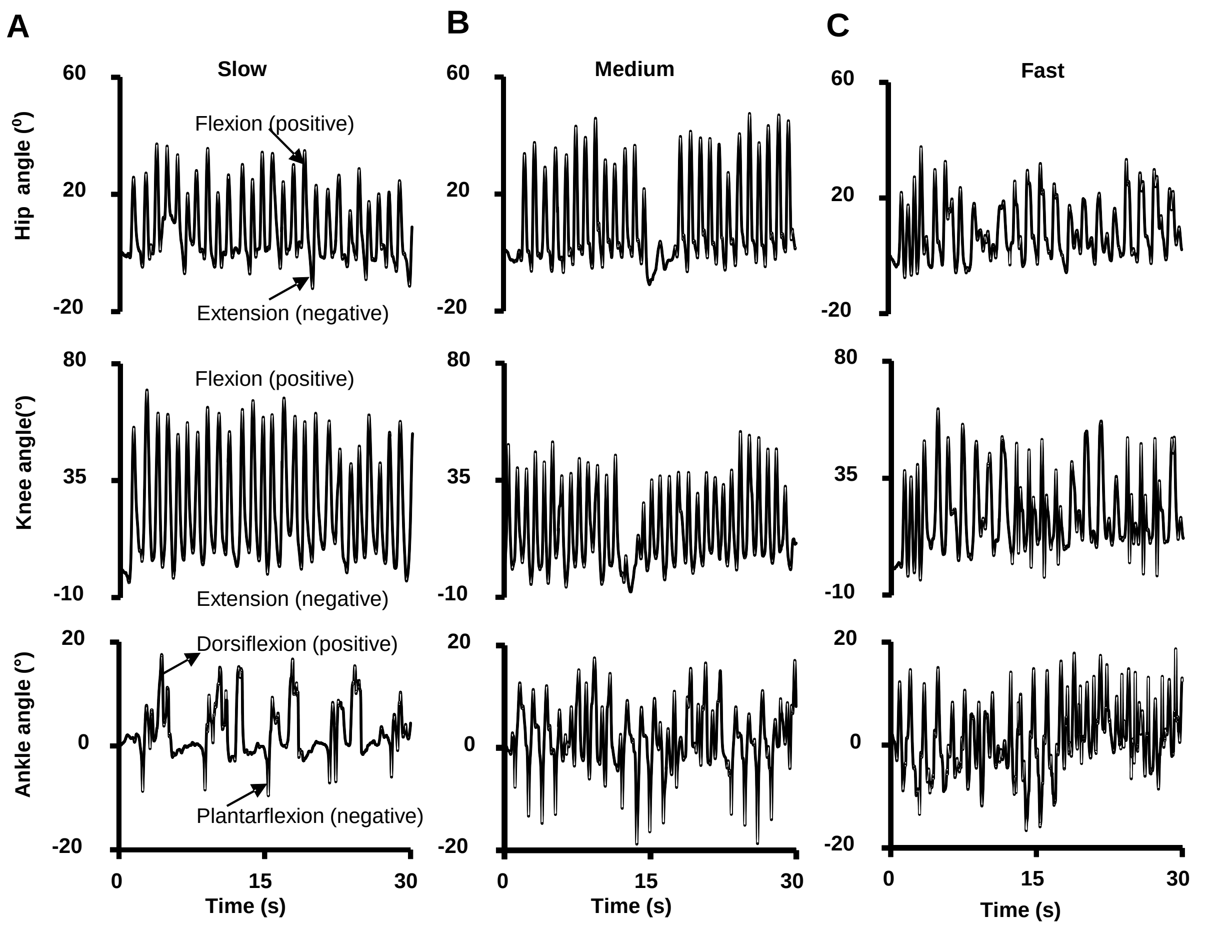

Figure 2: Plots showing hip, knee and ankle joint excursion angles (in degrees) over time for A) slow B) medium and C) fast-paced songs during the dance-based exergaming. The number of joint peaks increased for dancing to the fast-paced song.

2.2.5. Statistical analysis

Variations in total sway area, total CoM excursions, CoM peaks and excursions in either the AP or ML directions with song pace were determined by one-way ANOVA. Furthermore, effect of the song on movement in both the AP and ML directions and the interactions between song choice and dance direction were determined by 3*2 repeated measures ANOVA.

A 3*3 repeated measures ANOVA was used to determine the effect of song pace on the number of joint angle peaks and joint excursions and the interactions between song choice and extent of joint movement. Post hoc analysis for each song pace was performed to determine variable differences using paired sample t-tests with Bonferroni corrections for controlling multiple comparisons (adjusted significance level of $\alpha = 0.02$).

Lastly, one-way ANOVA was performed to determine any significant differences between step counts and song pace. Post hoc analysis with paired t-tests was performed to determine any statistical differences between step count for each of the dance songs (adjusted significance level of $\alpha = 0.02$).

Correlation and regression analyses were conducted to ascertain any relationship between the variables of interest. Correlations were classified as weak ($R < 0.49$), moderate ($0.5 > R > 0.69$) or strong ($R > 0.70$) (Nangolo & Musingwini, 2011). All statistical analyses had significance levels set at $\alpha = 0.05$, and analyses were performed using Statistical Package for Social Sciences (SPSS) software version 24 (IBM Corporation, Endicott, NY, USA).

2.3. Results

Results of the study showed significant variations in total sway area ($F (2, 41) = 4.95$, $p < 0.01$) and in total CoM excursions ($F (2, 41) = 5.98$, $p < 0.01$). Post hoc comparison for total sway area, depicted significantly increased sway area for SP dance compared with both MP dance ($p < 0.02$) and FP dance ($p < 0.02$) (Figure 1 & Table 2). For total CoM excursion, there was reduction in MP dance compared with both SP and FP dance ($p < 0.01$ for both) (Table 2).

Also, results demonstrated a significant main effect of song pace on CoM excursion ($F (2, 39) =12.34$, $p < 0.01$) as well as a significant interaction between song pace and direction of CoM movement ($F (2, 39) = 55.25$, $p < 0.01$). There were also significant effects of song pace on CoM excursions in both the AP ($F (2, 41) =18.55$, $p < 0.01$) and ML ($F (2, 41) = 55.25$, $p < 0.01$)

directions. The CoM excursions in both directions for SP dance were significantly reduced in MP and FP in comparison with SP ($p < 0.01$). Also, CoM excursion in AP direction was significantly greater than in the ML direction for SP dance ($p < 0.001$) but in the FP dance, it was significantly greater in the ML direction than in the AP direction ($p < 0.01$) (Table 2).

For the number of CoM peaks, results showed significant main effect of song pace ($F (2, 39) = 5.29$, $p < 0.01$). There were also significant differences in the number of CoM peaks in the ML direction for different song paces ($F (2, 41) = 14.61$, $p < 0.01$). The number of CoM peaks in the ML direction was a significantly greater in the MP dance than for SP dance ($p < 0.01$), as well as for FP dance than for SP dance ($p < 0.01$). However, number of CoM peaks in the AP direction depicted no significant differences for the three song paces. Moreover, the number of CoM peaks in the ML direction was significantly greater than that in AP direction for each song pace ($p < 0.01$ for all) (Table 2).

Furthermore, results demonstrated significant main effect of song pace on joint excursions (F (2, 78 = 25.16, $p < 0.01$) and a significant interaction between song pace and extent of movement ($F (4, 78) = 5.23$, $p < 0.01$). In addition, results showed significant variances between song pace for hip ($F (2, 41) = 3.51$, $p < 0.04$), knee ($F (2, 41) = 7.05$, $p < 0.02$) and ankle ($F (2, 41) = 4.61$, $p < 0.02$) joint excursions. Post hoc comparison between SP and MP, showed increased excursions of the hip and knee joints for MP dance ($p < 0.02$ for both). Also, comparison between SP and FP, depicted a greater excursion for the ankle joint in FP dance. There was also greater excursions of the ankle joint in FP dance than for MP dance ($p < 0.02$). Additionally, the knee joint excursion for MP was greater than for FP dance ($p < 0.02$). Further, comparisons of joint excursions within each song showed significantly increased excursions of the knee than of the hip and ankle for all songs, $p < 0.01$ (Table 3).

Likewise, results showed a significant effect ($F (2, 78) = 25.97$, $p < 0.01$) and interaction ($F (2, 78) = 7.64$, $p < 0.01$) of song pace on the number (#) of joint angle peaks. One-way ANOVA showed significant differences in the number of peaks of all joints ($p < 0.05$ for all). Post hoc analysis showed that the number of hip joint peaks was significantly greater for MP dance than for SP dance ($p < 0.01$). For the knee joint, the number peaks was significantly greater for FP dance than for MP and SP dance ($p < 0.01$ for both). Additionally, comparison between SP and FP dance, depicted significantly greater ankle joint peaks for FP dance ($p < 0.01$). For both MP and FP dances, numbers of ankle joint peaks were significantly greater than hip joint peaks ($p < 0.03$ for both). In addition, the number of peaks was significantly greater for the knee than for the hip ($p < 0.01$) for FP dance (Table 3).

Furthermore, the results demonstrated a significant effect of song pace on the number of dance steps taken ($F (2, 41) = 31.69$, $p < 0.01$). Also, the number of dance steps strongly correlated with song pace ($F (2, 41) = 18.68$, $R = 0.72$, $p < 0.01$). There was an increase number of dance steps with dances from SP ($M = 33.26$, $SD = 7.19$) to MP ($M = 41.33$, $SD = 4.40$) and to FP ($M = 47.92$, $SD = 6.31$), this increasing trend was significant, $p < 0.03$, see Table 3.

In addition, correlation between the CoM excursions in the AP and ML directions weak, negative and nonsignificant ($F (1, 26) = 2.92$, $R = -0.30$, $p > 0.05$) (Table 4). Also, CoM excursions and the number of CoM peaks in the AP direction showed a significant, moderate negative relationship ($F (1, 26) = 19.23$, $R = -0.65$, $p < 0.05$) (Table 4). Simultaneously, the number of AP CoM peaks showed a significant, moderately positive correlation with the number of dance steps ($F (1, 26) = 14.64$, $R = 0.61$, $p < 0.05$). In addition, the number of ML CoM peaks depicted a nonsignificant weakly positive correlative trend with step count ($F (1, 26) = 2.34$, $R = 0.09$, $p > 0.05$), see Table 4.

Lastly, results demonstrated a significant, weak positive association between the number of dance steps and the number of hip angle peaks ($F (1, 26) = 4.41$, $R = 0.39$, $p < 0.05$), and a nonsignificant weak positive association with hip excursion ($F (1, 26) = 0.01$, $R = 0.03$, $p > 0.05$). Further, the number of dance steps significantly correlated positively and moderately with the number of knee angle peaks ($F (1, 26) = 23.18$, $R = 0.69$, $p < 0.05$). However, the number of dance steps did not show a significant association with knee excursion ($F (1, 26) = 0.46$, $R = 0.14$, $p > 0.05$). Lastly, there was moderately positive correlation between the number of dance steps and the number of ankle peaks ($F (1, 26) = 9.44$; $R = 0.52$, $p < 0.05$), and the association between the number of steps to ankle excursions depicted similar pattern ($F (1, 26) = 18.68$; $R = 0.66$, $p < 0.05$) (Tables 4 and 5).

Table 2: Measures of postural stability during dance-based exergaming

Postural stability variables	**SP**	**MP**	**FP**
Total Sway Area (cm^2)	1077.60 ± 209.90*	212.90 ± 346.00	314.10 ± 133.60*
Total CoM excursion (cm)	629.8 ± 380.50*	311.20 ± 119.50	478.5 ± 149.00*
AP CoM excursion (cm)	45.70 ± 18.20*+	10.60 ± 4.50	12.90 ± 4.10
ML CoM excursion (cm)	15.00 ± 6.50	12.60 ± 2.90	23.00 ± 5.60*
# AP CoM peaks	5.60 ± 1.30	7.30 ± 1.10	8.80 ± 1.50
# ML CoM peaks	19.00 ± 4.10+	23.9 ± 3.50*+	20.30 ± 3.50+

Values are (Mean ± SD) for variables, $p < 0.05$. The sign * denotes significantly greater values within the same variable among the three song paces, + denotes significantly greater values between different variables within a song pace only, and *+ denotes significantly greater values within the same variable among songs and between variables within a song.

Table 3: Measures of mobility for dance-based exergaming

Mobility and physical activity variables	SP	MP	FP
Joint excursion (degrees)			
Hip	40.60 ± 11.00*	50.40 ± 8.50^{a,c}	44.20 ± 10.10
Knee	55.50 ± 15.50$^{+,-}$	83.10 ± 14.90$^{a,c,+,-}$	60.20 ± 23.20$^{+,-}$
Ankle	32.20 ± 12.70	34.30 ± 21.30	46.70 ± 21.70$_{b, c}$
# Joint peaks			
Hip	15.70 ± 1.70	21.10 ± 3.80^{a}	18.30 ± 1.50
Knee	20.60 ± 3.50	25.60 ± 4.80^{a}	30.80 ± 6.30$^{b,c,-}$
Ankle	25.70 ± 7.50	33.20 ± 9.50^{a,*}	33.10 ± 6.70^{b*}
# Steps (R_{pace}=0.72, $p < 0.05$)	33.30 ± 5.10	41.30 ± 7.30$_{i}$	47.90 ± 4.80 $_{ii,iii}$

Values are (Mean ± SD) of variables, $p < 0.05$. SP: Slow-paced song; MP: Medium paced song; FP: Fast-paced song. Significantly greater values are shown by; 1) Between songs in each joint: ^{a}SP vs. MP, ^{b}SP vs. FP, ^{c}MP vs. FP, 2) Between the joints in each song: *Hip vs. Ankle, $^{+}$Knee vs. Ankle, $^{-}$Hip vs. Knee, 3) # Step (step count) between songs: ^{i}SP vs. MP, ^{ii}SP vs. FP, ^{iii}MP vs. FP. R_{pace}=correlation coefficient between song pace and step count for the dance.

Table 4: Correlations (R) between postural variables

Postural variables	AP CoM excursion	ML CoM excursion	# AP CoM peaks	# ML CoM peaks	# Steps
AP CoM excursion		-0.30	-0.65*		
ML CoM excursion	-0.30			0.10	
# AP CoM peaks	-0.65*				0.61*
# ML CoM peaks		-0.10			0.30
# Steps			0.61*	0.30	

AP: anteroposterior; ML: mediolateral; CoM: center of mass. Values are correlation coefficients (R) between variables, * denotes p<0.05.

Table 5: Correlations (R) between mobility variables and steps

Mobility measures	# Steps
Hip excursion	0.30
Knee excursion	0.14
Ankle excursion	0.66*
# Hip peaks	0.39*
# Knee peaks	0.69*
# Ankle peaks	0.52*

Values are correlation coefficients (R) between variables, *denotes $p < 0.05$.

2.4. Discussion

This study assessed the determinants of postural stability and physical mobility (postural sway, CoM excursion and joint angle changes) and was able to develop a quantitative assessment method of dance-based exergaming using three different song paces (SP, MP and FP) in healthy young adults. Also, the generation of normative values of postural stability and physical mobility during the performance of dance by healthy young adults was successfully achieved in this study.

In dance-based exergaming, there is repeated shifting of CoM of individuals' to different spatial locations, change in movement speed and synchronization of multi-limb segments with audiovisual stimuli, thereby controlling their balance simultaneously. With SP dance possessing the least beats per minute, participants' maintenance of the pace and rhythm, while reaching a greater sway area and AP CoM excursion easily than for the other two song paces. The increase in song pace with MP and FP resulted in reduced sway area and excursions due to difficulty for participants to rapidly control their postural stability to its maximum level as a result of the limited time for movement transitions during dance (Figure 1 & Table 2). However, with the FP dance showing rather greater ML CoM excursion (Table 2), could merely indicate that the FP dance required more dance steps in the ML direction. The increase in ML stability plays a key role in fall prevention (Latt et al., 2008). Likewise, MP song depicting equivalent AP and ML CoM excursions could imply that the MP dance song required the execution of equal movements in both AP and ML directions (Figure 1a). It could also be that the dance sequences for MP song involved more of stepping in-place with few displacements in the AP and ML directions, which may have resulted in reduced CoM sway area and excursions. Given that the acquisition of AP and ML stability is required for maintenance of balance control during functional tasks (Latt et al., 2008), a full dance-based exergaming assessment protocol incorporating MP song and the other songs could enhance the testing and training of dynamic balance control in the AP and ML directions.

The comparatively negative association between CoM excursions and CoM peaks in AP direction for all song paces, was not evident in the ML direction (Table 4). This could be because similar trends for ML CoM excursions and peaks were exhibited in dance for all three songs. Previous studies have shown an association between ML CoM motion and the maintenance of dynamic stability and the increase in stability in the ML direction is a functional indicator of balance control during motor tasks (Fidler et al., 2005; Orendurff et al., 2004). It is possible that the young adults in this study displayed a compensatory adjustments to establish dynamic stability during dance and this resulted in the positive association between number of CoM peaks and CoM excursions in the ML direction. This was consistent with study by Ojofeitimi et al. (Ojofeitimi et al., 2003) that demonstrated increased ML CoM displacement in a weight shifting task in dancers. It is also known that since ML postural control is important for rapid voluntary weight shifting to different spatial locations (Chou et al., 2003) and, therefore, could support the assertion that all dance song paces would be pertinent for evaluation of ML postural control.

Additionally, joint mobility in terms of the number of joint peaks and joint excursions provides information on the ability to adhere to and perform dance movement sequences with respect to the song pace. The joint excursion pattern was greater for knee flexion, hip flexion and ankle plantarflexion in that descending order for all three dance songs. These results were similar to , other studies that showed similar patterns of maximum joint excursions (Bronner & Ojofeitimi, 2006; Kerrigan et al., 1998). Inferring from these studies, it is possible that the songs used in this dance-based exergaming may have positive effects on the key determinants of gait. With joint excursion being indicative of the total size of the free joint angle needed to perform motor tasks, the results (greatest excursion of knee joint with MP) may indicate that MP may be appropriate for the rehabilitation of knee joint, which may been need to perform functional activities such as sit-to-stand tasks and stair climbing ascent and descent. In addition, with the number of joint peaks representing the frequency of the joints' ability to reach maximum joint angles, the results (increased number of joint peaks for the knee and ankle with MP and FP) may imply that MP and FP could be relevant for training spatiotemporal parameters of gait such as gait speed, which require speed for proper execution.

Moreover, the results demonstrated a positive correlation between the number of AP CoM peaks and the number of dance steps (Table 4). Augmentation of balance and propulsion for improved gait may be occasioned by increases in stepping in the AP direction. The results also signified that increase in physical activity may play a critical role in increase in AP CoM peaks. Also, increases in step count during dance-based exergaming play an important role in improving cardiovascular endurance, thereby reducing inactivity and comorbidities in the general population (Latt et al., 2008; Tudor-Locke & Bassett, 2004). The increase in fitness is achieved by regular physical activity (Billinger et al., 2014; Gordon et al., 2004), and dance-based exergaming could afford an important opportunity to achieve this daily step counts.

The results of this study demonstrated that this dance-based assessment method with different song paces lead to increased dance steps, which correlated positively with ankle excursion and the number of knee and ankle joint angle peaks (Table 5). This could suggest that the testing of change in mostly knee and ankle joints, and less likely in the hip, could be performed with this assessment protocol (Table 5). These results of this study was consistent with data from previous studies that depicted increases in knee and ankle range of motion, which correlated with gait velocities in young and older adults (Bronner & Ojofeitimi, 2006; Orendurff et al., 2004). This suggests that dance-based exergaming assessment protocol could play a key role in testing gait speed. Dance therapy is shown to be effective for individuals with neurological conditions, therefore the kinematic evaluation of dance steps could provide a platform for objective quantification of pre-post training effect. Successful gait involves considerable single support period and control of ML balance during the change of support from one limb to the other (Neptune et al., 2001). Secondly, the ability to regain equilibrium during an unexpected perturbation of the body's position (e.g., a trip or slip), is important for fall prevention. It is suggested that the dance protocol with slow, medium and fast paced song could train gait speed and other spatiotemporal parameters of gait, which is a key determinant of fall risk. This dance assessment protocol with our chosen song paces would likely offer a sensitive and objective method of evaluating postural stability and risk of falling before and after dance training sessions.

In conclusion, this study established a protocol for dance-based protocol for the assessment of postural stability and mobility and also generated normative data for CoM excursions and joint excursions for different intensities of dance songs used for dance-based exergaming assessment. In recent times, there is greater momentum in the application of dance-based exergaming interventions with different genres and paces for rehabilitation among older adults and in individuals with neurological conditions. Furthering the knowledge in the biomechanics of dance would add vital information to literature by ensuring proper prescription of dance song for optimal training effect. These findings will provide the confidence to assess and prescribe dance-based exergaming for rehabilitation of individuals with postural instability and immobility.

Table 6: Summary of results for study 1 (young)

Outcome variables	**Results**
Total sway area	• Dance with SP had greatest sway area, followed by FP and MP in that order
Total CoM excursion	• Dance with SP had greatest Total CoM excursion, followed by FP and MP in that order
AP CoM excursion and Peaks	• Dance with SP had greatest AP CoM excursion, followed by FP and MP in that order. The number of peaks depicted an increasing trend from SP to FP.
ML CoM excursion and Peaks	• Increasing trend of ML CoM excursion from SP to FP. The number of peaks increased in MP and reduced slightly in FP.
Hip angle excursion and # Peaks	• Excursion was greatest in MP, followed by FP and SP. #peak depicted increasing trend from SP to FP
Knee angle excursion and # Peaks	• Excursion was greatest in MP, followed by FP and SP. #peak depicted increasing trend from SP to FP
Ankle angle excursion and # Peaks	• Excursion showed increasing trend form SP to FP and similar trend with # peaks.
Number of dance steps	• Increasing pattern with increase in song pace (positive correlation R = 0.72)

Chapter 3

Kinematic analysis of dance-based exergaming: a cross-sectional study

3.1. Introduction

Postural stability is the ability to control the body's center of mass (CoM) within a given base of support (Cathie, 1950; Ragnarsdóttir, 1996). It involves complex interactions between the sensorimotor components of the nervous and musculoskeletal systems for maintaining upright posture during static (Ivanenko & Gurfinkel, 2018; Reed-Jones et al., 2013) and dynamic (Ambrose et al., 2013; Winter, 1991; Woollacott & Shumway-Cook, 2002) tasks. Aging has been associated with deteriorated postural stability and mobility, leading to increased fall risk, especially during functional activities in older adults (Gill et al., 2001; Teasdale & Simoneau, 2001). In particular, it has been reported that postural stability under dynamic tasks are more challenging as a large number of falls occur during reduced stability (e.g., single limb support phase of the gait cycle) in aging (Tropp, 1988). Many researchers examining the factors affecting mobility in older adults reported that kinematics of lower extremity (LE) movement is closely associated with walking speed, a determinant used for predicting falls (Viccaro et al., 2011). Conventional rehabilitation methods provided through postural stability and gait training in outpatient therapy centers have shown to be efficacious for older adults (Chang et al., 2004; Kaesler et al., 2007). Despite the efficacy of conventional rehabilitation therapies, falls are still occurring at a rate of 20-40% among the high functioning community-dwelling older adults (Simpson et al., 2011). Moreover, both of these populations exhibit reduced compliance to conventional interventions in comparison to alternative therapies, such as dance and exergaming (da Silva Ribeiro et al., 2015; Strassel et al., 2011).

Dance therapy is an emerging alternative intervention that has shown increased compliance and effectiveness for improving physical function in healthy older adults (da Silva Ribeiro et al., 2015; Filar-Mierzwa et al., 2017; Rahal et al., 2015; Wu et al., 2016). Dance movements may be especially advantageous for aging as they facilitate training strategies, such as continuous CoM displacements within the individual’s stability limits. Studies have shown that healthy older adults were able to improve symmetrical weight distribution with training strategies implementing CoM displacement and suggested that such training is important for postural stability and mobility rehabilitation, along with a reduction in fall risk (Van Ooteghem et al., 2008; Van Ooteghem et al., 2009). A cross-sectional study on healthy older adults who received dance training showed improved flexibility, postural stability and reaction time in a finger-selection visuotactile upper extremity task and cognitive performance in comparison to their control counterparts (Kattenstroth et al., 2011). Another cross-sectional study also revealed greater LE joint Exs in dancers than in non-dancers while performing dance movements (Alricsson et al., 2003). A few systematic reviews about the effect of exergaming-based training support the use of exergaming in LE rehabilitation to improve postural stability and mobility (Laver et al., 2015; Laver et al., 2017). Recent studies on the benefits of both dance and exergaming have documented the implementation of dance-based exergaming (DBExG) training among healthy older adults (Sampaio et al., 2016; Smith et al., 2011; Subramaniam, 2015; S. Subramaniam & T. Bhatt, 2019). These studies have demonstrated the feasibility of the training protocol and showed improvement in postural control and gait (Smith et al., 2011; Subramaniam, 2015).

Consequently, kinematic analysis of movement control during DBExG is essential to quantify postural stability, mobility and understanding of the distinct movement adaptations gained with such gaming in the aging population. Previous studies using DBExG training have only used subjective clinical balance and functional measures (Berg Balance Scale, Timed-Up and Go, Six-Minute Walk Test, Activities-Specific Balance Scale) instead of using objective measures as the primary assessment tool to assess training effects (Cho et al., 2012; Karahan et al., 2015). While these measures are commonly used in clinical settings for examining the functional status of individuals, they are not capable of providing a qualitative assessment of postural stability. Further, studies have reported that these standard clinical outcome measures have significant floor and ceiling effects (Martina Mancini & Fay B Horak, 2010) and are not sensitive enough to assess dance movement pattern adaptations for DBExG training. As a supplement, an assessment of dance movement patterns using biomechanical measures of CoM displacements and LE joint angles during DBExG could provide a viable option for quantitative evaluation of postural stability and mobility during dancing**.**

Biomechanical researchers have recorded movement kinematics during dance, thereby advancing knowledge in the mechanism and effects of dance on movement control in dancers and young adults (Hansberger et al., 2018). While quantitative studies are yet to evaluate movement kinematics during dance and DBExG training, kinematic gait assessment has shown gait deficits to be present in healthy older adults. Typical gait deficits included reduced knee flexion at stance phase, ankle dorsiflexion at initial contact during the swing phase and/or ankle plantarflexion at push-off during terminal stance phase (Mann & Hagy, 1980). Further, aging alone has been shown to result in reduced knee flexion and ankle plantarflexion at toe-off as well as decreased hip and knee angle excursions with increased ankle excursions during the stance phase of gait cycle (Cofre et al., 2011). Considering that both gait and dance require dynamic balance control, it could be postulated that healthy older adults would exhibit poorer movement kinematics than the young adults with DBExG. Specifically, studies have reported numerous dance forms, including Korean, Ballroom, Argentine, Tango, Turkish Folkloristic, Greek, Caribbean and Aerobic, and categorized the forms to slow, medium, or fast-paced dance based on the movement patterns (Earhart, 2009; Filar-Mierzwa et al., 2017; Hackney & Earhart, 2009; Hackney et al., 2007; Sofianidis et al., 2009). These different paces of dance alter the biomechanical or kinematic demands of movement control and could result in distinct movement adaptations based on the song pace. Hence, given that there is still limited knowledge on how the quality of movement and postural stability changes with varying paces of dance, this study's biomechanical analysis could be particularly useful in identifying dance movement patterns in aging populations to help develop population-specific or customized assessment and intervention regimens.

Thus, the purpose of the present study was to evaluate and compare the postural stability and movement kinematics of dance movements to different song paces using DBExG between young and healthy older adults. It was hypothesized that postural stability (assessed by CoM sway area and CoM excursion) and mobility (assessed by LE joint angle excursions) for all song paces during DBExG would be greatest in young adults than in older adults. It was also hypothesized that postural stability would decrease as song pace increased.

3.2. Methods

3.2.1. Participants

The Institutional Review Board of the University of Illinois at Chicago (UIC) approved the study. Recruitment of all participants was completed by posting fliers across various notice boards on the UIC campus and by giving presentations at senior homes, rehabilitation and research centers in the Chicagoland area. The study included 11 participants for each population (healthy young and older adults) who provided consent to participate in the study. We ensured that all participants were nonprofessional dancers or had not been involved in any dance choreographic program within the past year. Healthy older adults were included in the study if they were able to walk and stand for at least five minutes and if they had no cognitive impairment (Montreal Cognitive Assessment [MOCA] score >26/30). Participants with low bone density (t-score < -2), any recent surgeries (< 6 months ago), any other neurological disorders (such as Parkinson's disease) and/or any cardiovascular conditions (as evaluated by heart rate at rest [>85% of maximal heart rate] and oxygen saturation at rest [<95%]) were excluded from the study.

3.2.2. Protocol

Participants were exposed to dance movements with segments from Microsoft Kinect 'Dance 3' [Microsoft Inc., Redmond, WA, U.S.A.] during one dance session. Participants danced to 30-second segments of videos for songs of three different paces (slow-paced [SP - "Dynamite"], medium-paced [MP - "Party Rock Anthem"] and fast-paced [FP - "Price Tag"]). These songs were specifically chosen because of the similarity in movement patterns or sequences of movements in the anteroposterior (AP) and mediolateral (ML) directions to control for any variability among the songs. Dance steps for all three songs involved rhythmic movements in the forward, backward and lateral directions, including single and double touches, sidekicks, step in-place, hip-hop bouncing and marching (in-place, forward and backward). All dance steps necessitated flexion and extension of the hip, knee and ankle joints, as well as some movements of the joints of the upper extremity. The only difference in these dance steps were the paces at which the songs were performed, which were classified as slow (120bpm), medium (130bpm), or fast (138bpm) paced with beats per minute (bpm) verified via BPM database (BPM, 2003-2017). Following two familiarization trials for all dance patterns, participants were required to perform three trials of each song pace, making a total nine trials for SP, MP and FP songs. The one-time dance-based assessment session lasted for approximately 60 minutes.

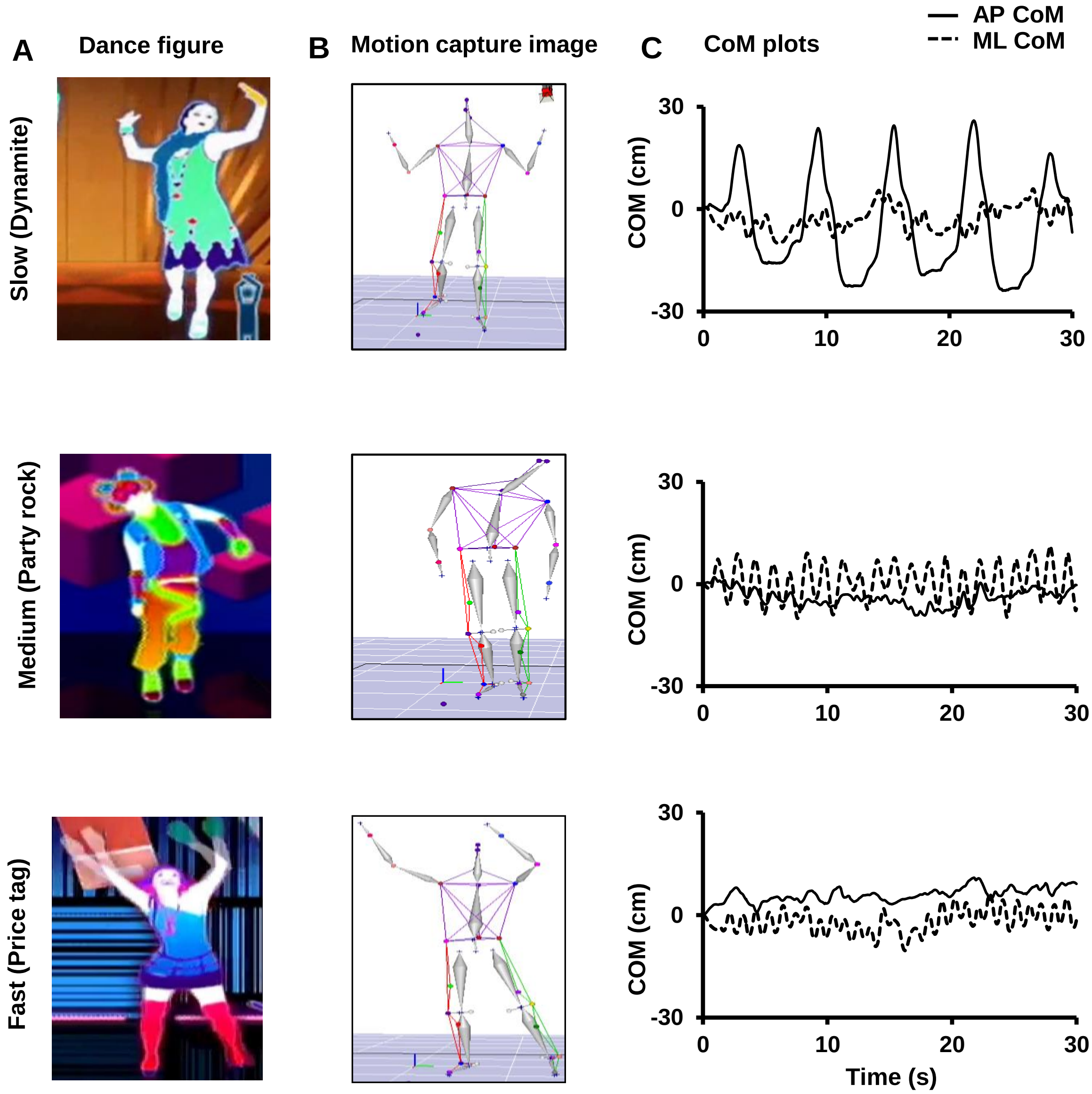

Figure 3: Representative frontal view of A) stick figures, B) motion capture images, and C) center of mass (CoM) plots in the anteroposterior (AP) and mediolateral (ML) directions for dance-based exergaming. The titles of the hip-hop songs used are shown as slow ('Dynamite'), medium ('Party Rock') and fast-paced ('Price Tag') dance in this study.

3.2.3. Data collection and instrumentation

All participants wore a safety harness system for the duration of the session. Participants had 29 reflective markers (Helen Hayes marker set) attached to specific joints and body segments. The movement of these markers was captured and recorded for 30 seconds during dancing for each song using an 8-camera motion capture system at 120 frames per second with Cortex-64 3.6.1 software [Motion Analysis, Santa Rosa, CA]. A customized MATLAB code was then used to perform initial processing of the raw data to compute the kinematic outcome variables of interest and then the average value from the three trials for each song pace collected was used for further analysis.

3.2.4. Outcome measures

The outcome measures of interest were divided into two domains, postural stability and mobility, and are described in details below:

Postural stability measures included total postural sway area, total CoM Ex, CoM Ex in the AP and ML directions, and the number of CoM peaks. Previous methods implemented in study 1 were used to obtain those outcome variables. These primary outcome measures were computed using formulas below , which were proposed and implemented in studies by Prieto and colleagues (Prieto et al., 1996).

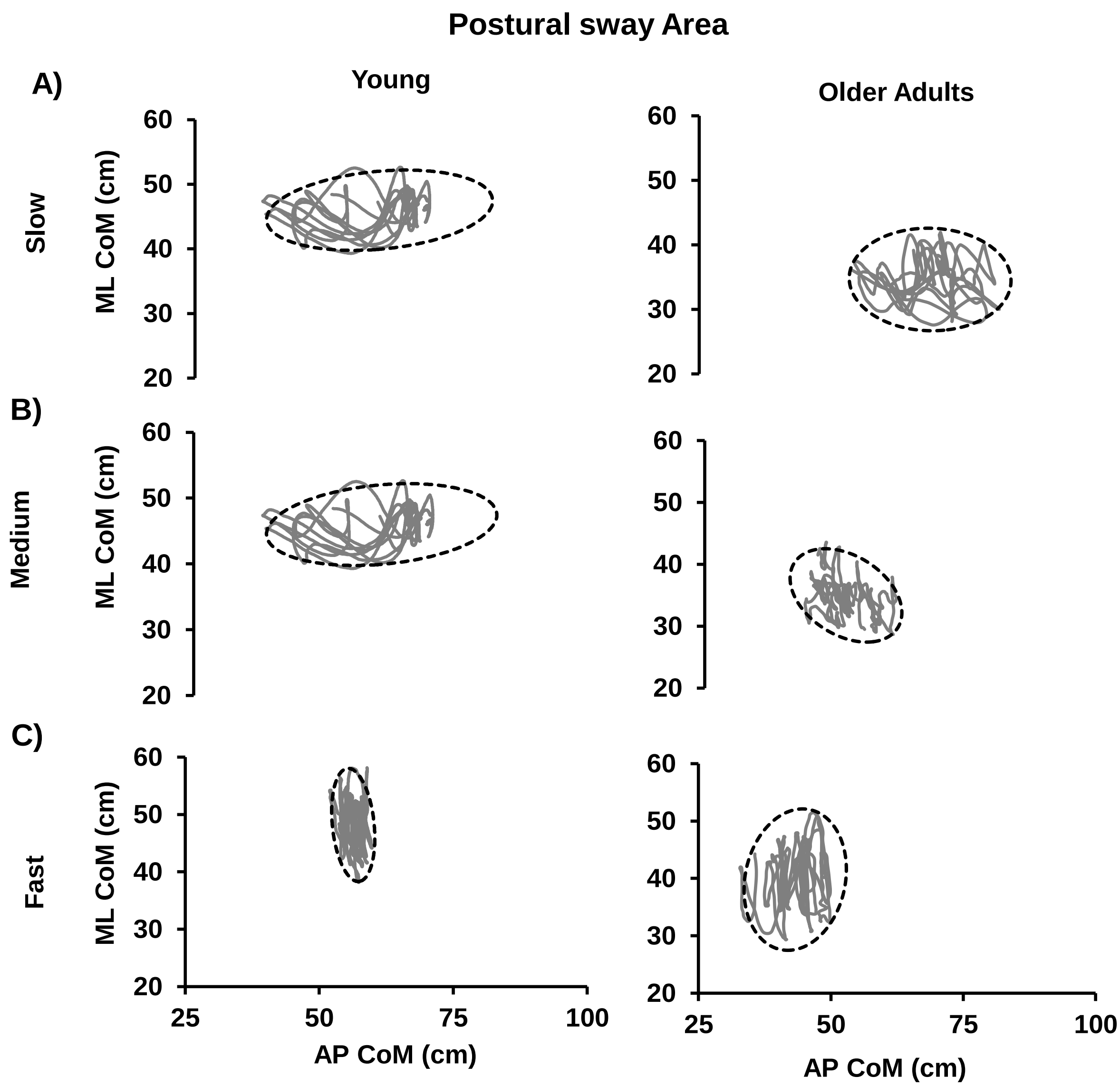

Figure 4: Plots of representative postural sway area for healthy young and older adults for dance-based exergaming with A) slow, B) medium, and C) fast-paced songs.

Mobility (range of motion) measures were obtained by determining the number of peaks and Exs of the hip, knee and ankle joints. The joint angles (in the sagittal plane) were generated through three-dimensional trajectories of segmental markers (Helen Hayes Marker set) by defining a reference frame in the proximal and distal segments using a custom-made MATLAB code

(Vaughan et al., 1999). The method of determination of these outcome measures used in study 1 was also implemented in this study.

3.2. 5. Statistical analysis

Demographic data in the form of mean age, height and weight of all participants was obtained.

For the number of CoM peaks and Exs, a 3x2 (song pace x group) repeated measures ANOVA was used to determine any differences in mean number of peaks and Exs of the CoM, along with total sway area. Interactions between song pace and group were determined for CoM peaks and Exs. Post hoc analyses were performed for each song pace to determine the differences in postural variables within and between groups using paired and unpaired t-tests with Bonferroni corrections for controlling multiple comparisons and an adjusted significance level of $\alpha = 0.02$.

To compare the differences between song paces (SP, MP and FP) and groups (young and old adults) 3x2 repeated measures ANOVA was performed on the number of joint peaks and joint Exs for each song. For each group, interactions between song pace and group were determined for each joint Ex (hip, knee and ankle). Post hoc analysis was performed for each song pace in order to determine any differences in the number of joint peaks and joint Exs with paired and unpaired t-tests, with Bonferroni corrections for controlling multiple comparisons and an adjusted significance level of $\alpha = 0.02$. Apart from post hoc tests, all other statistical tests had significance levels set at $\alpha = 0.05$. The analysis was performed with the Statistical Package for Social Sciences (SPSS) version 24 (IBM Corporation, Endicott, NY).

3.3. Results

3.3.1. *Demographic data*

The demographic data for all participants in the study is shown in Table 7. There were 11 participants from each group and they included six male (54.55%) and five female (45.45%) healthy older participants and five male (45.45%) and six female (54.55%) young adult.

Table 7: Demographic data of young and older participants

Group (n=11 each)	Age (Mean±SD) years	Sex (M/F)	Weight (Mean±SD) kg	Height (Mean±SD) cm	Foot length (Mean±SD) cm
Young adults	23.50±2.81	5/6	62.82±8.195	163.19±7.97	18.73±3.68
Healthy older adults	62.20±4.16	5/6	78.29±14.59	167±5.67	21.97±2.47

3.3.2. Postural sway area and CoM excursion

A 3x2 repeated measures ANOVA showed significant main effect of song pace on total sway area [F (1, 30) = 6.95, $p < 0.05$] and total CoM Ex [F (1, 30) = 5.89, $p < 0.05$] as well as a statistically significant group effect [F (1, 20) = 4.36, $p < 0.05$; F (1, 20) = 4.92, $p < 0.05$]. In addition, interaction effect between song pace and group was shown for total sway area [F (2, 30) = 10.02, $p < 0.05$] and no interaction between group and song pace for total Ex [F (2, 30) = 0.82, $p > 0.05$].

Post hoc analysis for the comparison of groups demonstrated significantly greater sway area in young adults than in healthy older adults for the SP dancing ($p < 0.02$). For MP dancing, sway area was significantly greater in healthy older adults than in young adults ($p < 0.02$). However, for FP dancing, there were no significant differences in postural sway among the two groups ($p > 0.02$) (Figures 4 & 5).

Within each group, there were reductions in total sway area and total CoM Exs from the SP to FP for young adults ($p < 0.05$) and healthy older adults ($p < 0.05$). Post hoc analysis for young and older adults revealed reduced total sway for MP dancing in comparison to SP ($p < 0.02$), significant increases for FP dancing in comparison to MP ($p < 0.02$), and significant increase for SP than FP dancing ($p < 0.02$). In addition, total CoM Ex decreased significantly from SP to MP, and increased from MP to FP ($p < 0.02$); however, the decrease from SP to FP was not significant ($p > 0.02$).

3.3.3. AP and ML CoM excursions

A 3x2 repeated measures ANOVA showed no significant main effects of AP [$F(1, 30) = 0.33$, $p = 0.98$] and ML [$F(1, 30) = 0.42$, $p = 0.53$] CoM Exs, and a nonsignificant group effect [AP: $F(1, 20) = 0.69$, $p = 0.42$; ML: $F(1, 20) = 0.27$, $p = 0.61$]. Additionally, there was no interaction between song pace and group for CoM Exs ($p > 0.05$). Post hoc comparison only showed significantly greater Exs for healthy older adults in comparison to young participants for dance with MP and FP song ($p < 0.02$). Within each group, AP CoM Ex depicted a decreasing trend from SP to FP, while ML CoM Exs increased from SP to FP. There was significant effect of song pace on AP, [$F(2, 32) = 31.61$, $p < 0.05$] and ML, [$F(2, 32) = 14.64$, $p < 0.05$] CoM Exs in the young participants. In the older adults, there was also significant effect of song pace on AP, [$F(2, 32) = 31.61$, $p < 0.05$] and ML, [$F(2, 32) = 6.83$, $p < 0.05$]. Post hoc showed significant decrease in AP CoM Exs from SP to MP and from SP to FP only for both groups ($p < 0.02$) (Figure 5).

3.3.4. Number of CoM peaks

A 3x2 repeated measures ANOVA showed no significant main effects of both AP [$F(1, 30) = 0.35$, $p = 0.56$], but a significant main effect of ML [$F(1, 30) = 366.12$, $p < 0.05$] CoM peaks. Additionally, AP CoM peaks showed no significant interaction of song pace with group [$F(2, 30) = 0.50$, $p = 0.61$] but with no group effect ($p > 0.05$). Also, there was no interaction between the direction of CoM and group ($p > 0.05$). A comparison of the number of peaks with song pace showed an increased number of AP CoM peaks in young adults than in healthy older adults for the FP song ($p < 0.02$). However, there were no between-group differences in the number of CoM peaks for other songs ($p > 0.02$). Within each group, the number of CoM peaks was greater in the ML direction than in the AP direction across all songs, as well as a slightly increasing trend of the number of CoM peaks from SP to FP (Figure 5).

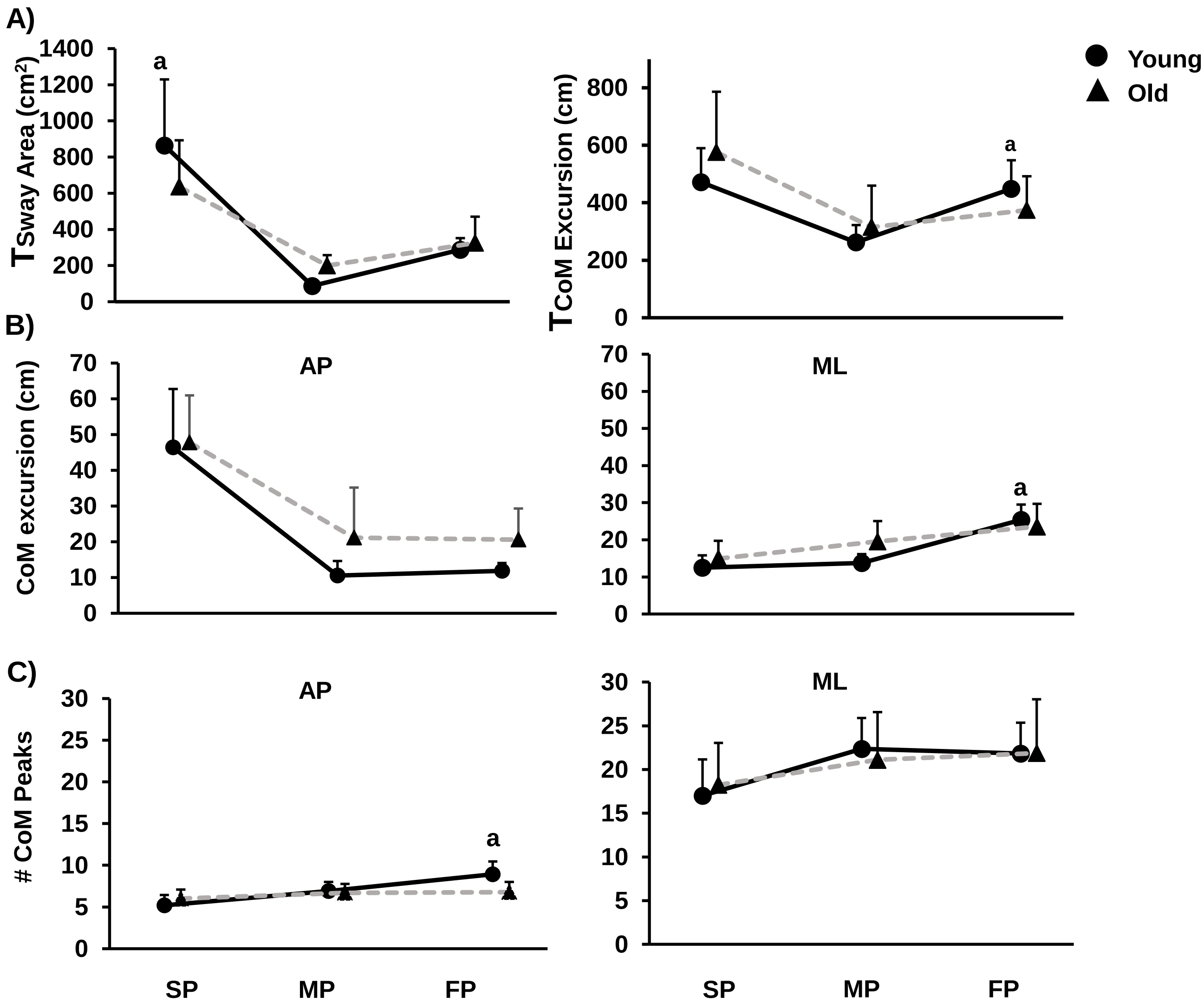

Figure 5: Plots of A) total postural sway area (TSway area) and total CoM excursions (TCoM excursion) with their constitutive B) AP (anteroposterior) and ML (mediolateral) CoM excursions and C) number of CoM peaks in the AP and ML directions for healthy young and older adults during dance-based exergaming with SP, MP and FP songs. Significant differences ($p < 0.02$) between groups were denoted by alphabetical letter with "a" to show significant difference between healthy young and older adults.

3.3.5. Number of joint peaks

There was a significant main effect of the number of peaks produced by all three joints during the performance of dance with difference song paces ($p < 0.05$). Of all the joints, only the number of peaks of the ankle joints showed significant main effect of song pace [$F(1, 30) = 3.07$, $p < 0.05$]. However, the frequency of peaks for the all joints did not depict significant group interactions ($p > 0.05$). Moreover, all joints exhibited nonsignificant group effects ($p > 0.05$). There were also significant differences between groups among the songs ($p < 0.05$). Post hoc comparisons between groups showed the number of peaks for the ankle was significantly greater for young adults than in healthy for dance with FP song only ($p < 0.02$). Within-group comparisons revealed that the young adults produced an increased number of peaks for all joints as the pace of song increased, especially from SP to MP ($p < 0.02$). This pattern of results was generally consistent in all joints of the healthy older adults increasingly evident in the knee joint (Figure 6).

3.3.6. Joint excursions

The results of the study depicted no significant main effects of Exs of the hip [$F(1, 30) = 0.54$, $p = 0.47$] and knee [$F(1, 30) = 0.01$, $p = 0.93$] joints along with a nonsignificant main effect of ankle Ex [$F(1, 30) = 0.31$, $p = 0.58$]. There were also no significant group effects of the Exs for all joints ($p > 0.05$). However, within each group the extent of hip and ankle Exs showed significant interactions with song pace ($p < 0.05$), but there were significant interactions of the extent of knee Exs with song pace ($p < 0.05$). A comparison of dance performance between the two groups of participants showed that the young participants had significantly lower knee and ankle Exs than the old for MP ($p < 0.02$), and greater in FP songs ($p < 0.02$). Dance with SP did not show any significant differences between the two groups, $p > 0.05$. Within each group, young participants exhibited significantly increased knee Ex in MP than FP, increased ankle Ex in MP than SP and increased ankle Ex in FP than MP ($p < 0.05$). However, with older adults, there were significantly increased hip Ex in MP than SP and in MP than in FP ($p < 0.02$) only (Figure 6).

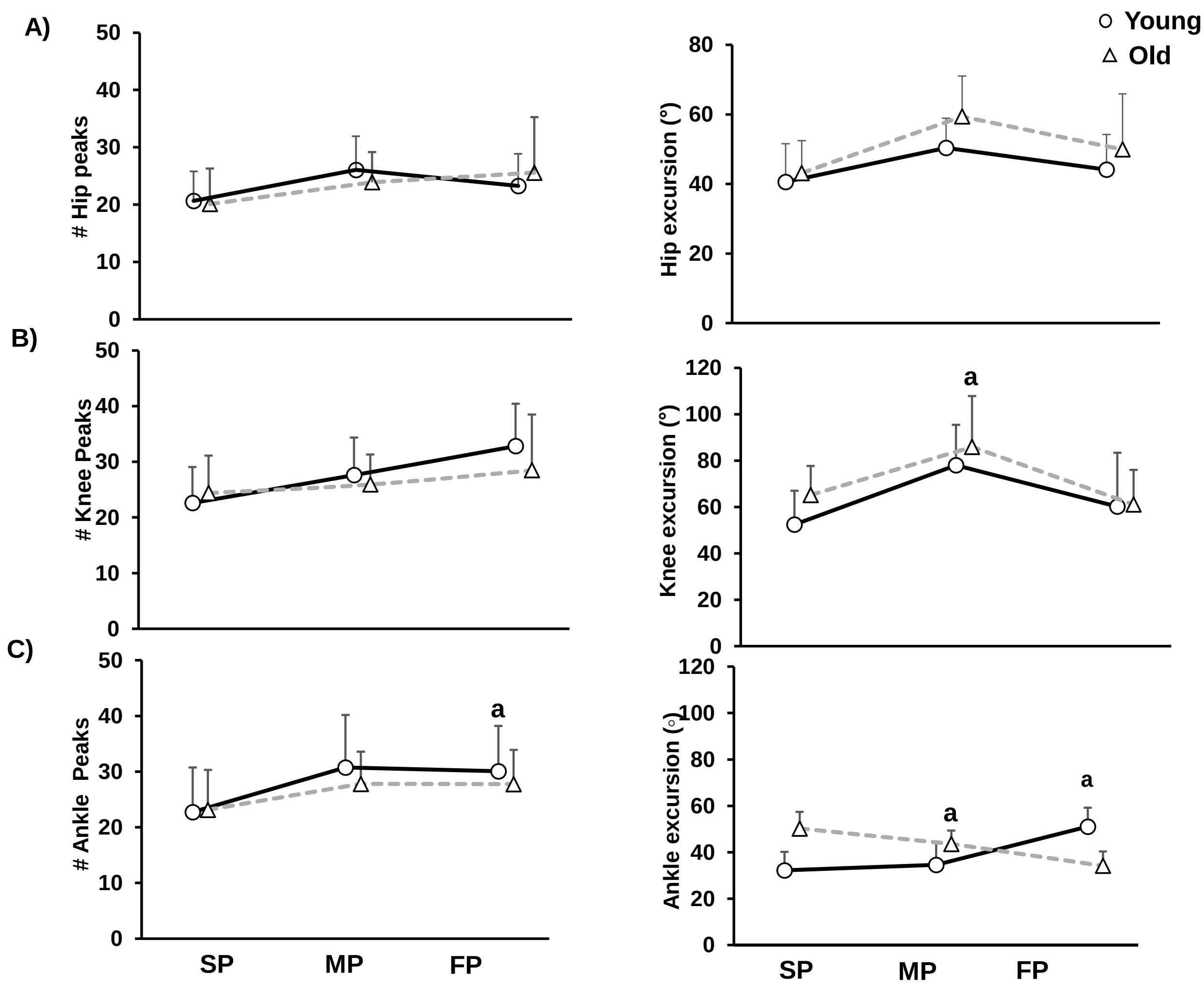

Figure 6: Plots showing the joint angle peaks and excursions of the A) hip, B) knee and C) ankle for young adult and healthy older adult depicted during dance with slow, medium and fast-paced songs. Significant differences ($p < 0.02$) between groups were denoted by alphabetical letters with “a” used between healthy young and older adults.

3.4. Discussion

This study evaluated postural stability and mobility changes across different paces of dance movements provided via dance-based exergaming (DBExG) to differentiate the movement kinematics of such dance between healthy young and older adults. The results supported the hypothesis that the healthy young participants exhibited higher postural stability (postural sway area, center of mass (CoM) excursions (Exs) and number of CoM peaks) and mobility (number of hip, knee and ankle joint angle peaks and excursions) at all song paces than healthy older adults. Healthy older adults exhibited similar levels of postural stability for the slow and medium-paced (MP) dance song; however, there were significant differences between the groups for fast-paced (FP) dance songs as young adults showed increase in CoM excursion than in older adults.

3.4.1. Effect of aging

3.4.1.1. Postural stability (postural sway area and CoM excursion)

The findings in this study showed higher postural stability in young adults in comparison to healthy older adults. The increased postural sway area in SP dance movements demonstrated by young adults could depict the ability to exhibit a greater control of CoM movement within the base support than the healthy older adults. Such increased postural sway area in SP dance in young adults could be because the song had the least beats per minute (song pace), allowing time to execute the target dance movement all the way to completion. Lesser postural sway area in older adults could simply suggest that they had reached their maximum ability to displace their CoM or they had less confidence in shifting their CoM towards the edge of BOS during dance. In line with the above postulation, studies evaluating the effect of age on only ML CoM during gait have shown older adults exhibiting reduced ML CoM in comparison to young adults (Hernandez et al., 2009). For the MP and FP dance movements, there was no difference in postural sway area between young adults and healthy older adults, however, young adults showed a higher total CoM Ex (AP and ML directions) during the FP song in comparison to healthy older adults, indicating that they were able to accomplish increased Exs to complete the dance steps. It should be noted that the total CoM Ex is not always consisitent with sway area. As shown in Figure 3C, the CoM position is fluctuating cyclically during dancing, indicating that the total CoM Ex is determined by the CoM Ex in AP and ML directions and their frequencies (number of CoM peaks in each direction), together. In contrast, the sway area is only deterimined by the CoM Ex in AP and ML directions. In other words, the sway area during dance represents the magnitude of CoM movements, while the total CoM Ex represents a combination of the magnitude and freqency of CoM movements.

Further, FP dance song resulted in comparatively significantly higher ML CoM Exs and AP CoM peaks in young adults compared to healthy older adults. The increased number of beats per minute with FP provided some difficulty for healthy older adults to rapidly shift their CoM to its maximum level due to the limited time for movement transitions, resulting in reduced Exs. In particular, lower ML CoM Exs in healthy older adults compared to young adults indicate a possible increase in ML postural instability. Lower ML CoM Exs has been identified in the performance of weight-bearing functional tasks as a risk factor for falls in the aging population (Brauer, 1998; Maki et al., 1994). Thus, it could be postulated that all FP song intensity would be useful for assessment of ML postural control in healthy older adults. Higher postural stability in young adults could be indicative of their normal postural control mechanism. Mainly, it could be that they were able to integrate their sensorimotor information and generate adaptive postural actions (change their movement speed as well as modulate the pace and rhythm while attaining a greater CoM Ex and peaks) for accomplishing increased Exs to complete the dance steps.

When investigating the motor control mechanisms underlying postural stability during dynamic tasks, the CoM has been considered as one of the most important variables to be controlled by the central nervous system (CNS) (Black et al., 2007; Verrel et al., 2010). Studies have reported that the CNS-mediated movement control deficits, such as the decreased speed of information processing, and motor execution has been shown with aging (Lacour et al., 2008; Li & Lindenberger, 2002). A reduced capacity to extend the CoM displacement towards the borders of the base of support has shown to increase the possibility of a fall, particularly during the performance of daily activities that challenge the limits of stability (LOS) (Devetak et al., 2019; M. Mancini & F. B. Horak, 2010). Thus, the lower postural stability, exhibited with smaller postural sway area and reduced CoM Exs in older adults during dance, could be indicative of increased fear of falls and fall risk.

3.4.1.2. Mobility (number of hip, knee and ankle joint angle peaks and excursions)

The maintenance of effective mobility during dancing requires joint movements through an optimal range of motion (Deighan, 2005). Our results depicted an increased number of joint angle Ex in young adults in comparison to the healthy older adults. Studies analyzing ankle joint kinematics during gait have also reported that healthy older adults demonstrated reduced joint angle Exs (van Hoeve et al., 2017). In particular, aging has been associated with deteriorations in the lower extremity kinematics when compared to young adults during gait (Boyer et al., 2017; Silder et al., 2008). These findings are in line with previous research done on gait and provide further support for the idea that limitations at the ankle joint may be a primary cause of age-related kinematic changes during DBExG in otherwise healthy older adults (Jonkers et al., 2009). Studies have indicated that neurophysiological changes with aging can render imprecise information from the somatosensory (proprioceptive, cutaneous and joint receptors), visual and vestibular systems, which results in reduced joint mobility (Dorfman Lj Fau - Bosley & Bosley, 1979; Potvin Ar Fau - Syndulko et al., 1980; Woollacott & Shumway-Cook, 2002). However, further investigations are necessary to determine the relationships between inaccurate information from the sensory systems and reduced joint mobility during dance.

3.4.3. Effect of pace of dance on aging

Another interesting facet of the current study is the evaluation of three different dance paces (SP, MP and FP) on aging. The findings demonstrate that the two groups exhibited higher postural sway area in the SP dance in comparison to the dance movement performance in MP and FP dance. Such a larger postural sway area in SP dance could be because the song had the least beats per minute (song pace), allowing time for slow and easy execution of dance movement. Additionally, although not statistically significant, the SP dance showed comparatively higher AP CoM Ex for all the three groups, but this could merely indicate that SP dance to the song "Dynamite" required the participants to accomplish increased Ex in the AP direction in order to complete the dance steps.

On the other hand, MP song showed larger Exs in the knee joint compared to the other song paces for both groups. Larger knee Ex pattern was evident in other studies of joint mobility both in gait and with dancers (Bronner & Ojofeitimi, 2006; Kerrigan et al., 1998), and so it could be possible that the MP song movements fall within the normal rhythm of human gait. This is important because increased knee Ex along with improved knee flexion and extension may play an essential role in proper stepping for effective postural stability. Normal gait requires increased ML postural stability (Chou et al., 2003; Hilliard et al., 2008; Neptune et al., 2001) with multiple instances of single leg support during the transition from one extremity to the other, and dance may possess all of these features similar to walking but with a different temporal and modulatory (rhythmic) pattern.

The results of the current study should be interpreted in light of its limitation with respect to its relatively small size. Further, this study used only one genre (hip-hop) of music for this dance-based assessment in healthy older adults and young adults, therefore, may not be generalized to other genres of music and all populations. Future studies should be conducted with larger sample size with other populations and genres of music to determine any potential impact of genre.

This study evaluated and compared the demands on movement control during DBExG with varying paces of songs from slow to fast between healthy young and older adults. Deteriorations in movement kinematic were greater for healthy older adults than for young adults. Such impairments should be taken into consideration when designing DBExG protocols. Additionally, given that the postural sway area, CoM Exs and number of CoM peaks are measures of postural control and lower extremity joint angle peaks and Exs are measures of mobility, the generation of movement kinematics with DBExG will serve as reference data for assessment and comparison of individuals' performance in dance therapy with different song paces for both healthy young and older adults.

Table 8: Summary of results for study 2 (young vs old)

Outcome variables	Results
Total sway area	• Significantly greater sway area in young than old for SP.
Total CoM excursion	• Significantly greater sway area in young than old for FP.
AP CoM excursion and Peaks	• No significant difference in AP CoM excursion from SP to FP. # peaks showed increasing trend, with Young > Old for FP.
ML CoM excursion and Peaks	• Young > Old for FP. No significant differences in #peaks.
Hip angle excursion and # Peaks	• Greatest excursion and # peaks seen in MP. There were no significant differences between the groups for each song pace.
Knee angle excursion and # Peaks	• Greatest excursion seen in MP, with significant greater excursion in old than in young participants. Increasing trend of # peaks from SP to FP.
Ankle angle excursion and # Peaks	• Increasing trend of excursion in young and decreasing trend in old participants from SP to FP. Significantly greater excursion in old for MP and significantly greater excursion in young for MP. #Peaks showed increasing trend from SP to FP in both groups. There were no significant differences between the two groups

Chapter 4

Effectiveness of a dance-based exergaming intervention for older adults with mild cognitive deficits

4.1. Introduction

Aging results in neuromuscular deterioration, such as impaired balance control, gait instability and worsening cognition (Fitzgerald et al., 1997; Reuter-Lorenz & Lustig, 2005; Y Tseng et al., 2014), with increasing evidence pointing to the over-reliance on cognitive function to perform even simple motor tasks (Heuninckx et al., 2005; Huxhold et al., 2006; Shumway-Cook et al., 1997). Such deterioration has been shown to affect daily functional activities, quality of life and cardiovascular fitness, along with an increase in the risk of falling (Filar-Mierzwa et al., 2017; Wingert et al., 2014). Recent literature has indicated that individuals with mild cognitive impairment (MCI) exhibit reduced gait speed during dual-tasking (DT) (performing a motor and cognitive task concurrently), thereby increasing the risk of falls for those with MCI (Beurskens & Bock, 2012) compared to healthy older adults. Impairment in cognitive function is depicted in slow gait speed and is a relevant predictor of falls in older adults with MCI (Beurskens & Bock, 2012; Shumway-Cook et al., 1997; Y Tseng et al., 2014).

Physical activity has been recommended as a means to slow down the neuromuscular deterioration, enhance gait stability and improve cognition in older adults with MCI (Granacher et al., 2012; Sturnieks et al., 2008; Tiedemann et al., 2011). Further, increased levels of physical activity have also demonstrated positive effects on cardiovascular fitness (heart rate variability, HRV) (Schuit et al., 1999). However, older adults with MCI do not meet the recommended daily requirement (of about 5,000 steps/day) due to reduced motivation and compliance to physical activity (Broeren et al., 2004). The lack of compliance may emanate from reduced levels of multisensory feedback, absence of involvement and the reduced participatory nature of most conventional physical therapy interventions. As a result, there is the need to implement an alternative therapy that is motivational and enjoyable for older adults with MCI leading to increased participation or involvement. Additionally, this therapy should provide increased sensorimotor feedback, while aiming to improve cognition, physical activity and balance for fall prevention.

Dance therapy, as an alternative therapy, has shown to increase both physical and cognitive function as well as increase motivation among older adults (Broeren et al., 2004) due to the stimulation of motivational brain centers of the nervous system. Dance stimulates active brain centers that mediate in motor control, ambulation and cognitive functions. Few studies have indicated that dance-based training activates Action Observation Network system (AON) and other brain centers, which is known to improve balance control through plasticity of neural systems (mirror neurons) for optimal observation and actual performance of dance (Carvalho et al., 2013; Lee et al., 2015). A preliminary study conducted with virtual reality (VR)-based dance has shown the integration of VR or exergaming and dance to be feasible in improving physical function and balance in stroke (Subramaniam & Bhatt, 2015). It is postulated that people with MCI could benefit from an integrated dance-based exergaming. However, there is no data on feasibility and effect of dance-based exergaming on compliance, cognitive, gait, postural stability and physical activity measures in adults with MCI. It is known that dance is enjoyable by older participants and encourages increased participation. However, compliance with the required the number of sessions of dance-based exergaming intervention in older adults has not been determined yet. Additionally, feasibility and compliance to dance-based exergaming for older adults with MCI have not been investigated. This pilot study, therefore, sought to examine the feasibility of alternative dance-based exergaming with the use of a commercially available and cost-effective Kinect system in the laboratory setting.

Further, the composite effect of reduced balance and cognition, gait abnormalities/gait disturbances and physical inactivity in older adults with mild cognitive impairments (MCI) leads to fear of falling and reduced participation in daily activities. Reduced physical activity leads to reduced cardiovascular fitness and deconditioning in older adults. Even though many conventional balance and strength training programs have been implemented for older adults with MCI, these adults do not receive adequate practice dosage to make significant improvements. The inadequate practice may emanate from lack of adherence to therapy and/or inadequate incorporation of all domains of the ICF model (body functions and structures, activities and participation) and targeting cognitive-motor interference, CMI (deterioration of motor and/or cognitive function when both tasks are performed together).

Theoretically, it is postulated that the brain centers for motivation are activated during the performance of dance, and this may play a critical role in compliance to dance therapy. Additionally, motor control centers within the higher cortical centers share resources with centers for balance control and cognitive processing. Under cognitively challenging conditions motor control requires minimal higher cognitive resources, this leads to a reduction in the "automated" mode of movement. Aging causes a gradual decline in balance, motor and cognitive functions, where these activities are mostly performed at an associative or cognitive stage as opposed to the autonomous stage. In mild cognitive deficit conditions, there is a loss of movement automation and motor control tends to be more vulnerable to cognitive distractions (cognitive-motor interference), subsequently increasing the risk of falls.

Mild cognitively impaired older adults present with further decline in physical function (Fitzgerald et al., 1997) in comparison with a non-MCI older adult. As a result, there is a reduction in gait speed, number of steps and reduced cardiovascular fitness as depicted by increased heart rate variability. The use of dance-based exergaming has been found to be relatively enjoyable to older adults due to increased motivation, which has led to the added improvement of physical and cognitive functioning. Thus, dance-based exergaming as physical activity intervention may improve cardiovascular system leading to better endurance and improved physical function in older adults (Subramaniam & Bhatt, 2015). To date, there are no studies examining the influence of dance-based exergaming on cognition among older adults with MCI. Thus, the overall aims of this pilot are to test the feasibility of dance-based exergaming paradigm in older adults with MCI and its effect on enhancing impairment (balance, gait and cognition) and physical fitness (PA/step count). It is of the belief that the net effect of improvement in these domains will result in improved quality of life of older adults with MCI.

The first aim of this study was to demonstrate feasibility and adherence rate of a dance-based exergaming paradigm in community-based older adults with mild-cognitive impairment (CB-MCI). The first hypothesis was that at post-training, participants will demonstrate high feasibility and adherence rate, which will be comparable to or as good as those reported in other training studies involving older adults. The second aim of the study was to determine the effect of training with dance-based exergaming paradigm on improving motor and cognitive function and on reducing CMI. The second hypothesis was that a comparison of post-training to pre-training would lead to significant improvement in motor and cognition (assessed by a neuropsychological test battery) resulting in overall reduction in CMI (dual-task cost during balance and gait tasks), gait (in spatiotemporal parameters), balance (on limits of stability test). The third aim of the study was to determine the effect of the dance-based exergaming paradigm on physical fitness (physical activity, PA) of community-based older adults with older adults with MCI. The third hypothesis was that post-training measures would depict a significant improvement in PA fitness. An ancillary aim was to determine if improvement cognitive-motor function and physical fitness with dance-based exergaming intervention would be translated into improved falls efficacy and quality of life after withdrawal of intervention. The supportive hypothesis was that at post-intervention or withdrawal, there would be increase in cognitive-motor function and cardiovascular fitness, which will translate into improved falls efficacy (improvement on Activities-specific Balance Confidence (ABC) scale).

4.2. Methods:

4.2.1. Design, participants and recruitment

This pilot study was a pre-post intervention-based study with a single group design, where participants will receive dance-based exergaming training for 15 sessions. Of the initial 14 eligible participants who provided consent, 12 started the dance training and only 7 completed all the 15 dance sessions. Participants were recruited primarily via the University of Illinois Outpatient Centers by working directly with the family medicine and geriatric division. This study was conducted in the Cognitive, Motor and Balance Rehabilitation laboratory at the University of Illinois at Chicago.

4.2.2. Participant eligibility

This study included seven older adults (≥ 65 year) with MCI as evaluated by Montreal Cognitive Assessment (MOCA) score of < 26. It was ensured that participants were not involved in any dance exercise routine or choreography in the past year. Participants had a good bone density (t-score ≥ -2), no recent surgery (< 6 months) and hospitalization (< 3 months). Participants also had no acute or chronic neurological, cardiopulmonary and any musculoskeletal conditions that would hinder the performance of dance routines. It was ensured that all participants could read and comprehend English language since all cognitive tests were in English. Participant were excluded if they had a heart rate (HR) greater than 85% of the maximal heart rate (HRmax = 220 - Age) and with resting oxygen saturation (measured by pulse oximeter) < 95%. Finally, participants with inability to stand or walk for at least 5 minutes and/or with a recent history of fracture (< 6 months) were excluded from the study.

4.2.3. Protocol

4.2.3.1. Intervention

Participants received the intervention (dance) of dance-based exergaming using Kinect “Just Dance 3” in the laboratory three times/week for five weeks (15 sessions) with each session lasting about 90 minutes, including rest period, warm-ups and cool down. Training consisted of 20 minutes pre-post-training (warm-up - joint mobility, walking and stretching exercises of moderate intensity and cool-down - low-intensity stretching exercises) and one hour of dance to

10 songs. Participants danced to 10 alternating slow and fast-paced songs (~3-5mins long each) and with a five-minute break after dancing to each set of 2-5 songs for five weeks. From the 4th to the 5th week of training, participant had an option to dance to either one slow-paced song, one fast-paced song or both songs, depending on their capacity to perform dance. After the first two weeks, once the participants reached a resting heart rate of ≤ 85 beats/min (as measured by the Panasonic EW3109W), they were be allowed to dance to the next song. For progression through the whole training, participants possessed a heart rate ≤ 85 beats/min. All participants were provided with a feasibility questionnaire and the compliance was recorded at the end of 15 sessions of dance training. The protocol of this dance-based exergaming intervention is shown in Figure 7.

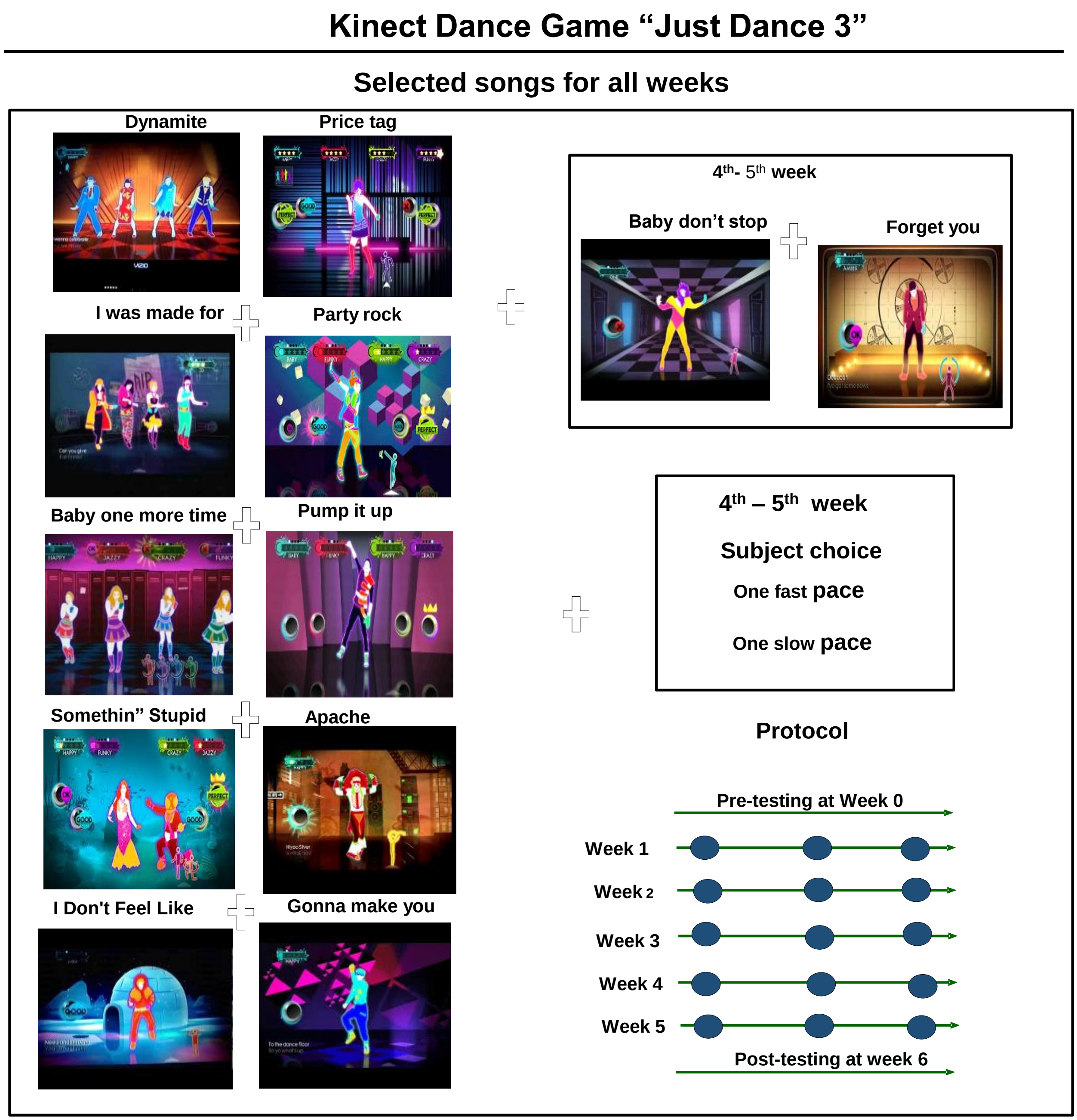

Figure 7: Figure showing the schematic of the protocol for the 15-session dance-based exergaming for older adults with MCI.

4.2.4. Safety

During the laboratory pre and posttests, participants were donned in a safety harness system. For clinical tests, participants were secured with a gait belt and allowed to use their assistive device (if using one) with close monitoring by the researcher or clinician. Similarly, during the dance training sessions, participants wore a gait belt and had external assistance (contact guard support) for safety.

4.2.5. Outcome variables:

4.2.5.1. i) Primary outcome measures:

4.2.5.2. Feasibility and adherence

Feasibility and compliance was determined by using structured questionnaire adapted from the ITC-Sense of Presence Inventory questionnaire of Lessiter et al. (Lessiter et al., 2001). This customized questionnaire included statements consisting the feasibility aspects scored from 1 (strongly disagree) to 5 (strongly agree). The questionnaire comprised of inputs regarding the patients' experiences in the virtual environment including perception and sense of presence in the virtual environment and about their experiences in the dance-based training environment, the presence of potential side effects and their input on the design and effects of the intervention. Adherence rate was determined via the percentage of the average number of training sessions completed by participants out of the total of 15 sessions post-intervention (McAuley et al., 1989).

4.2.5.3. Cognition function

Cognitive function was initially assessed by the Montreal Cognitive Assessment (MOCA), which is widely used for detecting MCI in older adults and with excellent sensitivities/specificities of 100/87% and 78/100%, respectively (Nasreddine et al., 2005). Secondly, participants' processing times were evaluated by the completion of Trail Making Test (TMT). Trail Making Test is a cognitive test of motor speed and visual attention with good validity (Gaudino et al., 1995). The TMT consists of 25 circles distributed over a sheet. Part A of the test comprises of only numbers in the circles, participants were instructed to draw a line to connect the numbers in sequence. However, part B contains both numbers and letters of alphabet. This part is more difficult to complete and participants were asked to connect the numbers and letters in sequence. Greater performance in pre-post was determined by reduction in time taken to complete each part of the test. Clients were then asked to perform single task, ST (serial subtraction) and dual task, DT (performing serial subtraction while walking on a Gait rite mat simultaneously) activities for pre and posttests. Finally, cognitive function was examined by using a neuropsychological battery (NPSY) test. With NPSY, participants underwent category fluency (CF - naming as many items that belong to a category) and verbal fluency (VF - naming as many items that start with a given letter of the alphabet) tests only (Mirandez et al., 2017; Nutter-Upham et al., 2008). For MOCA and NPSY, higher scores and accuracy in percentage (%) respectively refer to greater performance while better performance on the TMT is indicated by reduction in processing time pre-post.

4.2.5.3. Gait function

This was evaluated by assessing gait measures under single task (ST) and dual task (DT) conditions. During ST condition the walking task was performed alone while during DT gait task was performed with a cognitive task (serial subtraction: counting backwards from 100 by 7). Gait performance was examined via the Gait Rite electronic walkway system and spatiotemporal parameters were extracted (gait velocity, stride length, stride time and stride time variability). Higher stride time variability refers to lower performance of gait function.

4.2.5.4. Balance control

4.2.5.4.1. Volitional balance control

Limits of Stability (LOS) with the Equitest (Computerized Dynamic Posturography), which possesses high validity and reliability, was used to assess volitional balance control. Single and dual tasks in the backward sway directions were chosen in order to mimic the backward loss of balance (BLOB) during the slip perturbations. Each participant performed these tests in single and dual task conditions. Participants stood on the Equitest balance platform secured to a harness system. After a familiarization trial, participants were instructed to lean backwards toward a target and performed the same postural motion with a cognitive task (serial subtraction) without moving their feet and losing their balance. These numbered targets were projected on a screen in front of the participant. The center of gravity sway area was generated for each test by the software and provided data on reaction time, movement velocity, maximum excursion and directional control.

4.2.5.4.2. *Outcome variables*

Reaction time (RT) is the time in seconds taken between the command to move or lean forward or backward direction and the beginning of participant's movement. Smaller reaction time refers to better performance. Movement velocity (MVL) is the average speed of the center of mass sway in degrees per seconds. Faster movement velocity indicates a better performance. Maximum excursion (MXE) is the maximum amplitude (in percentage) of the center of mass excursion for each trial. Directional control (DCL) is the amount of sway in percentage of the center of mass in the projected direction of the targeted number to the amount of peripheral movement away from the target. Greater percentage of MXE and DCL indicates improved performance.

4.2.5.5. Reactive balance control

Participants were exposed to a laboratory-based slip perturbation test while in stance position (with feet aligned) on a moveable ActiveStep treadmill (Simbex, Lebanon, NH) in order to evaluate their response (categorized as fall, balance loss or recovery) to an unexpected slip perturbation. At all times, participants wore a harness suspended from an I-beam on the treadmill or the ceiling. Participants also had 29 reflective markers (Helen Hayes marker set) attached to specific parts, joints and segments of their bodies. Load cell attached to the harness system was able to determine fall outcomes during perturbation by recording the amount of body weight exerted by a participant. During the perturbation trials, participants were instructed that they might experience a perturbation and that they should try to recover their balance and assume their starting position.

After a single familiarization trial of slip perturbation (at level 3: belt velocity = 0.72m/s, displacement = 0.09m), participants were exposed to one slip (at level 2: belt velocity=0.41m/s, displacement = 0.04m) each for single task and dual task condition (serial subtraction). The onset time of the belt displacement was randomized to start at 5-20s when participant assumed stance position. To determine accurate perturbation onset, a marker was placed on the treadmill belt.

4.2.5.5. 1. *Data processing*

Locations of joint centers of the heels and toes were obtained from the filtered kinematic data (captured via motion analysis system) for all trials to compute the center of mass (COM) kinematics in the anteroposterior direction using a 13-segment human model. High-resolution digital video cameras recorded the participant's response in each trial. Motion data were subsequently used to compute the COM displacement-velocity trajectory using known segmental parameter information. The COM state (position and velocity) was calculated relative to the edge of BOS in the AP direction and then normalized by foot length or $\sqrt{g \times body\ height}$. The stability values were computed using a previously developed method for this COM status. Processing of the marker data were performed by a low-pass filter using 4th order Butterworth filter with a cutoff frequency of 6Hz. Data from the load cell were sampled at 1200Hz.

4.2.5.5. 2. *Outcome variables*

Fall outcome: The fall incidence (%) during slip perturbation tests was determined by the percentage of the occurrence of falls pre-post. A backward loss balance (BLOB) was determined by observation then verified and defined as i) a fall: when the amount of participant's weight exerted on the harness system is ≥ 30% of the body weight. This data was recorded by the load cell attached to the safety harness (Yang & Pai, 2011); ii) a recovery: when a participant executes a compensatory step(s) (Joshi et al., 2018; Salot et al., 2016). For slip, there is a sudden forward displacement of the belt leading to a BLOB. Participants then make an optimal compensatory step(s) in the backward direction to prevent a fall.

Compensatory steps: The number of compensatory steps taken to recover from slip perturbations were determined by careful observation and analysis of 3D video record. A backward compensatory step occurred when the complete heel and toe clearance leads to landing of the foot posterior to the stance foot. A forward compensatory step occurred when there was heel and toe clearance landing anterior to the stance foot. The first compensatory step was used to determine other kinematic variables such as the recovery step length, reaction or step initiation time, COM position and the stability at touchdown (TD).

4.2.5.5. 3. *Other kinematic variables*

To analyze the method of recovery from a BLOB, the step length, reaction or step initiation time, the COM position and stability at TD of the first compensatory step was determined. The compensatory step length was determined by the calculating the displacement heel marker of the stepping limb in the anteroposterior direction between liftoff, LO and TD after perturbation onset. The step length was then normalized to the individual's body height. The reaction or step initiation time was time taken between the perturbation onset and for a stepping foot LO. The stability values were computed with a previously developed method using this COM state (COM position and velocity). The COM coordinates were quantified from the kinematic data using parameters of segmental information in a 13-segment representation of the body.

4.2.5.6. ii) Secondary outcome measures

Clinical measures of Berg Balance Scale (BBS), Timed-up and Go test (TUG), and 6-minute walk test (6MWT), 10-minute walk test (10MWT) and Activities Specific Balance (ABC) scale were used to assess functional exercise capacity and balance confidence for community integration. These measures possess high reliabilities and validities for assessing objective functional balance measures in older adults.

4.2.5.7. Physical activity and fitness

Community-based physical activity (PA) levels for participants' pre-post intervention was evaluated by Physical Activity Scale for Elderly (PASE), which is an instrument that measures the physical activity levels in older adults ≥ 65 years old. The weighted PASE scores range from 0 to 400, with higher scores indicating higher levels of physical activity (PA). Additionally, the number of steps/dance session was assessed with commercially available activity, accelerometer-based wearable sensor, Fitbit surge (Fitbit Inc., San Francisco, CA, USA). Higher step counts indicate better learning and performance of dance routine and data will provide support to the idea of using dance as a PA for older adults to attain daily step count. To demonstrate the effect of the 15-session dance training on the cardiovascular endurance or fitness, pre-post blood pressure, heart rate (by BP monitor) and blood oxygen saturation (by pulse oximeter) recorded before and after 6MWT were analyzed for any differences.

4.2.5.8. Statistical analysis

To ascertain the main effect of dance on balance and gait measures, 2x2 ANOVA was perform with task (ST and DT) versus test (pre and posttest). Paired t-test was then used to resolve any differences in test scores between ST and DT conditions. To determine the effect of dance-based exergaming, pre-post changes of cognitive, balance, gait and physical activity measures were analyzed by paired sample t-test. A non-parametric test (Wilcoxon sign test) was used to determine the pre-post differences in fall rates during the perturbation test. A Pearson's correlation coefficient and linear regression analysis were performed in order to determine the relationship between the cognitive, balance and motor functions (cognitive test: accuracies of CF and VF, BBS, TUG and ABC scores) as dependent variables and postural stability (stability at TD) as independent variable. Significant level was set at 0.05.

4.3. Results

4.3.1. Demographics

Demographic data of participants are presented in Table 10. Participants (n=7) included individuals with MCI (screened by MOCA) who completed 15 sessions of dance training. The participants consisted of all females with age of 72.29±6.95 years, height of 167±9.99 cm, foot length of 25.29±1.36 cm and weight of 78.02±18.85 kg.

4.3.2. Feasibility and adherence

This dance training was safe and feasible for all participants as there was no report of falls, injuries or shortness of breath. With regards to adherence rate, out of 12 participants who initially started the dance training, the average number of sessions completed was 12.3±4.42, resulting in an adherence rate of about 82 (±29.49) %. Those who could not complete the total number of 15 sessions provided varied reasons ranging from loss of interest, forgetfulness of appointments, lack of transportation to the training facility and reduced motivation due to small amount of compensation for participation.

4.3.3. Cognitive function

The effect of dance training showed increased performance in most of the cognitive measures of older adults with MCI. There was a significant increase in MOCA score from pre to posttest ($t(6) = -4.83$, $p < 0.05$). With the Trail Making Test, the dance training depicted significant pre-post performance by decrease in duration of completion of test in part A ($t(6) = 3.42$, $p < 0.05$). Though the time take to complete the part B decreased from pre to posttest, it was not significant ($t(6) = 1.57$, $p = 0.17$). The performance of the neuropsychological battery (NPSY) test demonstrated significant and minor increases in accuracy respectively for category fluency (CF), $t(6) = -3.15$, $p < 0.05$, and verbal fluency (VF), $t(6) = -1.53$, $p = 0.18$ tests (Table 9).

4.3.4. Gait function

There was no main effect of test and task for all gait variables ($p > 0.05$). However, paired t-test showed some significant pre-post differences in test (pre vs posttest) and in task (ST vs DT).

Single task: Results showed a slight increase in gait speed and stride length from pre to post during single task, but this was not significant ($p > 0.05$). For stride time, there was significant change from pre to post ($p < 0.05$). CoV of variability also reduced significantly from pre to posttest ($p < 0.05$) for the ST condition.

Dual task: Similarly, there was a nonsignificant increase gait speed and stride length during dual tasking from pre to post training ($p > 0.05$). Also, stride time in dual tasking during gait depicted significant change from pre to post ($p < 0.05$).

However, between ST and DT, gait speed and stride length were greater for ST in both pre and post ($p < 0.05$). Also, stride time increased in ST than in DT both pre and posttest ($p < 0.05$).

Notably, stride time variability or coefficient of variability (CoV) decreased from pre to post-training, but it was not statistically significant ($p > 0.05$) (Table 9).

Table 9: Demographic and pre-post clinical test score of older adults with MCI

Participant characteristics (n=7)	Baseline/Pretest	Posttest
Demographic data		
Age (years) x (SD)	72.29 (6.94)	
Weight (kg) x (SD)	78.02 (18.85)	
Height (cm) x (SD)	167.28 (9.99)	
Foot length (cm) x (SD)	25.29 (1.36)	
Cognitive measures		
MOCA x (SD)	23.14 (1.95)	26.43 (1.72)*
TMT Part A (s) x (SD)	67.47 (43.51)	54.89 (37.57)*
TMT Part B (s) x (SD)	150.36 (75.54)	104.75 (46.22)
CF Accuracy (%)	76.95 (19.05)	89.43 (10.62)*
VF Accuracy (%)	87.09 (8.26)	90.84 (11.93)
Clinical balance and functional measures		
TUG (s) x (SD)	11.38 (2.22)	9.13 (2.04)*
6MWT (m) x (SD)	352.57 (56.62)	397.71 (74.21)*
10MWT (m/s) x (SD)	1.09 (0.18)	1.22 (0.24)
ABC (/100)% x (SD)	67.49 (16.14)	75.63 (12.16)
BBS (/56) x (SD)	50.71 (3.15)	53.14 (1.95)*
Gait parameters		
Gait speed ST (m/s) x (SD)	1.03 (0.24)[a]	1.08 (0.23)[a]
Gait speed DT (m/s) x (SD)	0.88 (0.23)	0.93 (0.27)
Stride length ST (m) x (SD)	1.16 (0.17)[a]	1.23 (0.17)[a]
Stride length DT (m) x (SD)	1.07 (0.18)	1.14 (0.17)
Stride time ST (s) x (SD)	1.15 (0.14)[a]	1.10 (0.13)*[a]
Stride time DT (s) x (SD)	1.35 (0.31)	1.25 (0.31)*
CoV Stride time ST x (SD)	12.80 (1.35)[a]	12.33 (1.29)*[a]
CoV Stride time DT x (SD)	25.50 (5.18)	23.98 (4.62)*

ST = Single Task, DT = Dual Task, CoV = Coefficient of Variation, MOCA = Montreal Cognitive Assessment, TMT = Trail Making Test, CF = Category Fluency, VF = Verbal Fluency, TUG = Timed Up and Go, 6MWT = Six Minute Walk Test, 10MWT = Ten Minute Walk Test, ABC = Activities Specific Balance Confidence, BBS = Berg Balance Scale. Significant differences between pre and posttest are depicted by *, while differences between ST and DT (for either pre or posttest) are denoted by letter a representing $p < 0.05$.

4.3.5. Balance control outcomes

Volitional balance control (Limits of Stability, LOS): There was no significant main effect of all variables of LOS test, $p > 0.05$. However, it will be important to show the changes in the variables of LOS. In single and dual task conditions, reaction time (RT) decreased pre-post in the backward sway direction. For maximum excursion (MXE), movement velocity (MVL) and directional control (DCL), single and dual task conditions showed increases in the backward sway directions (Figure 8).

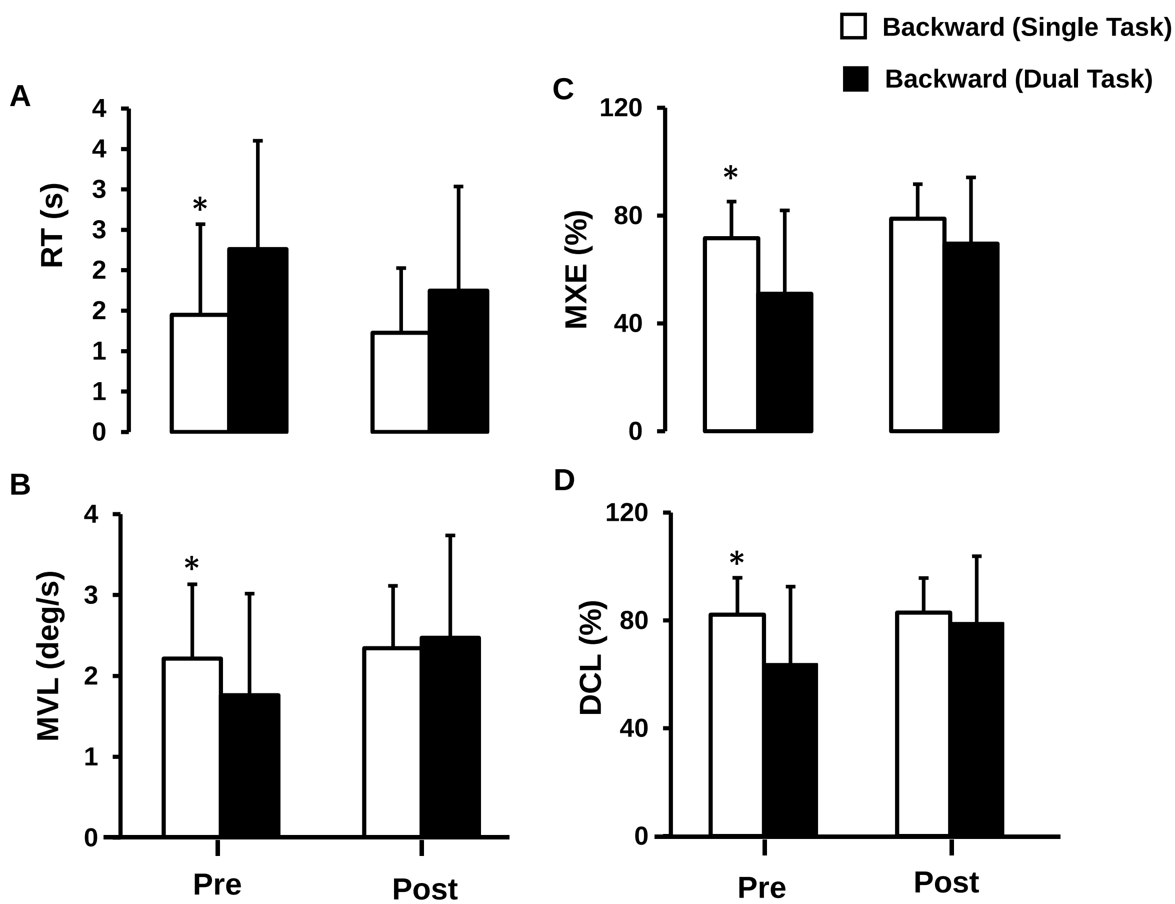

Figure 8: Figure showing pre-post variables of volitional balance (LOS: Backward sway) for older adults with MCI after completion of 15 sessions of dance-based exergaming. Variables include A) reaction time (RT), B) movement velocity (MVL), C) maximum excursion (MXE) and D) directional control (DCL). Significant differences pre-post were represented by * depicting $p < 0.05$.

Reactive balance control

For slip perturbation test, analysis was performed with data from six participants due to the inadequate data from one participant as a result of withdrawal from reactive balance test only. However, this participant completed all dance sessions and all other pre and posttest sessions.

Fall outcome: The fall rate during slip perturbations stayed the same during single task conditions ($Z = 0.01$) and reduced by two-fold in dual task conditions ($Z = 1.00$) from pre and post training, but this was not significant ($p > 0.05$), see Figure 9.

Compensatory step: Though not significant, there was a decrease in the number of compensatory or recovery steps taken by all participants from pre to post training, $t(5) = 0.89$, $p = 0.42$ during the single task conditions of the slip perturbation test. However, dual task conditions resulted in a significant reduction in the number of compensatory steps taken from pre to post training, $t(5) = 2.70$, $p < 0.05$, see Figure 9.

Slip perturbation outcome: Participants experienced a backward loss of balance (BLOB) and responded by executing at least a backward compensatory stepping resulting in a fall or recovery. There was significant main effect of test (pre vs post) for most variables of slip perturbation test, $p < 0.05$. However, there was no significant main effect of task (ST vs DT) for either pre or posttest, $p > 0.05$. For single task conditions, there was a significant reduction in the first compensatory step length from pre to post training, $t(5) = 2.32$, $p < 0.05$. Additionally, all participants had a significant reduction in reaction or step initiation time after dance training, $t(5) = 2.32$, $p < 0.05$, and a significant increases COM position at TD, $t(5) = -2.72$, $p < 0.05$ and stability at TD, $t(5) = -2.21$, $p < 0.05$ post training.

In dual task conditions, there was no reduction in compensatory step length, t (5) = -1.55, p = 0.18, and a significant reduction in reaction or step initiation time, t (5) = 2.23, $p < 0.05$ of the first compensatory step reduced after training. Additionally, COM position at TD significantly increased at posttest, t (5) = -2.27, $p < 0.05$ and a nonsignificant increase in stability at TD, t (5) = 0.53, p = 0.62 from pre to post training (Figure 10).

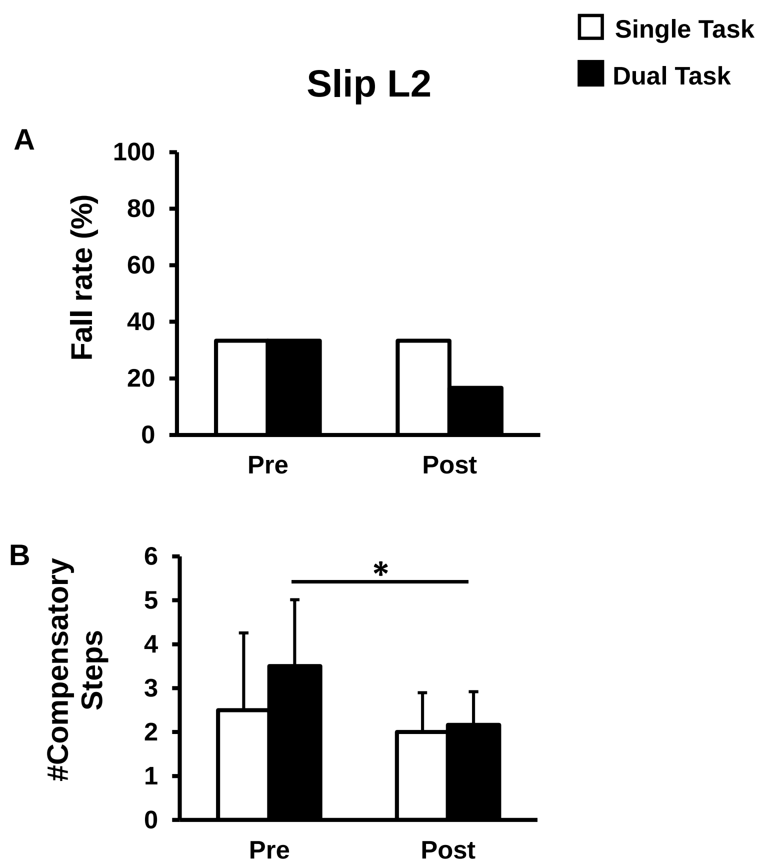

Figure 9: Figure showing pre-post results of perturbation outcome (fall rate and number of compensatory steps) in response to slip-like perturbations in single and dual task conditions for older adults with MCI after completion of 15 sessions of dance-based exergaming. Figures A and B represent fall rate and number of compensatory steps, respectively, for slip-like perturbations. All participants with MCI were had all slip tests at intensity level 2. Significant differences pre-post were represented by * depicting $p < 0.05$.

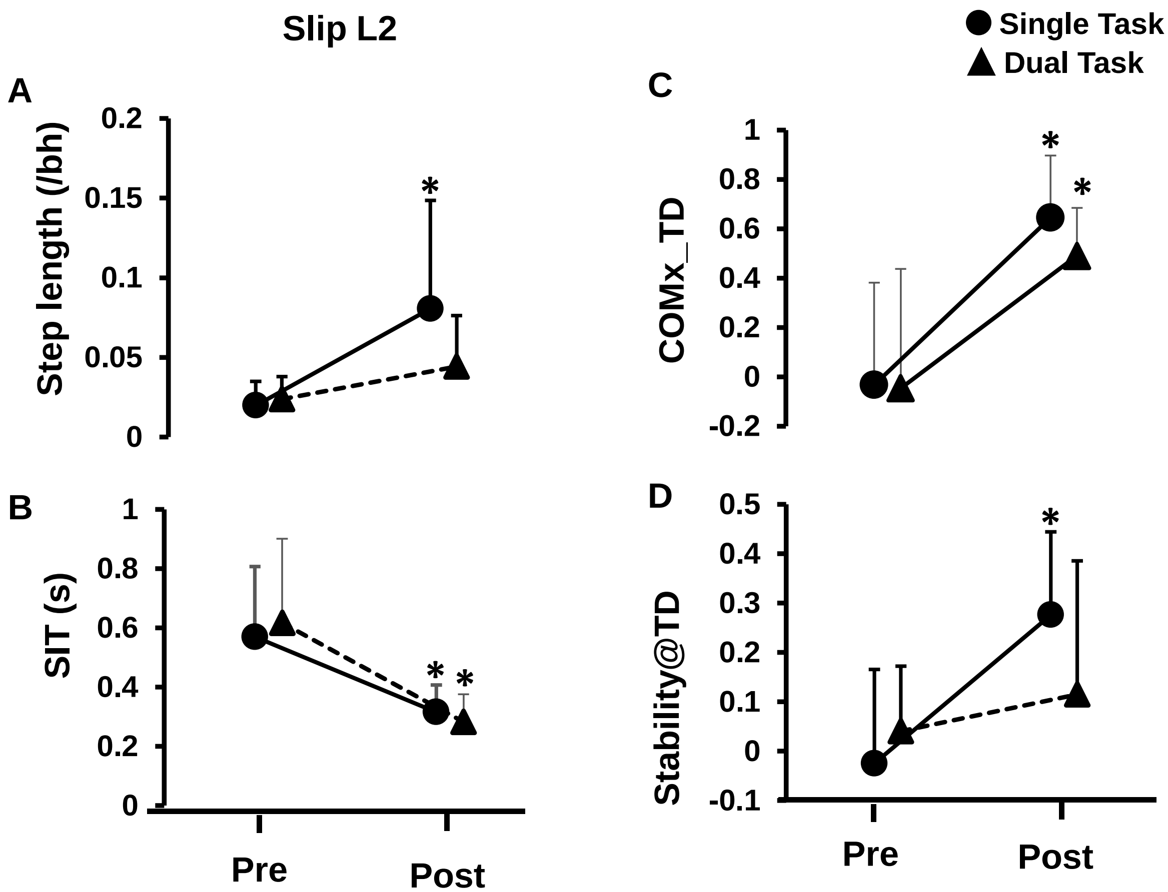

Figure 10: Figure depicting mean (SD) difference between pre and posttest of reactive balance outcome measures for older adults with MCI after completing 15 sessions of dance-based exergaming. The figure shows data of first compensatory step A) step length for slip-like perturbations, B) step initiation time for slip-like perturbations, C) center of mass position at TD and D) stability at TD for slip-like perturbations. Significant differences pre-post were represented by * depicting $p < 0.05$.

4.3.6. Clinical balance measures

Results from paired t-test showed significant improvement in the performance of most clinical and function balance measures. From pre to post test, there was significant increase in BBS [$t(6) = -2.28$, $p < 0.05$], reduction in TUG time [$t(6) = 3.95$, $p < 0.05$] and increase in distance covered during 6MWT [$t(6) = -4.37$, $p < 0.05$]. Though there were increases in walking speed during a

10MWT and in confidence (or reduction in fear of fall) in executing balance tasks during ABC test, these values were not significant ($p > 0.05$), see Table 9.

4.3.7. Physical activity and fitness measures

Results depicted a significant increase in mean PASE score from 77.04±48.71 to 150.17±87.03, $t(6) = -3.72$, $p < 0.05$. Additionally, step count data collected via Fitbit surge during 15 sessions of dance showed a significant increase from 2547.71±923.72 for the 1st session to 3072.86±770.94, $t(6) = -2.29$ for the 15th session, $p < 0.05$ (Figure 11). For cardiovascular endurance during dance training, baseline 6MWT scores of SBP significantly reduced pre-post training (142.00±20.40 – 132.297±24.26 mmHg), $t(6) = 3.52$, $p < 0.05$, while the post 6MWT also reduced significantly pre-post dance training (152.71±22.93 – 138.86±20.75 mmHg), $t(6) = 4.66$, $p < 0.05$. Additionally, there were significant increases in baseline (95.29±2.21 – 97.29±1.38 %), $t(6) = -2.76$, $p < 0.05$ and post (97.00±1.00 –98.43±1.13 %), $t(6) = -3.87$, $p < 0.05$, 6MWT scores of blood oxygen saturation (SPO_2) levels pre-post dance training. However, there were nonsignificant changes in DBP from baseline (81.71±10.29 – 79.71±9.79 mmHg) and post (81.14±6.69 – 84.43±9.59 mmHg) 6MWT scores, as well as reductions baseline (75.43±8.81 – 71.14±9.67 bpm), and post (78.29±11.91 – 75.86±7.34 bpm) 6MWT scores for HR, $p > 0.05$, from pre to post training.

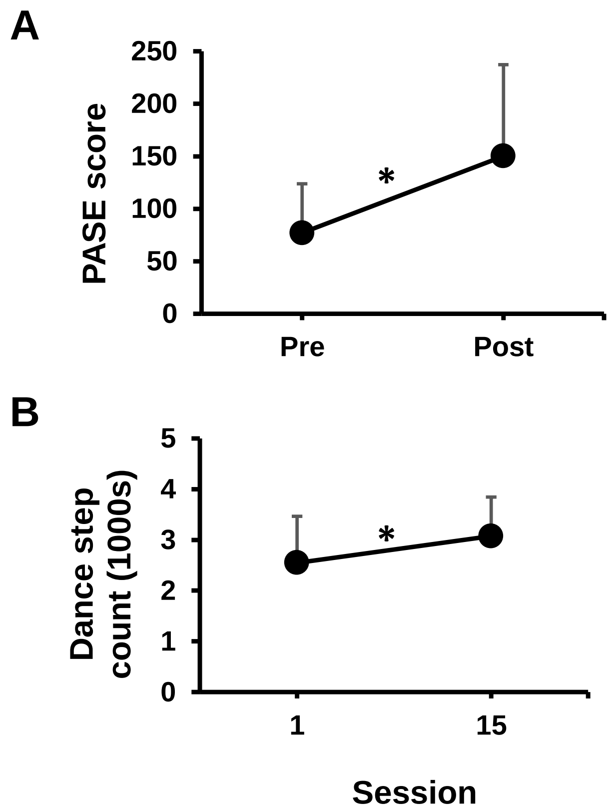

***Figure 11**:* Figure showing physical activity scores for older adults with MCI after completing 15 sessions of dance-based exergaming with a) showing pre-post PASE (Physical Activity Scale for the Elderly) scores and b) dance step counts or number of steps for the 1st and 15th sessions during the dance training. Significant differences pre-post were represented by * depicting $p < 0.05$.

4.3.8. Correlation between cognitive, balance measures and postural stability

Though the regression analysis performed resulted in no significant associations between the dependent variable and the independent variables ($p > 0.05$), it is worthy to note the correlation trends between the variables. For slip perturbation, results showed that cognitive and balance test scores correlated positively with postural stability at TD; CF [$F(1,11) = 0.71$, $R = 0.26$, $R^2 = 0.07$], VF [$F(1,11) = 1.6$, $R = 0.37$, $R^2 = 0.14$], BBS [$F(1,11) = 1.32$, $R = 0.34$, $R^2 = 0.12$], TUG [$F(1,11) = 0.59$, $R = 0.24$, $R^2 = 0.06$] and ABC [$F(1,11) = 0.99$, $R = 0.30$, $R^2 = 0.09$].

4.4. Discussion

This pilot study evaluated the effect of dance-based exergaming on physical functioning and quality of life of older adults with MCI. The results supported the hypothesis that this paradigm or protocol was feasible, safe and effective in improving cognition, gait function, balance control and fall efficacy in community-dwelling older adults with MCI. Additionally, a compliance rate of about 82 (±29.49) % lends some support to the feasibility of implementation of this protocol for older adults with MCI. Our adherence rate to dance intervention was consistent to ones reported in other studies conducted with older adults (Britten et al., 2017; Cramer & Rosenheck, 1998; Dishman, 1991; van Dulmen et al., 2007; Xu et al., 2020). There was also an increase in physical fitness assessed via PASE scores and step count during the training. The increase in PA during training could offer a new avenue for aerobic exercise with well-designed dance training as in-home or community-based exercises that would increase physical fitness in older adults and other populations.

The increase in cognitive functions (particularly with scores of MOCA and Trial Making Test, TMT, part A) during dance training lends increased support to the data which shows increased cognitive functions with dance (Doi et al., 2017; Hamacher et al., 2015; Kim et al., 2011; Rehfeld et al., 2017). Other studies have shown increase in cognitive function during dance is due to increased plastic changes that occur in brain centers responsible for motor control (Berrol, 2006; Kosmat & Vranic, 2017). These studies have indicated that there is learning and memorization of dance steps as provided via virtual systems such as Kinect system in our study. These learning and memorization during dancing also cause augmented neurological plasticity in the brain, which may have resulted in the increase of results in MOCA, TMT and other neuropsychological battery tests (accuracies of CF and VF tests). It is a well-established fact that increased cognitive function plays a critical role in improving motor control (Table 9).

The assessment of spatiotemporal parameters of gait in single and dual tasks is one of the ways of determining fall risk and the relationship between cognition and mobility in older adults (Muir et al., 2012; Taylor et al., 2013). Additionally, dual task conditions during gait are more applicable to activities of daily living that require walking. The results of this study showed a moderate increase in gait speed, stride length and significant increases in stride time for both single and dual task conditions. This may show that the rhythmical nature of dancing with alternate slow and fast-paced songs could have played a role in training the temporal factors of gait. The improved gait parameters in dual task could also demonstrate the relationship between cognition and gait, which implies that dual task could differentiate between MCI and non-MCI older adults in terms of the magnitude of the improvement in the gait parameters (Al-Yahya et al., 2011; Taylor et al., 2013). Moreover, since most of daily activities involve multitasking in walking, the improvement in gait parameters with dance may play a critical role in reducing fall risk in older adults. Further, the reduction in the stride time variability supports the assertion of improved gait parameters play key roles in reducing in fall risk in older adults with MCI. Results from other studies determining the effect of alternative therapies including dance on gait, support our results (Hackney & Earhart, 2009, 2010; Subramaniam, 2015; Verghese, 2006). (Table 9).

Balance control is achieved by the interaction between the anticipatory and reactive balance systems of the nervous system, which maintains the center of mass within the base of support (Aruin, 2002; Maki & McIlroy, 2006). The increased cognitive functions and appropriate learning of dance steps may have led to some moderate improvement in temporal (reaction time) and spatial (maximum excursion, movement velocity and directional control) parameters of intentional balance control evaluated by LOS in both single and dual task conditions. It is possible that dancing to fast-paced songs during the training could have trained intentional balance control leading to the faster reaction time in backward sway in the single task condition. This result is analogous to reduced reaction time depicted in fast movement training (Bisson et al., 2007). However, dual task conditions proved slightly difficult for performance of LOS in older adults with MCI, supporting the results that dual tasking may be used to differentiate MCI from non-MCI older adults. The fact that dance is voluntarily initiated by repeated, self-generated perturbations of the center of mass to the stability limits during the dance sequence may have led to some moderate increases in the maximum excursion, directional control and faster movement velocity. Additionally, the increased cognitive functions because of plasticity of cortical centers of the brain may play a key role in the moderate enhancement of intentional balance control post training. It will be interesting to investigate the effect of dance on the relationship between reactive balance control and volitional balance (Figures 8 & 9).

Reactive balance control is essential to maintain the center of mass within the base of support. Dance-based exergaming was able to improve reactive balance control of older adults with MCI as a result of reductions in fall rate and other perturbation outcomes during slip perturbations in single and dual tasks. The BLOB experienced by MCI older adults in slip perturbations were similar to fall outcome by healthy older adults. This may imply that the reduction in cognition has not deteriorated extensively to change the fall outcomes in older adults with MCI. It is important to note that the reduction in step initiation in slip test, in addition to increased stability at TD in single task condition, may signify some improvements in reactive balance during single task events. Dual tasking resulted in poor performance of reactive balance stability due to the impaired cognitive functions (Beauchet et al., 2005). Dosage in terms of the duration and frequency of the training plays a role in improving postural stability during slip events. It is possible that the dosage was not adequate to cause a tangible increase in reactive balance in older adults with MCI. However, a similar study in healthy older adults and participants with stroke led to increases in stability outcome variables (Subramaniam, 2015). Albeit, our dance-based exergaming lead to improvements in functional balance scores such as BBS, TUG, 6MWT, 10MWT and ABC, and this may play a critical role in reducing fall risk and improving the performance in activities of daily living by older adults with MCI. The increase in cognitive functions may be also be responsible for increases in functional balance measures (Alpert et al., 2009; Subramaniam, 2015) in older adults with MCI, as shown by the positive correlations or associations between the cognitive function and the functional balance outcomes with stability (Joshi et al., 2018) (Figures 10).

This study resulted in increased community-based physical activity (PASE) in older adults with MCI over the duration of five weeks of dance-based training (Figure 11). It may be due to the increase in cognitive functions because of dance-based exergaming. This lends support to the knowledge that increased cognitive function leads to increased physical activity and fitness in older adults (Subramaniam, 2015). It also supports the fact that the dosage of 15 sessions of dance was adequate to cause an increase of cognition and physical fitness in older adults. To lend support and credence to the implementation of aerobic dance at home and community settings, dance-based exergaming for 15 sessions was able to enhance physical activity during the training with adherence to recommendations by the American College of Sports Medicine (Chodzko-Zajko et al., 2009). Additionally, the increase in step count during 15 sessions of dance-based exergaming protocol may imply that the enhanced cognition function resulted in increased learning of the dance steps, leading to the increased step count (Gheysen et al., 2018). The increased step count during dancing could also indicate increased cardiorespiratory endurance (Tudor-Locke et al., 2011) demonstrated by reductions in BP, HR and increases in SPO_2 (for pre-post 6MWT test scores) during the course of 15 sessions of dance attained by the participants with MCI. Thus, with a well-designed home or community-based dance training, physical fitness in terms of attaining the daily step count could be realized for older adults. Dance-based exergaming may therefore be a great tool or avenue of improving both cognition and physical fitness of older adults with MCI.

Our results may be limited by the small sample size and thus results from this study should be interpreted with caution. Furthermore, this study was conducted as a one sample pre-post study design with no control group, as such the results may not be generalized to all populations. Additionally, there was no follow-up test to determine the length of retention of the gains of cognition, balance control and physical fitness after withdrawal of the dance-based exergaming intervention. Nevertheless, the feasibility and optimal adherence rate depicted in this study may provide credence to the implementation of dance-based exergaming in cognitively-impaired older adults. Future studies with large sample sizes should be conducted with a control group in order to determine the dosage of the intervention as well as the long term effectiveness of dance-based exergaming for possible translation into the home or communities of cognitively-impaired older adults.

In conclusion, the feasibility and effectiveness of this dance intervention (balance control and more evidential in functional balance measures) should provide knowledge for its implementation in the laboratory, home and community to prevent falls in older adults. Additionally, caregivers could then deliver this intervention either in an independent or assisted living facility after the caregivers receive training from the rehabilitation therapists. Based on the results of this feasibility or pilot study, future studies should look into extending this protocol into a large-scale randomized controlled trial (RCT) and develop a plan for the transition of the intervention to home and community settings via caregiver implementation**.**

Table 10: Summary of results for study 3 (MCI)

Outcome variables	**Results**
Feasibility	• Dance-based exergaming for 15 sessions in 5 weeks proved to be highly feasible for older adults with MCI. Dosage may be adequate to produce the positive effects in all variables.
Adherence rate	• Adherence rate of 82% was consistent with those obtained in other studies conducted with older adults.
Cognitive function	• Cognitive functions increased. Significant improvement in the performance for MOCA, TMT and accuracies for CF and VF NPSY tests from pre to posttest.
Gait	• Gait functions also improved. Pre-post improvement in gait function in ST and DT conditions was shown in all variables, but significantly stride time and CoV of stride time.
Volitional balance	• Improved performance in volitional balance control. Though not significant, pre-post scores of RT, MVL, MXE and DCL demonstrated improved performance.
Reactive balance	• Improved performance in reactive balance control. For slip perturbation, there were pre-post reductions in fall rate and significant reductions in the number of compensatory steps. Significant pre-post increases in compensatory step length, reduced SIT, increases in COM position and stabilities at TD.
Physical fitness	• Improvement in PA and cardiovascular endurance pre-post. Measures of PASE and number of dance steps significantly increased pre-post. Also, study showed significant reductions in SBP and increases in SPO_2.
Clinical balance and functional measures	• There were pre-post improvements in clinical outcome measures such as TUG, 6MWT, 10MWT, ABC and BBS. The

	improvements in these variables correlated positively with stabilities at TD during the reactive balance control.

Chapter 5

Validity of inertial sensors for assessing kinematics of mobility during dance training

5.1. Introduction

Imbalance and falls are common occurrences in older adults and in the neurologically-impaired populations resulting in numerous injuries and hospitalizations (Alexander et al., 1992; King & Tinetti, 1995; Yates et al., 2002). Voluntary and reactive balance control are mechanisms of resolving fall risks in all populations. In order to resist falls, these mechanisms must be improved or enhanced via various alternative fall prevention training programs such as dance and perturbation training (Eyigor et al., 2009; Fitzgerald et al., 2002; Granacher et al., 2012; McKinley et al., 2008; Pai et al., 2014; Parijat & Lockhart, 2012; Sofianidis et al., 2009). Fall prevention training in the form of dance has been extensively studied and the training effectiveness on physical performance has been evaluated in the clinical and laboratory settings by use of clinical outcome measures such as Berg Balance Scale (BBS), Timed-Up and Go (TUG), Six-Minute Walk Test (6MWT) and Ten-Meter Walk Test (10MWT) among others (Eyigor et al., 2009; Fitzgerald et al., 2002; McKinley et al., 2008; Pai et al., 2014). Optoelectronic motion capture system (MOCAP) is a gold standard tool for motion analysis and is capable of providing objective data on gait, joint mobility, balance and fall risks in studies relating to perturbation, gait and, recently, dance training (Ofori et al., 2019; Pai et al., 2014; Parijat & Lockhart, 2012; Subramaniam, 2015). The biomechanical analysis of balance control has been studied extensively in the laboratory setting with large equipment such as the MOCAP systems (e.g. VICON). Nonetheless, major limitations of the MOCAP systems are that of cumbersomeness, immobility and, therefore, restricted use outside of the laboratory settings (Saber-Sheikh et al., 2010). However, for seamless translation of laboratory training to the clinical and normal environment settings, as well as for assessment of results, it is imperative that these studies are replicated in the clinics and in the home and community where older adults visit and live.

Inertial sensors provide a new angle of motion analysis for the smooth evaluation of comprehensive kinematics of human motion (Bolink et al., 2016; Donath et al., 2016). Inertial sensors, such as Xsens, are readily available, cost-effective, small, lightweight and movable motion capture systems, which can provide similar kinematic data like the bulkier MOCAP system. Normally, inertial sensors possess tri-axial accelerometer, magnetometers and gyroscopes, therefore enabling measurement of kinematic variables such as joint and segment angles and center of mass during human motion (Gouwanda & Gopalai, 2015). The attachment of inertial sensors for evaluation of kinematic data can be useful in the analyzing human motion in any environment such laboratory, clinical and community setting. Thus, inertial sensors may play a key role in translating the effect of biomechanical research to the everyday activities of young, healthy and neurologically impaired older adults. A few studies have evaluated the validity and reliability of inertial sensors for human motion with variable outcomes ranging from moderate to high reliabilities (Bolink et al., 2016; Donath et al., 2016). Though inertial sensors have been used for analyzing some kinematic of self-generated motion during testing for clinical balance measures (Coulthard et al., 2015; Martina Mancini & Fay B Horak, 2010), no study to date has assessed the validity of inertial sensors for evaluating kinematic of mobility during the performance of dance.

Proper gait in terms of appropriate stepping strategy forms the basis of human locomotion and one's ability to resist falls due to slips and trips (Kovacs, 2005; Patel & Bhatt, 2015). The extent of gait parameters such as step length, stride length and cadence provide major information on proper walking function required for daily activities. For instance, a shorter step or stride length may be a risk factor for frequent falls and injuries in healthy older adults and adults with neurological impairments (Verghese et al., 2009). Also, slow walking speed may be indicative of gait impairment, which might be a predisposition to falls and injuries, mostly in older adults (Senden et al., 2012). On the other hand, joint angle of knee extrapolated from thigh angle may play a critical role in proper gait function (Begg & Sparrow, 2006; Mills et al., 2008), especially in toe clearance in the older individuals and stroke survivors. Although many studies on validity and reliability of inertial sensors have been conducted on over ground walking (Mathie et al., 2004; Saber-Sheikh et al., 2010), fewer studies have examined the validity of these sensors on stepping attributes and joint angles in dance training. Additionally, since proper stepping and joint angles play critical roles in balance and fall incidence, it will be advisable to determine the validity of inertial sensors in measuring these biomechanical factors or variables related to fall risk during dance.

Additionally, dance is a multisensory modality, which has the ability to improve gait, balance and fall risk (Alpert et al., 2009). However, only few studies examining kinematics of dance have been conducted with the large-sized motion analysis systems in controlled laboratory settings (Ofori et al., 2019; Savitha Subramaniam & Tanvi Bhatt, 2019). Some of mobility and balance measures such as COM position and velocity, joint angle from body segments, as well as postural sway have all been examined in these dance studies. With dance being a social activity, the transfer of its gains from the laboratory to the clinics, homes and community is critical for relevant and holistic wellbeing of participants, especially in regards to following the guidelines and recommendations by the Public Health Departments of city, state and federal Health Departments (Brownson et al., 2006). To do this, inertial sensors could be implemented in conducting studies in the clinic, home or community settings for proper evaluation of the effect of dance therapy sessions on fall risk during the performance of activities of daily living. In order to advance the application of dance therapy, it will be imperative to determine the accuracy of inertial sensors for measuring kinematic measures of dance as related to fall risk before its use in home or community-based settings. Moreover, the testing of the validity of inertial sensors in reactive balance control and dancing was because reactive balance control involves fast, rapid and "discrete movements", while dance falls under continuous movement within volitional domain. In effect, inertial sensors would be used to test their validities for the two main domains (reactive and volitional) of balance control.

Thus, the aim of the present study was to determine the concurrent validity of inertial sensors in measuring kinematic variables of mobility related to fall risk during dance with slow, medium and fast-paced songs. This was achieved by comparing the output of variables of inertial sensors to those from the MOCAP system for equivalence and accuracy. It was hypothesized that there would be reasonably good to excellent agreement and accuracy of values of the variables analyzed when both systems were compared.

5.2. Methods

5.2.1. Participants

Fifteen (15) young participants (18-35 years) without prior exposure to treadmill-based perturbation and without any involvement in dance routines for at least one year (via prescreening interview) gave consent to participate in the study. Participants responded to a general health questionnaire in order to ascertain their health status. All participants with recent surgery or any musculoskeletal or cardiovascular conditions, which may hinder successful participation of the study and performance of dance, were excluded from the study. This laboratory-based study was conducted in the Cognitive Motor and Balance Rehabilitation Laboratory of the University of Illinois at Chicago.

5.2.2. Instrumentation

Kinematic data were simultaneously obtained with an 8-camera motion capture system (Motion Analysis, Santa Rosa, CA, USA) and 7 inertial sensors (size:47 x 30 x 13 mm; weight: 16g; MTw Awinda, Xsens Technologies, Enschede, Netherlands). The 7 inertial sensors were attached on the sacral region, thighs, shanks and middle toe of each foot. These inertial sensors are infused with tri-axial accelerometers, tri-axial magnetometer (±1.9g) and tri-axial gyroscopes (±2000º/sec), and therefore able to capture the position, joint angles (estimated from segment angles) and COM measurements of human motion (Gouwanda & Gopalai, 2015). To generate output data, the inertial sensors are calibrated for misalignment and the manufacturer's specifications show a static accuracy of ±1.5º and a dynamic accuracy of ±2.25º. By this calibration, the inertial sensors are able to provide accurate orientation angle data (yaw ψ, pitch θ, and roll φ) through built-in integration of gyroscope, angular rate and magnetic field vector estimations while addressing drift error by data filtering (Bolink et al., 2016). Real-time data from the inertial sensor unit are collected and automatically saved on a computer, with a sampling frequency of 100Hz (Manual, 2016). The 8-camera optoelectronic MOCAP system was able to sense infra-red rays emitted by 29 reflective markers (Helen Hayes marker set), which were attached to various segments or joints of participants such as the sacrum, thighs, shanks, knee and ankle joints to generate both position, segment and joint angles. The MOCAP system and the inertial sensor system were time-synchronized in order to record data concurrently.

5.2.3. Data collection and Processing

For concurrent validity, participants underwent one activity, which included dance movements to three songs of varying paces from slow, medium to fast. Data collected were processed by digitization via motion analysis and inertial sensor software to generate initial segment angle data. Then, further processing was completed by the use of a customized MATLAB code in order to generate absolute segmental angles of the lower limbs.

5.2.4. Tasks /Tests and outcome variables

5.2.4.2. *Dance*

For the dance activity, participants were asked to dance to three songs of slow (120bpm), medium (130bpm) and fast pace (138bpm). A protocol used by Ofori et al. in Chapter 2 (Ofori et al., 2019) was implemented to deliver songs or dance steps. The only variation with the protocol of Ofori et al. is that the three trial recordings for each dance song were set at a lesser time of 10 seconds in this study. Dance to each song was recorded three times and the average values of variables of these trials was used for analysis. For analysis, segmental angle excursions (difference between maximum and minimum angle peaks) of the right and left thigh (Rt and Lt thigh), right and left shank (Rt and Lt shank), as well as right and left foot (Rt and Lt foot) joints in the sagittal plane were compared between the two motion capture systems for equivalence and accuracy. The thigh and shank segment angles were determined by the calculation the angle between the body segment and the vertical axes, while the foot segmental angles were established by calculating the angle between the foot and the horizontal axis. The primary outcome measures, mainly segmental excursions, were computed using segmental method formulas which were proposed by Prieto and colleagues (Prieto et al., 1996) and this formula was also used for analysis in a previous study on dance (Ofori et al., 2019).

5.2.3. Statistical analysis

A paired t-test was performed to determine any significant differences between variables of inertial sensor and motion capture systems. A concurrent validity and reliability analysis via SPSS (IBM Corporation, Endicott, NY) was conducted in order to determine the similarity between the variables of interest during dancing with varying paces of song. Initially, Bland Altman plots and the determination of root mean square error (RMSE) were used to ascertain the validity and agreements of mobility variables between the two motion capture systems. Lastly, Pearson's correlation coefficient (R) and ICC were used to determine the agreement of variables between the inertial sensor and MOCAP systems, and p-values were reported. To demonstrate the effect of each song on each segment, correlations between each song pace and each segmental angle excursions were det ermined. Significant level, α, was set at 0.05.

5.3. Results

5.3.2. Dance

For the dance task, there were 42 data points (data from dance with all 3 song paces) obtained from 14 participants, which consisted of data for 3 dance songs from each participant. Data for 1 participant were excluded as a result of noise in data created by distortions in the inertial sensor system. Results conducted with paired t-tests for balance and mobility variables during the dance movements with three paces of songs showed no significant differences of variables between the two motion capture systems. The statistically results are as follows; Rt thigh ($t(41) = 0.49$, $p = 0.63$), Lt thigh ($t(41) = 1.97$, $p = 0.10$), Rt shank ($t(41) = 1.50$, $p = 0.14$), Lt shank ($t(41) = 1.49$, $p = 0.15$), Rt foot ($t(41) = 1.78$, $p = 0.10$) and Lt foot ($t(41) = -0.16$, $p = 0.87$). Additionally, Bland Altman plots and RMSE depicted that all the data were within 1.96 SD of absolute difference (see Figure 12). Additionally, correlation and ICC scores depicted moderate to high validity values for all segmental angle excursions. The correlation coefficient, R, and ICC scores of all songs for mobility variables included segmental angle excursions Rt thigh ($R = 0.71$; $ICC = 0.71$, $p < 0.05$), Lt thigh ($R = 0.60$; $ICC = 0.59$, $p < 0.05$), Rt shank ($R = 0.78$; $ICC = 0.77$, $p < 0.05$), Lt shank ($R = 0.85$; $ICC = 0.84$, $p < 0.05$), Rt foot ($R = 0.47$; $ICC = 0.45$, $p < 0.05$) and Lt foot ($R = 0.79$; $ICC = 0.71$, $p < 0.05$), see Table 11.

Table 11: Validity of segmental angle excursions during dance testing

Variable	R value	ICC	RMSE
Rt thigh_exc	0.71	0.71*	1.9
Rt shank_exc	0.78	0.77*	12.46
Rt foot_exc	0.47	0.45*	7.69
Lt thigh_exc	0.60	0.59*	9.79
Lt shank_exc	0.85	0.84*	13.06
Lt foot_exc	0.79	0.71*	9.28

Significant validity (R and ICC) was shown by * denoting $p < 0.05$.

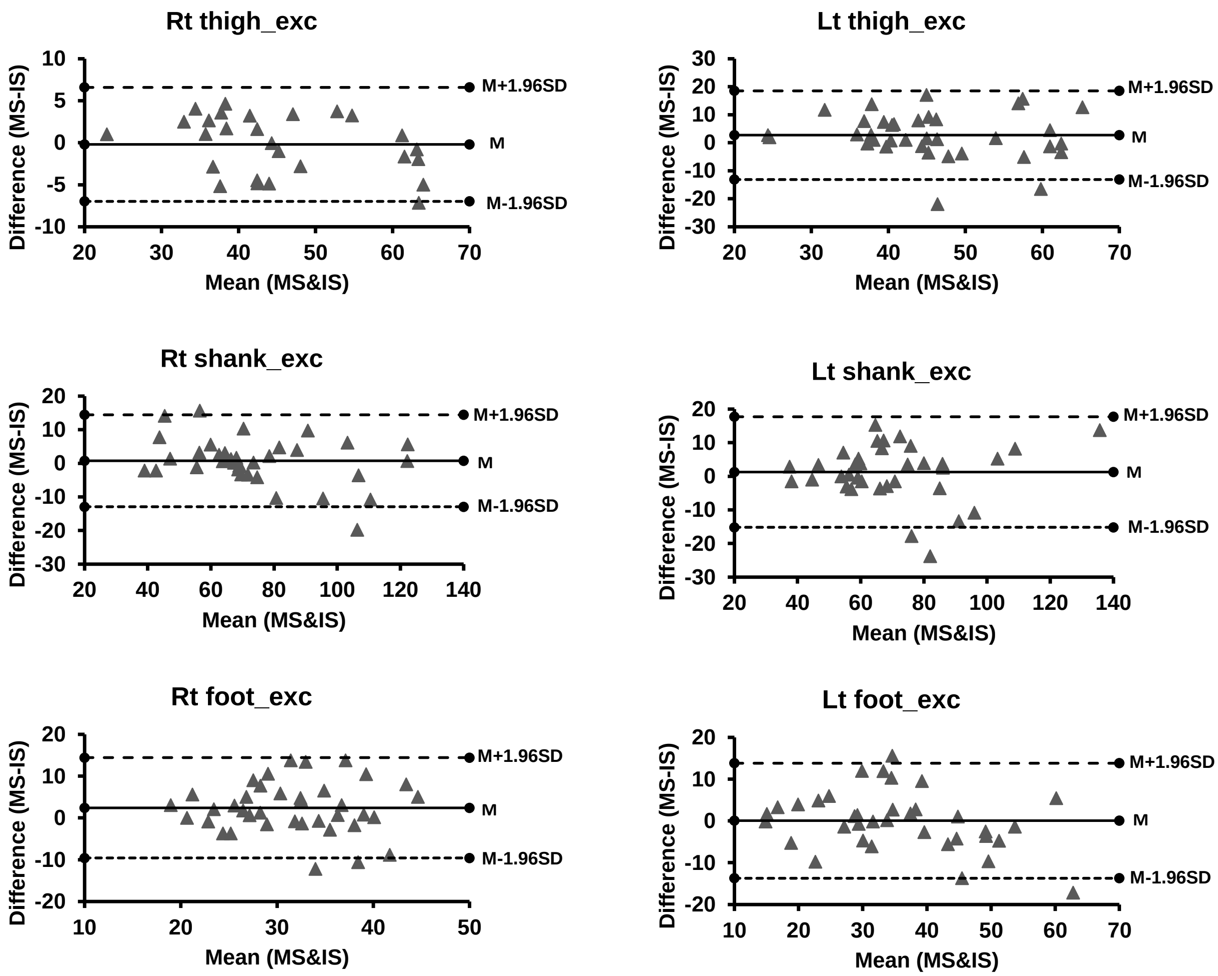

Figure 12: Bland-Altman plots of segmental mobility measures for motion (MS) and inertial sensor (IS) systems. The solid line represents the mean (M), while the two dash lines above and below M, represent the upper (M+1.96SD) and lower (M-1.96SD) limits of agreements (1.96 standard deviations) respectively.

5.3.3. Correlations between each song pace and joint mobility

For each song, there were good concurrent validity for joint mobility scores between the two motion capture systems because the R and ICC scores positively correlated with all segmental angles. Dancing with slow-paced song correlated highly with Rt shank and Lt foot angle excursions ($p < 0.05$). With medium-paced song, there were significant correlations with Lt shank and foot excursions, while dance with fast-paced song demonstrated significant correlations with all segmental angle excursions ($p < 0.05$), with the exception of the Lt foot excursion, see Table 12.

Table 12: Correlations between each song pace and segmental angle excursions

	Slow-paced song			**Medium-paced song**			**Fast-paced song**		
	R	**ICC**	**Cronbach's alpha**	**R**	**ICC**	**Cronbach's alpha**	**R**	**ICC**	**Cronbach's alpha**
Rt thigh_exc	0.28	0.38	0.44	0.38	0.53	0.55	0.77*	0.86	0.87
Rt shank_exc	0.80*	0.87	0.89	0.45	0.54	0.60	0.75*	0.72	0.72
Rt foot_exc	0.12	0.14	0.13	0.38	0.51	0.55	0.57*	0.67	0.67
Lt thigh_exc	0.41	0.41	0.52	0.25	0.36	0.39	0.53*	0.67	0.68
Lt shank_exc	0.35	0.47	0.52	0.79*	0.82	0.88	0.82*	0.58	0.86
Lt foot_exc	0.87*	0.93	0.93	0.73*	0.80	0.81	0.4	0.32	0.33

Significant validity (R) was shown by * denoting $p < 0.05$.

5.4. Discussion

This study demonstrated that motion analysis via inertial sensors possess high validity and could provide precise kinematic data on body segments compared with optoelectronic MOCAP system during the performance of dance. In this study, the mobility measures (segmental angle excursions) during dancing with varying paces of song were equivalent in both systems. This implies that the hypothesis of similarity and reasonably good agreement of values analyzed between both systems was adequately realized in this study. It should be noted that by further advanced processing, joint angles could be extrapolated from the segment angles presented in the results. Thus, segment angles will be referred to as joint angles in the following paragraphs.

The optoelectronic MOCAP has been predominantly explored in the data collection, processing and analysis of motion and reactive balance for varying populations in the laboratory setting because it is the gold standard for motion analysis (Bhatt et al., 2011; Pai et al., 2014; Patel & Bhatt, 2015). Albeit, the system comes along with logistical constraints and also results in potential minor measurement errors from soft tissue and skin artifacts resulting from the shifting of reflective markers (Bolink et al., 2016). Inertial sensors attached to the body segments via Velcro could serve as a rigid baseline that results in some minute errors in measurements compared to MOCAP (Vogt et al., 2003). Inertial sensors produce similar data of mobility and balance as MOCAP, but the sensors provide the added advantage over MOCAP that they can be utilized in the laboratory as well as in the community setting for data collection, processing and analysis via system-specific software (Agner et al., 2015; Bolink et al., 2016; Donath et al., 2016; Saber-Sheikh et al., 2010).

Dance is an emerging alternative intervention that is generally acceptable by every population group and is increasingly being implemented to improve gait, balance and mobility or range of motion (Al-Yahya et al., 2011; Subramaniam, 2015). Additionally, dance has been extensively studied in various populations such as young and old adults, to depict improvement in clinical measures such as Berg Balance Scale (BBS), Six Minute walk test (6MWT) and in Timed Up and Go (TUG) (Al-Yahya et al., 2011; Hackney & Earhart, 2009; Hackney et al., 2012; Subramaniam, 2015; S. Subramaniam & T. Bhatt, 2019), but these clinical measures are predominantly insensitive and possess floor effect (Martina Mancini & Fay B Horak, 2010). Therefore, the clinical gains of dance may not translate into real life situations. As such, MOCAP was resorted to in the analysis of data on dance in order to assess its effectiveness, since it can provide objective data of balance and mobility (Muyor et al., 2017). However, with dance being a social event enjoyed by all ages, there is the need to evaluate its effectiveness on balance and mobility with a tool such as lightweight and mobile inertial sensors, which provide same variables as the gold standard optoelectronic MOCAP (Bolink et al., 2016). Reporting of data on excursions of the joint or a segment of the body in study is vital because they provide an estimate of the extent or range of joint movement from smallest to the largest joint or segment angle in order to difference the performance of dance with varying paces of song. Our study also revealed moderate to high correlation coefficients and ICC as the absolute agreements and accuracy of joint angle excursions were compared between inertial sensors and MOCAP systems. This shows that there was high validity of inertial sensors in the evaluation of joint angle excursions during the performance of dance with varying paces of song. It also demonstrated that inertial sensors may be a great tool for assessing joint angle excursions during the performance of dance. With dance being cyclical and depicting similar attributes to gait, studies on gait and other daily activities also revealed high validity of inertial sensors in analysis with joint angles (Bolink et al., 2016; Buganè et al., 2014; Takeda et al., 2009) and agreement of variable values between inertial sensor and MOCAP systems (Buganè et al., 2014; Takeda et al., 2009). These results could provide increased assurance in analysis of kinematics of dance movement by the use of inertial sensors. Inertial sensors could therefore serve as the ideal tool for data collection, analysis and the evaluation of the effectiveness of dance therapy implemented mostly in the home or community settings for the advancement of community-based therapy.

The results of this study also demonstrated that as song pace increases, the positive correlations and the concurrent validity also increases. It suggests that inertial sensors produced accurate measures of mobility in the shank and foot with slow-paced and medium-paced songs and then proved to be highly valid and reliable for assessing all segmental angles of the lower extremity with fast-paced song. It also implies that inertial sensors showed high validity for evaluating each segmental angle during dancing. It therefore suggests that inertial sensors may produce highly accurate values of all segmental angles of the lower limbs and that different song paces for dance could be used to achieve specific goals in specific segmental angles with the use of inertial sensors. For instance, with high R scores with inertial sensors, it may imply while slow and medium-paced song may be conducive for assessing and improving mobility of the knee and ankle joints, dance with fast-paced song will be beneficial in evaluating all joint angle excursions of the lower extremities. These results indicate that the type of song should influence the goals of evaluating and training the mobility of a specific joint (Table 12).

This study was able to demonstrate concurrent validity of inertial sensors by showing that analysis of mobility outcome measures during dancing could be performed with inertial sensors with high accuracy, similar to the MOCAP systems. Though there are scanty evidence on studies on dance training, which have been conducted with MOCAP system, this study showed that studies on dance therapy could be also conducted to determine its effects on kinematics of mobility with inertial sensors. With the determination of the moderate to high validity of inertial sensors for assessing balance and mobility kinematics of various activities such as dancing, we can confidently obtain object clinical data that will provide assurance for clinicians to evaluate the progress of patients' home therapy. Additionally, with the current momentum shifting towards the translation of research into the daily activities of healthy young people, older adults and individuals with neurological conditions such as stroke, the increased validity and reliability of inertial sensors will pave the way for the increased home or community-based research and conduct objective assessment of balance and fall risk of participants during.

Table 13: Summary of results for study 4 (concurrent validity of inertial sensors vs MOCAP)

Outcome variables	Results
Validity for all songs	• Concurrent validity was high for inertial sensors and MOCAP from for all segmental angle excursions during dance-based exergaming with all songs.
Validity for each song	• Concurrent validity was high for inertial sensors and MOCAP from for all segmental angle excursions during dance-based exergaming for each songs. • Specifically, inertial sensors proved reliable for assessing shank and foot range of motion (ROM) during dancing with SP and MP songs. • While, inertial sensors showed improved validity for evaluation of all segmental ROM during dancing with FP song

Chapter 6: Conclusion and future directions

Physical inactivity leads to deterioration of cognition, gait, balance and cardiovascular endurance in older adults, individuals with MCI and those with other neurological conditions. Further, reports have indicated that only a few older adults in the United States achieve the recommended physical activity (PA) levels to maintain health outcomes (Billinger et al., 2014). As such, 28-34% of adults 65 to 74 years old are physically active. As a result, there is frequent falls in older adults, which is doubled in older adults with MCI. Recent studies have shown an older adult's compliance with dance-based therapy is comparatively higher than conventional therapy (Subramaniam, 2015) . Furthermore, dance activates the brain centers that help in cognition, balance control and ambulation, and application of such interventions leads to an increase in long-term compliance with PA (Gordon et al., 2004; Michael et al., 2005). Therefore, it is obvious that many conventional and emerging alternative forms of rehabilitation methods target the incorporation of improvement in physical function. This dissertation proposes a holistic approach to focus on cognition, gait, balance and physical fitness in an attempt to increase PA and community ambulation in older adults with MCI.

To arrive at this training protocol for dance-based exergaming, an assessment method for the analysis of postural stability (center of mass) and mobility was established for young adults (Chapter 2). This method was then extended by implementing the protocol in healthy older adults (Chapter 3). These two studies formed the basis for development of a training program for older adults with MCI. In order to translate the benefits of our training protocol to clinical, home and community settings, we conducted a validity study of inertial sensors for proper data collection of postural stability and mobility measures (Chapter 5).

In the decade ahead, inertial sensors will be extensively utilized as the tool to translate the benefits of dance-based exergaming to the clinics, homes and communities of older adults with MCI and those with other neurological disorders, such as stroke and Parkinson's disease. The above-mentioned studies formed the foundation for designing the study on the feasibility and effectiveness of the dance-based exergaming training paradigm on cognitive, gait, balance and physical fitness in older adults with MCI (Chapter 4). This study's results showed most improvements of the variables in the domains studied and can provide enough confidence to introduce a dance-exergaming as a PA option in the homes and communities of seniors with MCI.

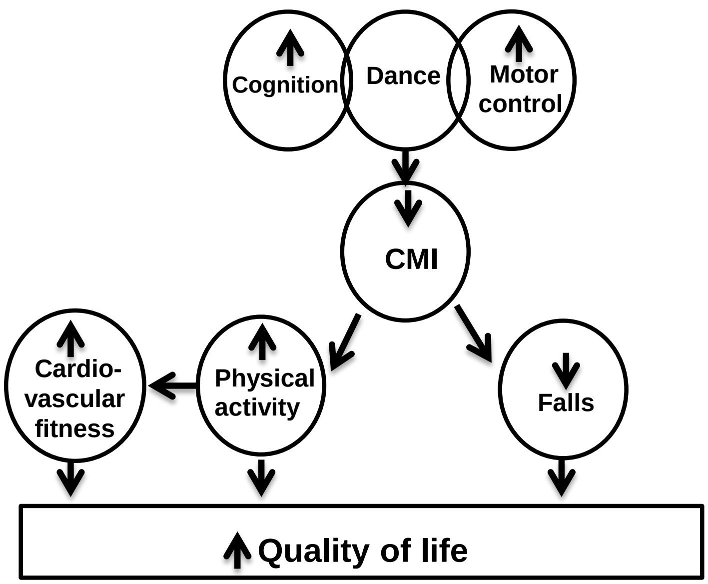

Figure 13: Schematic of the conceptual framework.

Although dance rehabilitation has the potential to address all of the above features, implementation of dance rehabilitation is tedious, resource-intensive and costly. Recently, VR-based dance training using the commercially available off-the-shelf Kinect gaming system has shown to be feasible, cost-effective, customizable, controllable, and able to provide multi-modal simulations of real-life environments (Haeuber et al., 2004). Thus, the proposed dance-based exergaming paradigm can primarily address the challenges of linking multiple domains of the ICF (International Classification of Functioning, Disability and Health), specifically reducing impairments at the body function/structure level (e.g., cognition levels), activity level (e.g., increased PA) and community participation level (e.g., increased community integration). Secondly, as the training protocol was provided via the cost-effective Kinect system, makes the training economical, with the potential to lower health care costs. In addition, this protocol can provide motivation, activity enjoyment, which are vital for long-term PA adherence. The studies in this dissertation will serve to provide pilot data on efficacy for power analysis and sample size calculation to seek extramural funding to run a larger RCT. In addition, the results will assist to develop a protocol to transition therapy to caregivers via appropriate training and remote supervision via economical technological platforms such as Skype or Zoom.

In conclusion, the results of this dissertation demonstrated the development of assessment protocol for postural stability and mobility during dance-based exergaming in young adults and in healthy older adults. In addition, the results of this dissertation showed that dance-based exergaming was feasible, safe and had an optimal compliance rate similar to other studies conducted in older adults. Furthermore, dance-based exergaming had positive effects on most variables of cognitive and gait functions in older adults with MCI. Moreover, the results also showed some progressive results in outcomes of volitional and reactive balance, clinical balance and functional measures required for the performance of activities of daily living (ADLs) in older adults with MCI. Lastly, this dissertation gave promising results by increasing PA scores during dance-based exergaming. For the translation of benefits of dance to the clinics, home and community of older adults and to assess of effectiveness of dance-based exergaming training, inertial sensors, which proved to be highly valid and reliable for determining measures of mobility during dancing, will be very useful. With an appropriate study design (RCT), dance-based exergaming could serve as a home-based PA to enhance adherence, cardiovascular endurance and other functional measures for an improved quality of life in older adults.

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APPENDIX

Approval Notice

Continuing Review

November 6, 2019

Tanvi Bhatt, PT, MS, PhD

Physical Therapy

Phone: (312) 355-4443 / Fax: (312) 996-4583

RE: **Protocol # 2018-1074**

Effectiveness of alternative therapy for improving cognition, balance, and physical activity in order adults with mild cognitive deficits for home or community-based translation

Dear Dr. Bhatt:

Your application was reviewed and approved by the Convened review process on November 6, 2019. You may now continue your research.

Please note the following information about your approved research protocol:

Please note: if you wish to continuing enrolling subjects, you must submit an amendment to increase enrollment numbers.

<u>Protocol Approval Period:</u> November 7, 2019 - November 6, 2020

<u>Approved Subject Enrollment #:</u> 20 (19 currently enrolled)

Performance Sites: UIC

Sponsor: National Institute on Aging

Institutional Proposal (IP) #: P30AG022849
Grant/Contract No: Not available
Grant/Contract Title: Not available
Research Protocol(s):

a) Protocol- Alternative therapy for improving physical function, Version 3, 10-24-18

Documents that require an approval stamp or separate signature can be accessed via OPRS Live. The documents will be located in the specific protocol workspace. You must access and use only the approved documents to recruit and enroll subjects into this research project.

Recruitment Material(s):

a) Flyer; v2, 10.24.18
b) Phone Screening; v 4, 9/24/2019
c) Recruitment presentation; 10.03.18
d) Ad for Television, Radio, Recruitment Email; v, 08.30.18

Informed Consent(s):

a) Exception to informed consent for the purpose of screening, recruiting, or determining eligibility of prospective subjects [45 CFR 46.116(g)].
b) Consent- Alternative therapy for improving physical function, Version 5, 11-5-19

Additional Determinations for Research Involving Minors:

These determinations have not been made for this study since it has not been approved for enrollment of minors.

Please remember to:

→ Use your **research protocol number** (2018-1074) on any documents or correspondence with the IRB concerning your research protocol.

→ Review and comply with the policies of the UIC Human Subjects Protection Program (HSPP) and the guidance ***Investigator Responsibilities.***

Please note that the UIC IRB has the prerogative and authority to ask further questions, seek additional information, require further conditions, or monitor the conduct of your research and the consent process.

Please be aware that if the scope of work in the grant/project changes, the protocol must be amended and approved by the UIC IRB before the initiation of the change.

We wish you the best as you conduct your research. If you have any questions or need further help, please contact the OPRS office at (312) 996-1711 or me at (312) 413-4060. Please send any correspondence about this protocol to OPRS via OPRS Live.

Sincerely,

Samantha S. Bettinger, MS
IRB Coordinator, IRB # 1
Office for the Protection of Research Subjects

cc: Ross Arena, Physical Therapy, M/C 898
OVCR Administration, M/C 672

Date: 07/15/2020

Dear Editorial Board of the Journal of Physical Therapy Science,

I am preparing
Book/Journal: Dissertation/Thesis (Not yet Published) (Vol. No.)
Article title: Dance-based exergaming in older adults: Effect on movement Kinematics & physical functioning.
Author(s): Ernest Kwesi Ofori
Publisher: University of Illinois at Chicago (UIC) Library & Proquest

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Journal: Journal of Physical Therapy Science (Vol. 31 No. 9)
Page: 708 - 716
Article title: Kinematic analysis of dance-based exergaming: Effect of song pace on Center of mass & joint mobility
Authors: Ernest Kwesi Ofori, Savitha Subramaniam, Shuaijie Wang, Tanvi Bhatt
Figures/Tables/Lines: 7 : 5 tables and 2 figures

Full acknowledgement will appear in legends for the figures as follows:
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Yours sincerely,

Name: ERNEST KWESI OFORI

Affiliation: University of Illinois at Chicago (UIC), USA

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Date: July 16, 2020

Signature

President, Society of Physical Therapy Science

VITA

ERNEST KWESI OFORI

EDUCATION

PhD (Rehabilitation Sciences) August 2015 - Present
University of Illinois at Chicago (UIC)
Master of Science (Biomedical Engineering) August 2011 - May 2014
Southern Illinois University, Carbondale (SIUC)
Bachelor of Science (Physical Therapy) August 2003 - August 2007
University of Ghana

LICENSURE

- Eligible for Physical Therapy Licensure in most states of the United States
- Ghana Physiotherapy Association Permanent Registration

PEER-REVIEWED PUBLICATION

1. Frimpong, E., **Ofori, E. K**., Kaoje, Y. S., Ababio, E., & Dzudzor, B. (2019). Muscle Damage and Repeated Bout Effect from High Intensity Non-Eccentric Exercises. *Journal of Exercise Physiologyonline*, *22*(5).
2. **Ofori, E. K**., Frimpong, E., Ademiluyi, A., & Olawale, O. A. (2019). Ergometer cycling improves the ambulatory function and cardiovascular fitness of stroke patients—a randomized controlled trial. *Journal of physical therapy science*, *31*(3), 211-216.
3. **Ofori, E. K**., Subramaniam, S., Wang, S., & Bhatt, T. (2019). Kinematic analysis of dance-based exergaming: effect of song pace on center of mass and joint mobility. *Journal of physical therapy science*, *31*(9), 708-716.
4. Teah, G., & **Ofori, E**. (2016). Kinematic analysis during an Xbox Kinect virtual-reality based dance in aging and stroke: A Cross-Sectional Study. *Journal of Kinesiology and Nutrition Student Research*, *4*.
5. **Ofori, E. K**. (2014). Effect of optogenetic stimulation on neuroplasticity of the embryonic chick motor system (MS Thesis).
6. **Ofori, E.K** (2007). Effect of ergometer cycling on ambulation in post-stroke patients – University of Ghana College of Health Sciences Library (BS Thesis)
7. **Ofori** & Bhatt. (Under review). Kinematic analysis of dance-based exergaming: cross-sectional study

PRESENTATIONS/CONFERENCES ATTENDED

1. Poster presentation – (**Ofori**, Teah, Subramaniam & Bhatt) *Kinematic analysis dance-based exergaming in aging and stroke: A Cross- Sectional Study* **-** Statewide Conference for Diversifying Faculty in Illinois (DFI) Fellows, NIU DeKalb, Illinois, February 15-16, 2019.
2. Discussion panelist - TRIO/UB/UHP Health Sciences Conference- Health Sciences Careers High School Conference, UIC Student Center West, Chicago, April 20, 2019.
3. Participant - 27th Annual Illinois Latino Council on Higher Education (ILACHE) Professional and Student Development Conference **–** Isadore and Sadie Dorin Forum, UIC**,** Chicago, April 19, 2019
4. Participant - University of Illinois Chicago Aging & Health Symposium, May 21, 2019
5. Poster presentation – (**Ofori**, Teah, Subramaniam & Bhatt) Kinematic *analysis during a Kinect virtual-reality based dance in aging and stroke: A cross sectional study*- ISPGR World Conference – June 26-30, 2017, Fort Lauderdale, Florida.
6. Poster presentation – (Teah, **Ofori**, Subramaniam & Bhatt) *Kinematic analysis during a Kinect virtual-reality based dance in aging and stroke: A cross sectional study* - UIC RARE scientific presentation –April 15, 2016.
7. Podium presentation: **Ofori, EK** (2014): *Effect of optogenetic stimulation on neuroplasticity of embryonic chick motor system* - 2015 Midwest American Society of Biomechanics (ASB) Regional Meeting at the University of Akron, Akron, Ohio – February 17-18th, 2015.

MINI COURSE PROJECT

- Creation of Wikipedia page on the topic (Spring 2017): 'Key determinants of gait' available at *https://en.wikipedia.org/wiki/Key_determinants_of_gait*,

POSITIONS

Research Assistant August 2015 - Present
Cognitive, Motor and Balance Rehabilitation Laboratory, University of Illinois at Chicago, Physical Therapy

Student Coordinator/Tutor March 2017 – August 2018 & May 2019 - Present
University of Illinois at Chicago, Urban Health Program (UHP), Applied Health Sciences

Fitness Attendant/Supervisor January 2016 - January, 2017
University of Illinois at Chicago Sports and Fitness Center

Teaching Assistant August 2015 - December 2015
University of Illinois at Chicago Department of Physical Therapy Anatomy (PT 603 –Gross Anatomy)

Research Assistant July 2012 - August 2014

SIU School of Medicine Anatomy/Biomedical Engineering Lab, Carbondale Illinois.
Junior Physiotherapist December 2007 - December 2008
Tema General Hospital Physiotherapy Department Ghana, West Africa

SCHOLARSHIPS/GRANTS/FELLOWSHIPS

Diversifying Higher Education Faculty in Illinois (DFI) Predoctoral Fellowship 2018 - Present
Illinois Board of Higher Education

Roybal Predoctoral Research Grant (Grant No. P30AG022849) 2018 - Present
National Institute of Aging of the NIH

HONORS AND AWARDS

- UIC Chancellor's Student Service & Leadership Award 2018, 2019 & 2020
- Urban Health Program Student Leadership Award 2017, 2019 & 2020
- College of Applied Health Sciences Student Leadership Award 2017, 2019 & 2020
- UIC Research Open Access Article Publishing (ROAAP) Fund Award 2018 & 2019
- Best Lab researcher/student of the month 2019
- College of Applied Health Sciences Scholarship Fund Award 2016
- Lillian Torrance scholarship award 2016
- Van Doren Scholarship 2017
- MLK Scholarship Award 2017-2018

AFFILIATION

- Member – International Society of Posture and Gait Research 2016 - Present
- Basic Life Support for Healthcare Certified – American Red Cross Society May 2015 – Present.