WALKING TO METRICALLY CUED MUSIC: HOW IT AFFECTS GAIT AND BALANCE IN HEALTHY OLDER ADULTS

by

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ABSTRACT

DARRYL GRANT. Walking to metrically cued music: how it affects gait and balance in healthy older adults. (Under the direction of ABBEY THOMAS FENWICK)

Introduction: Gait impairments are a major cause of falls in older adult populations, associated with decreased functional capacity and increased morbidity. Recent studies have reported using rhythmic auditory stimuli to positively influence motor skill capacity. It is likely that rhythmic auditory stimuli may present a means to improve gait and, therefore, function in healthy older adults.

Objective: To examine the efficacy of auditory isochronous stimuli (AIS) at improving gait and balance in healthy older adults.

Methods: Thirty-five recreationally active healthy older adults participated in this study. Participants completed a baseline testing session consisting of clinical tests for functional performance and fall risk, and a plantar region analysis of gait. This was followed by a 4-week walking intervention. Participants either walked while listening to music including AIS (CLICK), walked while listening to music without AIS (MUSIC), or simply walked for 30 minutes 3x/week. Following the intervention, participants repeated clinical tests and gait analysis. Clinical tests for functional performance and fall risk included a timed up and go (TUG) test and unipedal stance test (UPST). Gait analysis was conducted with the Pedar-X insole system while participants walked at a comfortable speed for a distance of 30 feet. All clinical test and gait analysis outcomes were analyzed using group × time repeated measures ANOVAs. Tukey's *Post hoc* analysis and paired samples t-tests were conducted in the event of significant interactions. Statistical analysis was performed using SPSS (v24, IBM Corporation, West Armonk, NY). Alpha was set *a priori* at $P<0.05$.

Results: There was a significant group × time interaction for TUG ($P=0.044$). Additionally, there was a significant time main effect, suggesting improved TUG times at post-testing compared to baseline ($P=0.046$). *Post hoc* analyses revealed that the CLICK group improved their scores from baseline to follow-up ($P=0.035$).

Gait data revealed no significant group × time interactions for any variable. There was, however, a significant time main effect for stride time suggesting that regardless of group, participants demonstrated lower post-test stride times compared to baseline ($P=0.031$).

Conclusions: Walking while listening to music that included AIS improved TUG test performance in healthy older adults. This intervention had minimal effects on gait. Given the association between TUG time and fall risk, it appears that walking while listening to music with embedded AIS can be an effective intervention to reduce fall risk in community dwelling, older adults.

DEDICATION

To my parents Edward and Gunnhild Grant, and my uncle Richard Grant. Your endless support of my pursuits – on, off, and back on the academic track, is why this was possible.

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CHAPTER 1: INTRODUCTION

Walking is often perceived as an automated task; an indiscriminate rhythmic action that, once learned, involves no consideration or cognitive contribution. In the past decade studies have challenged this notion, proposing a much greater involvement of higher cognitive function in the motor planning of walking. (Sheridan, 2007) The role of motor planning is to continuously modify the pattern of gait as needed to accomplish a task through a complex integration of cognitive, proprioceptive visual and vestibular information (Wunsch, 2017). Between the voluntary effort to achieve a goal and the involuntary modifications to navigate one's environment, there are conscious and unconscious processes at work in walking reflective of this aspect of executive function. (Haworth, 2008). Recent evidence suggests that music may mitigate motor planning.

The ability to recognize the metrical rhythm of certain stimuli is necessary for a variety of human behaviors, from prediction of an object's line of movement to language comprehension. Studies show that, not only do humans possess the ability to spontaneously produce metric rhythms with simple tasks such as tapping, they reproduce metrical rhythms with greater accuracy than they do non-metrical rhythms (Hikosaka, 1999; Essens and Povel,1985). It has been further postulated that through familiarization of rhythmic interval durations, humans may also improve their motor ability timing (Meegan,et al., 2000). Analysis of gait with an external auditory rhythm present showed lower variability and increased focus of electromyographic (EMG) activity among patients with brain injuries (Thaut and McIntosh, 1992). Likewise, EMG activity also exhibited decreased variability in hemiplegic patients, presenting itself in improved double stance time and stride symmetry (Prassas and Rice, 1993). Furthermore, in patients with Parkinson's Disease, rehabilitation with accompanying auditory cues resulted in a more rhythmic gait cycle as well as improved postural stability (Miller et al., 1996). Collectively these studies show that the application of an auditory rhythm in addition to gait rehabilitation, may improve fine and gross motor control, postural reflexes, and gait patterns (Paul and Ramsey, 2000).

As humans age, gait changes. Specifically observed are decreased gait speed and step length along with increased step width and double support time (Woo, 1995). These changes are speculated to encompass an adaptive change to better maintain balance and establish a more stable platform for visual and vestibular responses (Woo, 1995). The choice of older adults to walk at a speed below their ability raises the concern of motor planning limitations at play instead of a decline in automated motor processes (Haworth, 2008). For, while cognitive activity is a healthy process of the brain, motor planning requires time. This represents time that, when summed up in measures of latency, can be detrimental to reaction times in stabilizing the body, hindering corrective responses to potential falls. It has been put forth that interventions improving planning and purposive action may be beneficial to the locomotive process if the time for obstacle recognition and fall recovery can be accelerated (Lezak, 2004). In turn, interventions bringing about an improvement in motor actions may signify potential improvement in the planning of human locomotion.

With walking as an activity for health maintenance in older adults, and music, providing a motivational source for exercise, further accentuation of rhythmic intervals within the music, via AIS may theoretically improve motor control processes during walking more so than music alone. This would, in turn, allow for increased independence of daily activities and, ultimately, improved quality of life. Understanding if music can influence gait is an important first step to understanding music's ability to influence motor planning and higher cognitive function. Therefore, the purpose of this study was to investigate the influence of AIS within music on the gait and balance of healthy community-dwelling older adults. This study looked at the differences among three groups of individuals following participation in a four-week walking program. While walking, one group listened to music of their choosing (MUSIC); a second group listened to music of their choosing as well as integrated isochronous cues (CLICK); and a third group walked without music (CONTROL). This study aimed to show that music reinforced with an AIS may further strengthen the synchronization between auditory and motor pathways such that, when applied over time to locomotive action, will result in changes of gait and balance measures.

Specific Aim 1: To determine if older adults who walk while listening to AIS in music improve their gait more than older adults who walk without this auditory stimulus.

Hypothesis 1.1: Older adults in the CLICK group would demonstrate increased gait speed, single support time, and swing time with concurrent decreases in contact area, contact time, stance time, stride time, and double support time compared to the MUSIC and CONTROL groups.

Specific Aim 2: To determine if older adults who walk while listening to AIS in music improve their functional performance more than older adults who walk without this auditory stimulus.

Hypothesis 2.1: Older adults in the CLICK group would demonstrate improved static (single leg) and dynamic (timed up and go [TUG] test) balance compared to the MUSIC and CONTROL groups.

1.1 Operational Definitions

ADL – activities of daily living

AIS - audible isochronous stimulus

EMG - electromyographic activity

TUG test - Timed Up and Go test

UPST - Unipedal Stance Test

Isochronous - at equal time intervals

Metric Rhythm - a regular, recurring pattern of strong and weak beats.

Non-Metric Rhythm - lacking a strong sense of beat or rhythm

OA - osteoarthritis

Stance Time - the cumulative amount of time in a gait cycle while either a single foot or both feet are in contact with the ground.

Swing Time - the time in a gait cycle while the foot of a single limb has no ground contact.

CHAPTER 2: REVIEW OF RELATED LITERATURE

The purpose of this literature review is to detail: 1) gait and associated age-related changes in walking; 2) perception of rhythm sequences; and 3) how rhythm plays a role in human movement.

2.1 Implications of Age-Related Changes in Locomotion

A normal gait cycle encompasses the actions occurring between the time one foot touches the ground and the time the same foot touches the ground again. The duration of these actions includes the stance time and swing time for each leg, as well as a double stance time when both feet are on the ground providing support for weight transference from one leg to the other (Haworth, 2008). In normal gait the swing time accounts for 40% of the cycle, the stance time 60%, and the double stance time(s) for 10% each. Likewise, stride to stride variability is a measure (Whittle, 2007).

Standing and walking are sensorimotor tasks that are developed in childhood. Following childhood, these tasks are performed because of executive function, as significant cognitive input is necessary to modify these well-learned skills (Haworth, 2008). Control of locomotion and posture relies on an organized network of pattern generators that allows for an intricate interplay between afferent (sensory) and supraspinal motor pathways. With aging, these sensorimotor tracts suffer a natural functional decline in conjunction with waning neuromuscular systems and restructuring of the brain. Studies have shown that older adults incorporate higher level sensorimotor cortical areas during motor tasks, suggesting a greater reliance on cognitive input and cortical sensory processing for movement control (Heuninckx et al., 2008). In this scenario, control of gait shifts to a level of greater conscious awareness and motor planning.

With empirical, age-related changes growing self-apparent to the older adult, their level of conscious directive over ambulation promotes what is known as a “cautious gait” (Nigg et al., 1994). This manner of locomotion presents changes in gait measures of speed, length, width, and stance time. Older adults essentially exhibit a slower walking speed comprised of a greater number of shorter steps traversing over a wider base of gait. Likewise, increased time spent in the double-stance phase of the gait cycle inhibits overall gait speed (Prince, 1997). Older adults walking with a cautious gait also commonly exhibit a decline in the initiation of voluntary protective steps—the rapid-response steps necessary for recovery of a postural perturbance to one’s walking pattern (McIlroy, 1996). This decline in responsive initiation is a possible reflection of poor motor planning. In relevance to activities of daily life, this is concerning as it raises the question whether older adults fall increasingly with age because they trip and stumble more frequently or because they lack the recovery capacity after a gait disturbance has occurred (Pizzigalli, L., 2011)

Despite the cause, yearly approximately one-third of older adults (≥65 years of age) sustain fall related injuries; incurring increasing direct medical costs. The U.S. Center for Disease Control and Prevention predicts that by 2020 this will approach a financial toll of $55 billion (Stevens, 2005). Because falls come about from impairments in more than one domain, interventions to their prevention must likewise focus on more than one area. Gait, balance, and self-confidence are three of the areas that carry the most impact within multifactorial interventions (Chang, 2007; Kumar, 2013). Therefore, developing effective and engaging interventions to decrease fall risk is imperative to not only improving the health and safety of our older adults, but also to decreasing the financial burden these injuries place on our healthcare system.

2.2 Perception and Entrainment of Rhythm Sequences

The perception of a rhythm sequence requires predicting sensory stimuli in time and it has been suggested that this sensory prediction shares a reliance on the same internal mechanisms that govern the motor planning processes prior to action initiation (Engel, 2001). The synchronization of movement with music has been greatly studied, with a growing focus on the aspect of spatialization and movement between successive synchronization points. In this aspect, latency and reaction time may be analyzed as well as the directional intention of one's gait movement. It is established that a startling auditory stimulus can trigger the release of a prepared motor response at a shorter latency of a voluntary reaction task (Valls□Solé, J., 1999). Similarly, it may be possible that rhythmic entrainment of an auditory stimulus may shorten the reaction time of a voluntary task. With an improved role of the body as a mediator for music perception and rhythm prediction, an older adult's protective stepping measures may require less cognitive processing, which is evident in faster initiation and more accurate leg placement (Maranovic, 2015). Hence, the voluntary protective steps required in the response to gait disruptions and potential falls may transition to a less voluntary, more automated reaction.

2.3 Rhythm Entrainment and Body Movement

Moving the body to music is also a matter of synchronization with fixed points as well as bridging a connection between these points (Styns, 2007). Evidence of this connection was examined in Bengtsson's work with neural processing of temporal regularities. Functional magnetic resonance imaging (fMRI) showed greater activity in the superior prefrontal cortex when listening to metric rhythm intervals versus a single isochronous interval, making the argument that complexity of rhythm is an important factor in modulating and preparing motor activity (Bengtsson, 2008). Grube and Griffiths (2008) reinforce this argument with studies supporting increased accuracy of (temporal) pattern encoding for rhythm sequences of higher metric complexity. Complexity of meter, therefore, holds importance in the process of rhythm entrainment as a framework to shape one's perceptions and predictions of temporal regularities within a rhythmic sequence (Grube, 2008).

Although bodily movement to music is a common manifestation in listeners, with neural crosstalk between perception and action, the question arises: Does bodily movement actively assist the processing of temporal structures? The temporal structure of focus is the pulse which, in music, is considered a series of balanced, identical psychological events arising endogenously in response to a rhythm (Cooper, Meyer, 1960). As a subjectively experienced isochronous process, identifying the pulse represents the basic principle of rhythmic entrainment to auditory stimuli.

Following from this principle, Todd et al. proposed the "sensorimotor theory" of temporal tracking, emphasizing the body's inherent motor representation of sensory input as a tracking and synchronizing mechanism (Todd et al,2002). The importance of body movement is further explored in Su and Poppel's study of musically trained and untrained subjects. In their research, participants sought not to move to a previously extracted pulse but began moving (foot tapping) as soon as a sequence of tones began.

Doing so required them to use an overt motor action to aid in "tuning" to the rhythm of the pulse (Su and Poppel, 2011). The success of this task by participants with no musical training is evidence of an inherent positive audio-motor feedback loop. Their movement, which may not have initiated in sync with the sequence of tones, did so progressively because of a possible attraction to the underlying rhythm (Repp, 2006). Essentially, body movement supplementary to the search for a pulse may apply a "hearing by moving" strategy to the auditory entrainment process.

2.4 Anatomical Support for Neurological Music Therapy

Although some gait deficiencies may improve with pharmacological therapy, they often can be resistant to medication(s); over time, becoming the most incapacitating aspect of these conditions. Neurological Musical Therapy (NMT) has been a field exploring the benefits of music as rehabilitative auditory stimulus for some time, utilizing the symbiotic mechanisms of the audio-motor neural pathway (Nombela, 2013). Anatomical design offers the backdrop for proposing that sound has direct influence on spinal motor neurons (Nodal and Lopez, 2003). The connection between cochlear root neurons and the reticulospinal neurons constitutes one of the shortest sensorimotor circuits in the auditory pathway, seen in the significantly reduced muscle response time of the "startle reflex" (Thaut, 2003). Within the reticular pathway, auditory information is integrated with sensory information and prioritized by the brain. Should this priority be the initiation and propagation of gait, rhythmic audible stimuli supplemental to music may directly increase excitability in pattern generating neurons already housing prepared locomotive action and anticipatory gait responses. The higher level of cognition at work in older adults as they walk places the directive(s) for gait and balance, by default, at a heightened priority. In this context, the top down command for locomotion is primed and awaiting the modulating input of rhythmic audible stimuli. The magnet effect of these modulated stimuli on rhythm perception, prediction, and subsequent body movement is what this study aims to magnify in order to improve gait and balance measures in community-dwelling healthy older adults.

2.5 Conclusion

In older adults, changes in gait and balance may represent a manifestation of higher cognitive processing. Higher pre-motor cortical activity during tasks such as walking possibly stems from an increase in precautionary thinking and planning prior to action. Should the latency prior to action be minimized, walking and balance control might become more automated actions. Walking to music has proven beneficial to older adults' health, both physical and cognitive. Because the auditory and motor neural pathways are closely linked, there lies potential in developing motor pathways in "piggy back" fashion to audio-sensory pathways. This involves entrainment of one's bodily actions adjunct to his or her auditory perception. Rhythmic movement of one's body, or the pursuit thereof, may in turn further heighten one's audio-sensitivity to rhythmic meter. Walking to music with accentuated isochronous cues may essentially bolster this cyclic effect. As the motor and audio-sensory pathways symbiotically serve one another, they both stand to grow and benefit. With stronger pathways for both in place, the initiation time for step placement may decrease. It is in this context that the benefits may serve the older adult community. Based on the assumption that a number of human planning skills are supported by intact executive functions, motor planning skills should decrease as people grow older (Lezak, 2004). Making the rhythmic processes of walking second nature, makes a clinically recommended activity accessible once again to a population in danger of growing more sedentary.

CHAPTER 3: METHODS

3.1 Participants

Forty-five healthy, community dwelling, older adults participated in this study. Inclusion criteria required that participants must have: 1) been 65-85 years of age; 2) been able to understand English; 3) had no diagnosed cognitive impairment that would prevent completion of surveys or consent forms; 4) had no diagnosed balance impairment; 5) had no restrictions by a physician from walking; or 6) needed no physical assistance from another individual or device (i.e. walker, cane, etc.) to perform activities of daily living. Participants were excluded if they had not been consistently physically active for the previous 3 months or failed to meet any of the inclusion criteria. The Institutional Review Board at University of North Carolina at Charlotte approved this study.

3.2 Study Design and Randomization

This study utilized a quasi-randomized controlled experimental design. Participants were recruited from two senior centers in the Charlotte Mecklenburg region. Participants from one senior center were randomized into one of 2 walking groups, walking to music with AIS (CLICK) and walking to music without AIS (MUSIC). Randomization occurred following completion of baseline data collection by means of a sealed, opaque envelope containing group assignment. Randomization was performed using an online random number generator with stratification by participant sex. The other senior center served as the control location. Control participants walked without music (CONTROL).

3.3 Data Collection

Data were collected before and after a 4-week walking program. All participants completed identical assessments at the baseline and follow-up time points.

The International Fall Efficacy Scale (FES-I) measured confidence in performing a range of activities of daily living (ADL) without falling. This scale reliably correlated with measures of balance and gait (Dewan, 2014). The FES-I asked a participant if they are "not at all”, “somewhat”, “fairly” or “very” concerned with falling during activities of daily living such as getting dressed, preparing meals, getting up from a chair, reaching overhead, walking on an uneven surface, visiting friends, etc. A higher FES-I score reflects a lower confidence in performance of ADLs.

Gait was measured while participants walked at a comfortable pace over 30 feet (9.14m) wearing the Pedar-X insole system (Novel Inc., St Paul, MN). The Pedar-X is an in-shoe dynamic pressure distribution measuring system, which utilizes capacitive sensors. It was used to capture spatiotemporal aspects of gait. The Pedar-X system was comfortably connected to a portable, belt-worn battery and transponder unit at the waist. It transmitted the following real time data: gait speed, stride time, single leg stance time, and double leg stance time. Data were simultaneously collected from the left and right limbs.

Physical function was measured using over ground walking as described above, the TUG test, and UPST. The TUG test, a performance measure of functional mobility, was used to assess balance, both static and dynamic. An assessment time of >13.5s classified individuals in a category of high risk of falls (Barry, 2014). Performing the

TUG required the participant to rise from a standard armchair, walk 3 meters at a safe pace, turn around, walk back to the chair and sit down. The entire performance was timed using a standard stopwatch. The better (faster) score of 2 attempts was taken (Barry, 2014).

The Unipedal Stance Test (UPST) measured static aspects of balance. Participants stood on one foot with their shoes on for up to 30s. The time the individual was able to maintain his/her balance was measured with a stopwatch. A UPST score of ≥ 30s associated with a low risk of falling (Hurvitz, 2000). This test was administered on both sides. The best measure of 3 attempts was taken. However, if the participant balanced for 30s, the test was stopped even if 3 trials were not completed.

3.4 Walking Intervention

The walking program involved both outdoor and indoor walking with music including AIS, music without AIS, or no music. The program was conducted at least 3 times per week for 30 minutes per bout of exercise. The MUSIC and CLICK groups walked while listening to music streamed through Wayzon Mini Clip mp3 players (Shenzhen, China) and over-the-ear headsets (Shenzhen, China). Isochronous cues for the CLICK group were embedded by Mark Campbell at Audioworks Studio (Charlotte, NC). Participants were allowed to select their preferred musical genre, era, artist, etc. and were provided with a customized playlist based on those preferences. Participants walked to those songs during each exercise session. The control group maintained their daily level of activity including walking 3 times a week for thirty minutes each session without music.

3.5 Statistical Analysis

The independent variables for analysis were group (MUSIC, CLICK, and CONTROL) and time (pre- and post-intervention). The dependent variables for analysis were: UPST, TUG, and gait speed, contact area, contact time, double support time, single support time, stride, swing time, and stance time. All statistical data was analyzed using SPSS (v24, IBM Corporation, West Armonk, NY). Because limb was not a variable of interest, gait data were compared between limbs for all groups using paired samples t-tests to determine if data could be collapsed across limbs. Group × time repeated measures ANOVAs were utilized to compare data between groups and over time. Tukey's *Post hoc* testing and paired samples t-tests were performed in the event of significant interactions. An alpha level of 0.05 was set *a priori* for determining statistical significance. For the occurrence of any missing follow-up data, all last observations were carried forward through the statistical analysis.

CHAPTER 4: RESULTS

Forty-five participants were enrolled for this study. Of these, 10 were excluded for either withdrawal from the study (n=2) or were lost to follow up (n=8). A resultant sample size of 35 individuals participated in our study. Participant demographics at baseline are located in Table 1. A significant difference in BMI between groups was observed (P=0.044). *Post hoc* analyses revealed statistically higher difference for BMI between the CLICK compared to the CONTROL groups (P=0.042).

Table 1. Participant demographic data (mean ± standard deviation)

Group	N (% female)	Age (yrs.)	BMI (kg/m^2)	Fall History (prev. 6 months)	FES-I
CLICK	11 (77.78)	71	32.03±7.11*	0.09±0.30	22.55±6.27
MUSIC	11 (92.31)	69	27.35±5.61	0.00±0.00	22.45±6.71
CONTROL	13 (80.00)	72	26.09±4.33	0.00±0.00	22.31±5.65

*Significantly greater than CONTROL (P=0.042)
FES-I: International Fall Efficacy Scale

4.1 Balance

There was a significant group × time interaction for TUG outcomes (P=0.044; Table 2). Additionally, there was a significant time main effect, suggesting improved TUG times at post-testing compared to baseline (P=0.046). *Post hoc* analyses revealed that the CLICK group improved their scores from baseline to follow-up (P=0.035).

4.2 Gait

Paired-samples t-tests indicated there were no differences in gait variables between limbs at baseline across the three groups ($P>0.05$). Therefore, only the right limb was used in all subsequent analyses. There were no significant group × time interactions observed for any gait variable (Table 3). There was, however, a significant time main effect for stride time suggesting that regardless of group, participants demonstrated lower post-test stride times compared to baseline ($P=0.031$).

Table 2. Functional performance data. Data are mean ± standard deviation.

	CLICK		MUSIC		CONTROL		P value
	Pre	Post	Pre	Post	Pre	Post	
TUG (s)	8.83±1.82*	7.76±1.28	7.11±1.11	7.09±1.08	7.22±1.94	7.16±1.95	0.04
UPST-L (s)	9.13±10.43	13.18±10.53	23.00±11.57	22.11±11.04	22.06±9.40	21.67±10.49	0.11
UPST-R (s)	10.63±10.67	14.00±11.39	21.38±11.24	24.63±10.19	23.21±10.37	22.63±11.80	0.20
GAIT SPEED (s)	8.62±1.54	8.33±1.16	7.34±0.70	7.76±0.87	7.93±1.60	7.60±1.36	0.11

*Statistically different from post-test (P=0.035)
FES-I = Falls Efficacy International

Table 3. Gait data (mean±standard deviation).

	CLICK		MUSIC		CONTROL		P value
	Pre	Post	Pre	Post	Pre	Post	
Contact area (cm^2)	147.41±16.52	148.33±16.91	143.10±15.23	147.84±17.12	140.85±18.50	142.05±21.27	.661
Contact time (ms)	669.11±44.54	651.22±35.11	628.67±61.45	638.89±64.90	658.75±54.85	623.25±47.87	.110
Double support time (ms)	135.57±15.00	125.22±13.74	120.83±27.78	120.56±20.61	125.81±24.02	116.25±19.40	.455
Stride time (ms)	1091.76±43.85	1046.39±48.93	1036.39±109.89	1043.89±94.09	1070.63±73.88	1016.25±65.77	.145
Single leg support time (ms)	432.06±24.24	424.33±31.12	413.56±30.49	424.67±42.59	435.50±28.48	418.00±26.25	.064
Stance time (ms)	669.11±44.54	651.22±35.11	628.67±61.45	638.89±64.90	658.75±55.85	623.25±47.87	.110
Swing time (ms)	423.80±60.24	397.59±18.78	405.83±43.75	404.72±32.96	410.63±28.15	392.19±24.36	.478

CHAPTER 5: DISCUSSION

The purpose of this study was to determine if an AIS embedded in music listened to while walking improved gait and balance in community dwelling, healthy older adults. Overall, our results showed no differences in gait measures between groups. However, TUG performance improved in the CLICK group following intervention.

Following a 4-week walking program the CLICK group exhibited improved performance on the TUG test. TUG scores improved by 1.07s in this group, which exceeds the minimally clinically important difference of 0.08 established for this measure (Wright, 2011), suggesting that walking with AIS can improve physical function in healthy, older adults. Despite this improvement in TUG scores, the CLICK group completed the TUG more slowly than the MUSIC and CONTROL groups at all time points. It is possible that the difference in BMI may contribute to the higher TUG scores in the CLICK group. However, the higher BMI seems to be due to one participant who had a BMI of 48kg/m^2. Exploratory analysis with this individual excluded eliminated the group difference in BMI but did not change the TUG results; therefore, it seems unlikely that BMI is driving the difference in TUG scores and the individual was retained in our statistical analysis. Another potential explanation is that two additional participants in the CLICK group were identified as non-responders to the intervention for TUG outcomes. Both of these participants reported symptomatic knee osteoarthritis (OA) on the day of testing, which likely influenced their performance. Difficulty in ADLs are commonly reported functional limitations of individuals with knee OA, especially women (Nur, 2017). Women with knee OA were reported to have worse functional status and showed more functional decline than men and healthy women (Logerstedt, 2014), supporting our hypothesis that individuals with symptomatic knee OA at the time of testing may have influenced TUG outcomes. Notably, the TUG test was developed to assess fall risk in community-dwelling older adults, with times of 13.5s or higher indicating persons at risk for falling (Shumway-Cook, 2000). Our participants did not demonstrate fall risk based on this predefined cutoff time. However, improvement of TUG test times suggests this intervention may be beneficial to reducing fall risk in community dwelling, older adults.

UPST scores did not change in any of the groups following the 4-week protocol, suggesting that walking with or without music and AIS had no influence on static balance. Having adequate static balance is important to successful completion of ADLs, including walking. However, it has been demonstrated in other populations that to truly improve static balance, one must train static balance (Jacobsen, 2011). Considering our walking intervention did not specifically train static balance, it is logical that we did not observe any improvements in UPST across groups.

Gait remained relatively unchanged by the intervention with the exception of stride time. Participants demonstrated shorter stride times following the intervention. Shorter stride times are associated with faster walking speeds. Yet, our participants completed the 30-foot walking task in similar times before and after the intervention. Improved gait speeds may have important implications, such as decreasing fall risk, among older adults. However, the minor changes in gait observed in our participants cannot be attributed directly to the AIS intervention. Instead, the overall change may be simply attributed to participant adherence to a walking regimen for the duration of 4 weeks, and that a training effect had taken place.

That TUG times improved in the CLICK group without concurrent changes in gait suggests a need for future analysis of the components of the TUG test. A study conducted by Chen et al. (Chen, 2017), looked specifically at the sit-to-walk and turning performance phases of the TUG test. Those authors saw a positive association between balance control and TUG test outcomes after controlling for lower extremity muscle strength, which is associated with gait capacity and, subsequently, field test outcomes for older adults (Chen, 2017). Furthermore, when strength was added back in to their regression equations, it was found to associate more with the sit-to-walk component of the TUG test than the turning performance component (Chen, 2017). Muscle synchrony in the upper extremities has been shown to improve resulting from combined temporal sensory cues (Wing, 2009). This occurrence of synchronized muscle response could account for improved sit-to-walk times within the TUG testing protocol. If healthy older adults can incur improved synchrony in their lower extremity muscle activation for the initiation of a dynamic balance test, their outcome would reflect the improvement in TUG test outcomes that our study reflects in the CLICK group, despite no significant improvements in gait speed.

5.1 Limitations

This study was not without limitations. First, the use of a self-reported survey to assess fall history and efficacy carried with it the risk of recall bias. Although participants were given thorough instructions on how to complete the survey, we could not guarantee accuracy of recalled information. Additionally, there was an unequal distribution of males (n=5) to females (n=30). Previous studies have shown TUG times stratified by sex, confirm that females score higher in all age groups (Pondal, 2008). Although inclusion of both sexes allowed for better generalizability of our findings, future studies would benefit from analyzing sex-specific differences in AIS interventions. The heterogeneity of our sample demographics presented another limitation. Socioeconomic differences across the groups does, however, allow for greater generalizability of our findings. For safety and consistency with testing we were unable to include any individuals with balance impairments or persons who walk with assistive devices. Thus, we could not draw any conclusions about the benefits of walking with AIS to these populations. Additionally, participants engaged in this program in a group setting; however, the listening devices were individually worn by participants. Therefore, the social nature of this intervention allows no conclusions to be drawn to the benefits of a group exercise structure. Attention-to-task during balance exercises may improve functional capacity and reduce fall risk in older adult populations (Woolacott, Shumway-Cook, 2002). Dependent on the setting, training of an individual could allow for less distraction and greater focus on exercise demands. Finally, the music selections were tailored to the preference of the individual participants, preventing any conclusions to be made on the benefits of an identical playlist for all participants. Other research providing qualitative analysis of self-selected music used for cardiac rehabilitative exercise showed improved positive subjective experiences including physiological arousal (Clark, 2016). This suggests the potential for preferred music selection(s) to provide increased exercise adherence and positive lifestyle health adaptations.

5.2 Conclusion

Walking to music with an embedded AIS improved TUG test outcomes in healthy older adults. This intervention, however, had minimal effects on gait. Given the association between TUG time and fall risk, it appears that walking while listening to music with an embedded AIS can be an effective intervention to reduce fall risk in community dwelling, older adults, though further investigation is warranted.

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APPENDIX A: PATIENT REPORTED OUTCOMES

FES-I

Now we would like to ask some questions about how concerned you are about the possibility of falling. Please reply thinking about how you usually do the activity. If you currently don't do the activity (e.g. if someone does your shopping for you), please answer to show whether you think you would be concerned about falling IF you did the activity. For each of the following activities, please tick the box which is closest to your own opinion to show how concerned you are that you might fall if you did this activity.

		Not at all concerned 1	*Somewhat concerned 2*	*Fairly concerned 3*	*Very concerned 4*
1	Cleaning the house (e.g. sweep, vacuum or dust)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
2	Getting dressed or undressed	*1* ☐	*2* ☐	*3* ☐	*4* ☐
3	Preparing simple meals	*1* ☐	*2* ☐	*3* ☐	*4* ☐
4	Taking a bath or shower	*1* ☐	*2* ☐	*3* ☐	*4* ☐
5	Going to the shop	*1* ☐	*2* ☐	*3* ☐	*4* ☐
6	Getting in or out of a chair	*1* ☐	*2* ☐	*3* ☐	*4* ☐
7	Going up or down stairs	*1* ☐	*2* ☐	*3* ☐	*4* ☐
8	Walking around in the neighbourhood	*1* ☐	*2* ☐	*3* ☐	*4* ☐
9	Reaching for something above your head or on the ground	*1* ☐	*2* ☐	*3* ☐	*4* ☐
10	Going to answer the telephone before it stops ringing	*1* ☐	*2* ☐	*3* ☐	*4* ☐
11	Walking on a slippery surface (e.g. wet or icy)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
12	Visiting a friend or relative	*1* ☐	*2* ☐	*3* ☐	*4* ☐
13	Walking in a place with crowds	*1* ☐	*2* ☐	*3* ☐	*4* ☐
14	Walking on an uneven surface (e.g. rocky ground, poorly maintained pavement)	*1* ☐	*2* ☐	*3* ☐	*4* ☐
15	Walking up or down a slope	*1* ☐	*2* ☐	*3* ☐	*4* ☐
16	Going out to a social event (e.g. religious service, family gathering or club meeting)	*1* ☐	*2* ☐	*3* ☐	*4* ☐