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Characterizing music and dance relationships on Rhythmic Movement Sequence performance in healthy adults and those with MCI: A Pilot Study of Rhythmic Movement Sequences

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
of Emory University in partial fulfillment
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Abstract

Characterizing music and dance relationships on Rhythmic Movement Sequence performance in healthy adults and those with MCI: A Pilot Study of Rhythmic Movement Sequences

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Importance: Rhythmic movement sequences (RMS) are modified gait movements set to various rhythms to create movement-rhythmic patterns of varying and increasing complexity that investigate participants' relationship with learning spatial (movement shape) and temporal (rhythm) variables during trials.

Objective: To determine group differences in RMS performance and characterizing music and dance relationships that are translated into performance on RMS trials.

Design/Setting: Cross-sectional pilot study.

Participants: 8 healthy young adults (HYA; age = 24 ± 4.8 yrs; 6Female (F)), 7 healthy old adults (HOA; age = 70 ± 11.5 yrs; 4F), and 8 adults with MCI (MCI; age = 71 ± 6.4 yrs; 5F).

Main Outcome and Measure: RMS trial performance, Music Relationship Questionnaire, Dance Relationship Questionnaire, Rhythm Assessment

Results: When comparing RMS performance between groups, HYA performance on spatial RMS trials was significantly better than MCI (5.71% difference; $p = 0.005$). When comparing group performance on spatiotemporal trials, HYA performance on spatiotemporal trials was significantly better than MCI (3.42% difference; $p = 0.008$). When regressing music relationships and temporal trial performance, there was no significant correlation between music relationship and performance on temporal trials between all groups. When regressing dance relationships and spatial trial performance, there was no significant relationship or trend identified between dance relationship and spatial performance between all groups. When regressing dance relationships and temporal trial performance, there was a significant correlation between dance relationship and performance on temporal trials amongst HYA ($R^2 = 0.74$; $y = -2.97x$; $p = 0.008$). There was a statistically significant relationship identified for HYA between rhythm assessment score and performance on temporal trials ($R^2 = 0.75$; $y = -2.41x$; $p = 0.006$).

Conclusion and Relevance: To our knowledge, this is the first study that investigates music and dance spatial and temporal components using RMS on HYA, HOA, and MCI. Furthermore, it is not necessarily known what mechanisms differ between these groups and drive differences in performance on spatial, temporal, and spatiotemporal RMS. This thesis investigated how relationships to music and dance and proficiency in rhythm impact the ability to perform spatial and temporal modifications to gait and how that changed in individuals with different physical and cognitive abilities.

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Table of Contents

Introduction..1

Methods..5

Results..10

Discussion..14

Tables and Figures..18

Table 1: Participant Data

Table 2: Swing Modifications

Table 3: Stance Modifications

Table 4: Temporal Modifications

Table 5: Spatiotemporal Trials

Figure 1: Biomechanical Targets

Figure 2: MRQ

Figure 3: DRQ

Figure 4: Rhythm Assessment

Table 6: Group Differences

Figure 5: Spatial Performance Between Groups

Figure 6: Temporal Performance Between Groups

Figure 7: Spatiotemporal Performance Between Groups

Figure 8: Music Relationship and Temporal Trial Performance

Figure 9: Dance Relationship and Spatial Trial Performance

Figure 10: Dance Relationship and Temporal Trial Performance

Figure 11: Rhythm Assessment and Temporal Trial Performance

Figure 12: Dance Relationship and Rhythm Assessment Score

References..27

Introduction

The transitional state between cognitive changes of normal aging and early dementia are being recognized as a risk factor for Alzheimer's disease and can be represented as mild cognitive impairment (MCI) (Grundman et al., 2004). An individual with MCI experiences cognitive decline that is worse than expected for an individual's age, but not significant enough as that experienced by individuals with dementia (Peterson, 2011). Dementia does not imply a specific cause or pathologic process however, it is a clinical syndrome characterized by acquired losses of cognitive and emotional abilities that are severe enough to interfere with daily functioning and quality of life (Geldmacher and Whitehouse, 1996). MCI due to AD is typically separated as the prodromal stage of AD and is diagnosed using criteria specific to the early stages of AD (Albert et al., 2011). These criteria include memory problems, objective memory disorder, absence of other cognitive disorders or repercussions on daily life, normal general cognitive function, and absence of dementia (Portet et al., 2006).

The ability to move effectively and/or independently in one's environment to accomplish tasks or goals is referred to as mobility and is important for measuring independence and quality of life (Barberger and Fabrigoule, 1997; Stalvey et al., 1999), including in those with MCI. Changes in mobility are important for researchers and clinicians to monitor in MCI populations because aspects of mobility may decline over time in older adults with possible MCI (O'Connor et al., 2010). Studies evaluating gait parameters indicate the close relationship between cognitive function and mobility (Pedersen et al., 2014). Among adults with MCI, executive function deficits were associated with poor mobility performance and future risk for falls (Verghese et al., 2008).

A meta-analysis demonstrated that music-based therapy that includes dancing positively affects the gait and gait-related activities of individuals with neurodegenerative disease (de Dreu et al., 2012). Dance and rhythmic training may provide a synergistic sensory adjuvant to motor skill training in aging and disease models. Rehabilitation, including that found in dance, and music-movement therapies, that combines physical and cognitive challenges may be most effective (Fabel, 2008). A worthwhile approach to slow down the progression of disability due to AD is a music-based exercise program. One study has suggested its efficacy in a group of patients with moderate to severe dementia (Van de Winckel et al., 2002). Exercise is the only known intervention known to improve cognitive function among those with MCI as there are no FDA-approved MCI medications (Petersen et al., 2018). Physical activity can improve cognitive function for older adults who have already developed MCI or dementia when compared with those with cognitive impairment who are not physically active (Ahlskog et al., 2011). Furthermore, studies show that compared to sedentary controls, six to 12 months of exercise for those with MCI or dementia results in better cognitive scores (Öhman et al., 2014). Meta-analysis showed that aerobic exercise, when combined with standard medical treatments for dementia, helps improve cognition in older adults with AD (Groot et al., 2015). Disease modifying therapies for Alzheimer's disease that are used early in the disease process before the onset of significant functional impairment could be most effective (Cummings et al., 2007).

Few studies have investigated cognitive effects of exercising to music in patients with AD. However, many caregivers note therapeutic effects of either individualized or group-based music sessions in patients with AD (Groene, 2001; Gerdner, 2000; Groene, 1999). These effects include behavioral, speech, motor integration and rhythmic movement (Norberg et al., 1986; Mathews et al., 2001; Sambandham and Schirm, 1995; Palo-Bengtsoon and Ekman, 2002; Clark et al., 1998).

Dance therapy is a type of movement therapy based on dance applied in a clinical context. Furthermore, it has great therapeutic potential both in age-related cognitive decline and in a broad range of health conditions. Currently substantial attention is focused on the potential health benefits of music therapy and dance as gait rehabilitation in patients with Parkinson's Disease (Pereira et al., 2019). Over the last 15 years, touch-based rehabilitative partner dance designed by PI Hackney that incorporates rhythmic entrainment and spatiotemporal movement has been shown to improve mobility and cognition in older populations with neurodegenerative disease (McKee and Hackney, 2013). Rhythm is the most important element of music in dance, and dance is almost always performed to music (Leisman and Aviv, 2020). The importance of rhythm to dance means that the ability to perceive temporal regularity in musical rhythm (beat perception) (Bouwer et al., 2016), is also relevant to the neuroscience of dance. Thus, dance therapy could be a meaningful intervention for those with MCI. However, specific beneficial aspects of music such as rhythm and tempo have never been systematically investigated in participants with MCI. Previous research on therapy of auditory cues have improved movement. Specifically, positive effects of rhythmic auditory stimulation were noted on freezing and gait parameters in people with Parkinson's disease (PD) (Song et al., 2015).

Clinically relevant spatial and temporal movement characteristics such as swing and stance phases of gait cycles were manipulated to create a protocol for evaluating the research question. Rhythmic movement sequences (RMS) are modified gait movements set to various rhythms to create movement-rhythmic patterns of varying and increasing complexity that investigate participants' relationship with learning spatial (movement shape) and temporal (rhythm) variables during trials. To facilitate learning of RMS, movements are broken down into their spatial and temporal components. RMS protocol can be used to study music and movement rigorously and performance can be distinguished between healthy young adults, healthy older adults, and participants with mild cognitive impairments. The primary outcomes to validate RMS protocol include quantifying the ability to modulate spatial and temporal components of movement. Spatial outcomes correspond to biomechanical targets. The closer a participant is to a biomechanical target, the closer they are to having the ability to modulate their gait. Temporal performance is quantified as the ability to step to prescribed patterns of quick and slow steps when walking to music. The frequency of steps was determined by the musical tempos.

Motor-cognitive integration may be improved in individuals with pAD through RMS rehabilitation that involves cognitive engagement from the domains of attention, executive function, spatial cognition, memory, detecting and interpreting music beats, and working memory. Motor-cognitive integration involves vestibular, visual and somatosensory systems necessary for balance and executive function. Former therapies have neglected motor cognitive interaction, and RMS therapy will target that.

Our team has begun to address the challenge of therapy involving motor cognitive interactions by characterizing the impacts of cognitive deficits on individuals' ability to modulate spatial and temporal features of rhythmic movement through the MYSTIC study: *Moving in* *space and time: identifying spatial and temporal components of rhythmic movement training for people with prodromal Alzheimer's disease.* Drs. Madeleine Hackney, Trisha Kesar, Laura Emmery, and J. Lucas McKay are investigators. Dr. Michael Rosenberg is the postdoctoral collaborator. Skills required by RMS are having the ability to modify the swing and stance phase of the gait cycle to varied rhythms. Identifying principles of human-music interactions through RMS could inform approaches to music rehabilitation for older populations with MCI. Thus, this thesis aims to determine if the ability to perform spatial and temporal modifications of movement differs between healthy young adults (HYA), healthy adults over 50 (HOA), and adults over 50 years with mild cognitive impairment (MCI). My contributions included developing a dance dictionary library, developing psychosocial questionnaires that explored lifelong music, dance, and health relationships, and conducting rhythm, motor, and cognitive assessments.

Further, this thesis will investigate how music and dance experience impact the performance of spatial and temporal movement modifications between these groups. My premise is that differences in performance across age and function groups can be partially explained by differences in the ability to translate music and dance relationships into task performance. Therefore, I predict that HYA will achieve target kinematics compared to HOA and MCI.

Methods

This study was approved by the Emory Institutional Review Board (protocol 003507). All participants gave written, informed consent prior to participation.

Gait Modifications: We constructed a library of 64-movement patterns comprised of modifications to the swing and stance phases of the gait cycle in which several possible combinations of swing- and stance- modifications were created. A subset of movement patterns that deviated from inter-joint coordination patterns of normal walking and could be safely performed by groups were selected to produce the RMS's used in the study.

Spatial parameters: Modifications have corollaries in ballet, are quantitatively distinguishable from normal forward gait cycles, and are feasible for HOA and MCI. Normal gait is characterized by executed coordinated and precisely timed movements of the hip, knee, and ankle that move the body forward (Daly and Ruff, 2007). The modifications deviate from highly stereotyped flexion-extension coordination and coupling of hip, knee, and ankle during normal gait (Ivanenko et al., 2005). In some gait training studies, there are a lack of results due to insufficient consideration of brain plasticity and associated motor learning principles when constructing the intervention (Daly and Ruff, 2007). We modified spatial components of gait in three classes: swing, stance, and swing-stance modifications. There were three trials for each gait phase subgroup. For swing-only and stance-only, the two different movements performed start with a movement performed on the left leg and a movement performed by the right leg. For swing-stance, the two different movements are performed by the left leg. Within each gait phase subgroup (swing-only, stance-only, and swing-stance), modifications were ranked from easy to moderate to hard difficulty based on the amount of deviation from the normal gait cycle. Furthermore, spatial complexity was defined as the number of times the movement sequence required modulation of movement amplitude or level of uncoordinated gait. Before recordings, subjects watched a video of PI Hackney performing the movement, received instruction of the biomechanical targets of the movement, and practiced for a few iterations of the movement.

Spatial performance was quantified by participants' reaching biomechanical targets. For example, coupe is a swing modification of least complexity with biomechanical targets of 45-

degree knee flexion, maximal plantar flexion, and toe at stance lower extremity medial malleolus (Table 2). Releve is the most complex stance modification with biomechanical targets of flat foot to full plantar flexion (Table 3).

Temporal parameters: Auditory cues play a strong role in guidance of movement. Participants were trained in rhythms in a non-musically technical way using the system of quicks (q) and Slows (S) (2q=1S) used in ballroom instruction. The RMS protocol matrix consisted of three types of modified ballroom dance rhythms (simple duple, complex duple, and simple triple) composed by MPI Emmery. These rhythmic patterns were designed to increase in complexity in which absences of accents on a strong beat or a rhythm that emphasizes offbeats encompasses the most complex rhythm. Both waltz (triple meter) and tango (duple meter) support and encourage different qualities of movement. For the RMS protocol, *Libertango* (by Astor Piazzola, 1974) at 100 beats per minute (BPM) was used as the background for duple meter trials. *Waltz No. 2* (by Dmitri Shostakovich, 1938) was used as the background music for triple meter trials and the 80 BPM version was used for HYA and 60 BPM version was used for HOA and MCI. In duple and triple meter, we created rhythms, using a ballroom dance system of quicks (q) and slows (S) (Table 4). The rhythms were constrained to a typical dance "8 count" for duple meter, and "3" or "6 counts" for triple meter. Simple duple, complex duple, and simple triple trials were randomized and the three rhythms within each trial were randomized for a total of 9 recordings. The participant would watch a brief video of PI Hackney demonstrating multiple iterations of the rhythm, practice walking a few feet in the meter, and practice walking a few feet in the meter and to the music. At the start of each length, the beat would be clapped to establish the meter and then one iteration of the newly learned rhythm.

Spatiotemporal parameters: To quantify how participants move in space and time, 4 trials were randomized in which spatial and temporal parameters are combined for one trial recording. The participant is briefly reminded of the rhythm and spatial modification. Afterwards, they are presented with a brief video of PI Hackney performing the rhythmic and spatial modification to the designated meter. For example, Coupe passe to duple meter is considered easy spatial and easy temporal (Table 5). An example of hard spatial and hard temporal is heel releve to triple meter. For all spatial, temporal, and spatiotemporal trials, HYA performed two laps (4 lengths approximately 44 feet). HOA and MCI performed at least 1 lap (2 lengths approximately 22 feet), with distance determined by the assessor to mitigate fatigue.

Rhythmic Movement Sequence (RMS): RMS assessment consisted of wearing Opal V2Rs (APDM, Inc., Portland, USA) while performing baseline walks, 9 spatial, 9 temporal, and 4 spatiotemporal trials. Opal V2Rs are Inertial Measurement Unit (IMU) sensors that measure and report angular rate and force and acceleration experience by the body part it is attached to. 15 sensors were attached to the hands, wrists, upper arms, head, sternum, lumbar, upper legs, lower legs, and feet. The sensors measured the neck, back, shoulder, elbow, wrist, hip, knee, and ankle kinematics using APDM's Moveo Explorer software. There was an optional adaptation trial to quantify if after performing recently learned RMS for 10 laps (approximately 220 feet total)

Music and Dance Relationship Questionnaires (MRQ and DRQ): The Music and Dance Relationship Questionnaires consisted of 10-items on a Likert scale with seven response categories. The seven-point scale has been shown to reach the upper limits of the scale's reliability. There are three open ended questions that ask for levels of agreement with statements regarding music experience, and current and historical attitudes towards music. Some items include "Music is important in my life" and "I listen to music in my typical day." Similarly, the DRQ has 10-itmes on a Likert scale with seven response categories and three open ended questions that asks for level of agreement with statements regarding experience with dance/moving to music, current and historical attitudes towards dance/moving to music. Items include "Dance is important in my life" and "I actively choose to move when music is playing." Participants completed the survey at home via a secure individual link through REDCap (Harris et al., 2019), an online HIPAA approved database used to store and protect research data.

Objective Rhythm Assessment: This brief, 10-15 minute assessment assays participants' ability to clapback four heard rhythmic patterns, read two measures of Western notation of music, and to aurally recognize meter in five audio clips. For the first part, participants listen to a brief clapped rhythmic pattern three times and after are instructed to clap it twice. Allowing a participant to increase the frequency of clapping a rhythm may aid in learning and performing a rhythm more accurately. Their clapping is recorded and in total the participants clap four different rhythmic patterns. Then, the participants are presented with two measures of Western notation of music in 4/4 time. They are asked if they can or cannot read the musical notation and are given the option to attempt to clap back either way. After a minute of practice, they clap the rhythm twice and it is recorded. For the third part of the assessment, five audio clips less than 60s in length are played one at a time for up to three times. After each playing, the participant answers whether the audio is grouped in patterns of twos, threes, or other patterns.

The entire assessment is scored out of 10 points. For parts 1 and 2, 1 point is given for clapping back the correct rhythm, 0.5 points given if ½ of the repetitions of the clapback are correct, and 0 points if both repetitions of the clapback are incorrect. For part 3, 1 point is given for the correct meter and 0 points is given for the incorrect meter. These assessments were given both in person or via video conference as needed.

Statistical Analysis: Pre-computed joint kinematics exported from the Moveo software were processed using custom scripts in MATLAB 2021b (Mathworks, Natick, USA). Spatial outcomes corresponded to the ability to achieve biomechanical targets. The closer a participant was to a biomechanical target, the closer they were to having the ability to modulate their gait. Biomechanical targets corresponded to peak hip, knee, ankle angles during stance and swing (Figure 1). For spatial trials, we computed only spatial performance. Temporal outcomes corresponded to the ability to step to prescribed patterns of quick and slow steps when walking to music. The frequency of steps was determined by the musical tempos. For temporal trials, we computed only temporal performance. For spatiotemporal trials, we computed both spatial and temporal performance. Percent differences relative to the biomechanical or temporal targets were used to account for differences in the range of motion and tempo of different movements during spatial, temporal, and spatiotemporal trials. For each participant we averaged percent differences across spatial, temporal, or spatiotemporal trials. Differences between groups describe differences in performance due to the mechanisms (e.g. cognitive function) that may differ between the groups.

To test for group differences between the three groups, we conducted independent-samples t-test with unequal variance. We used univariate linear regression to determine if music relationships and rhythm assessment scores were associated with temporal trial performance and if dance relationships were associated with spatial trial performance. We extracted regression accuracy (R^2) and slopes. A statistically significant regression slope would imply a non-trivial relationship between X and Y. To gain additional insight into observed group differences in performance that were not explained by relationships to music or dance, we conducted post-hoc analyses that used univariate linear regression to determine if dance relationships were associated with temporal trial performance and rhythm assessment score. All tests were two-tailed and used a significance level of $\alpha = 0.05$. All analyses were conducted using Microsoft Excel's Analysis Toolpack.

Results

RMS Protocol:

5 swing modifications and 4 stance modifications were used in the protocol (Table 2 and Table 3). From least to most physically challenging swing modifications were ranked: coupe, passe, attitude, developpe, and battement. Coupe, Passe, and Attitude all comprise of plantar flexion that differ in angles in knee and hip flexion. Developpe and Battement involve swinging the leg to horizontal and differs in the extension of the knee into swing. For stance modifications, ranking from least to most physically challenging were: pique, tombe, exaggerated heel strike, and releve. Both Pique and Releve differ in the execution to maximal planta flexion with metatarsal contact only. Tombe is comprised of mild knee flexion and a flat foot and exaggerated heel strike is comprised of maximal dorsi flexion at initial stance.

For temporal trials in the RMS protocol, 3 trials were simple rhythms to duple meter, 3 trials were complex rhythms to duple meter, and 3 trials were simple rhythms to waltz meter (Table 4). For simple rhythms in duple meter, 4 step sequences (qqSS and &&qS) or 6 step sequences (qqqqSS) were performed. All complex rhythms in duple meter were 6 step sequences (e.g. qSqqqS). All simple rhythms in waltz meter were 2 step sequences (qS) and 4 step sequences (&&qq and qSSq). Temporal complexity was defined as the absence of accents on a strong beat or rhythm that emphasizes offbeats.

There were four spatiotemporal trials used in the RMS protocol (Table 5). Two trials were to duple meter and two were to waltz meter. They were paired with an easy spatial and easy temporal, easy spatial and hard temporal, hard spatial easy temporal, and hard spatial hard temporal. Spatiotemporal complexity translated to participants needing to vary the amplitude and speed of their torso, head, arm, and leg movements during stepping to align with the music rhythms. This movement complexity was challenging for many and could lead to feelings of incoordination. During trials, some participants would either sacrifice the spatial or temporal component to adapt. An example of a spatiotemporal trial to waltz meter with a hard spatial and easy temporal component was the movement Battement-Pique with the qS rhythm.

Dance and Music Relationship Questionnaires and Rhythm Assessment

Figure 2 shows composite scores for the MRQ in which a higher score indicates a stronger music relationship. For average composite MRQ scores across groups, HYA hypothetically had the strongest music relationship (4.80 ± 0.85), followed by HOA (4.79 ± 1.23), then (3.99 ± 0.64). Figure 3 shows composite scores for the DRQ in which a higher score indicates a stronger dance relationship. For average composite DRQ scores across groups, MCI had the strongest dance relationship (4.05 ± 1.04), then HYA (3.88 ± 1.07), and HOA (3.24 ± 1.25). 21 Rhythm Assessments were conducted. Figure 4 shows scores on the Rhythm Assessment, in which a higher score indicated a higher proficiency in aural dictation of rhythms. On average, HYA scored highest (8.88 ± 1.36), then HOA (7.92 ± 1.43), and MCI scored lowest (5.64 ± 1.89).

RMS data quantifying performance:

Spatial, Temporal, and Spatiotemporal group differences

We recruited and collected Rhythmic Movement Sequences (RMS) data with Opals from 23 participants (8 HYA, 7 HOA, and 8 MCI). When comparing RMS performance between groups, HYA performance on spatial RMS trials was significantly better (lower percent difference vs. Biomechanical targets) than MCI (5.71%; $p = 0.005$) (Table 6) (Figure 5). While it did not reach statistical significance, HYA exhibited slightly better spatial performance than HOA (3.49%) (Table 6).

We did not identify significant differences in temporal performance between groups during temporal trials (Figure 6). The median of HYA (12.67) and the median of MCI (19.95) had an observable difference, but this did not reach statistical significance.

When comparing group performance on spatiotemporal trials, HYA performance on spatiotemporal trials was significantly better than MCI (3.42% difference; $p = 0.008$) (Figure 7) (Table 6). HYA may be better at modulating the combination of spatial and temporal components of their gait than adults with MCI. While it did not reach statistical significance, HYA exhibited slightly better spatiotemporal trial performance than HOA (1.28% difference) (Table 6).

Does Music Relationship predict temporal RMS performance?

When regressing music relationships and temporal trial performance, there was no significant correlation between music relationship and performance on temporal trials between all groups (HYA: R^2=0.20; y = -2.00x; p = 0.262) (HOA: R^2 = 0.00; -0.001x; p = 0.999) (MCI: R^2=0.10; y = -2.71x; p = 0.439) (Figure 8). Although a statistically significant relationship between music relationship and temporal performance was not identified, there may be a possible negative trend that may be revealed for each group given a larger sample size. Given the stronger the relationship to music, there is possibility for a reduced percent error of temporal modifications of gait. A larger sample size could indicate whether there is a relationship between a participant's music relationship and higher temporal trial performance.

Does Dance Relationship predict RMS performance?

When regressing dance relationships and spatial trial performance, there was no significant relationship or trend identified between dance relationship and spatial performance between all groups (HYA: R^2 = 0.08; y = -1.05x; p = 0.490) (HOA: R^2 = 0.25; y = -1.37x; p = 0.257) (MCI: R^2 = 0.07; y = 0.59x; p = 0.534) (Figure 9). Thus, having a strong relationship to dance may not aid in learning spatial modifications of gait. In a post-hoc analysis, dance relationships and temporal trial performance were regressed. When regressing dance relationships and temporal trial performance, there was a significant correlation between dance relationship and performance on temporal trials amongst HYA (R^2= 0.74; y = -2.97x; p = 0.008) (Figure 10).

Rhythmic Assessments and RMS performance

There was a statistically significant relationship identified for HYA between rhythm assessment score and performance on temporal trials (R^2 = 0.75; y = -2.41x; p = 0.006) (Figure 11). There was no statistically significant relationship between rhythm assessment score and temporal trial performance amongst both HOA (R^2 = 0.06; y = 0.677x; p = 0.650) and MCI (R^2 = 0.06; y = 0.75x; p = 0.587) (Figure 11). Performance differences between groups were not explained by music and dance relationships for all RMS and groups, thus an exploratory analysis was conducted to identify if there is a correlation between dance relationships and rhythmic assessment scores. There was no statistically significant relationship identified between dance relationships and rhythmic assessment scores between groups (Figure 12). HYA had an almost statistically significant correlation between a stronger dance relationship and higher rhythm assessment score ($R^2 = 0.45$; $y = 0.85x$; $p = 0.067$).

Discussion

To our knowledge, this is the first study that investigates music and dance spatial and temporal components using rhythmic movement sequences (RMS) on HYA, HOA, and MCI. Furthermore, it is not necessarily known what mechanisms differ between these groups and drive differences in performance on spatial, temporal, and spatiotemporal RMS. This thesis investigated how relationships to music and dance and proficiency in rhythm impact the ability to perform spatial and temporal modifications to gait and how that changed in individuals with different physical and cognitive abilities. I first wanted to determine differences between groups and found statistical significance for HYA performance on spatial and spatiotemporal trials compared to MCI. However, larger sample sizes are needed to more robustly identify group differences. I found that there was not a statistically significant trend between music relationship and temporal performance and dance relationship and spatial performance which did not support my hypotheses.

I predicted that HYA would achieve target kinematics compared to HOA and MCI. Additionally, we predicted that HOA would differ from MCI. Note that differences between HOA and HYA individuals are mostly physical, while the differences between HOA and MCI are mostly cognitive, though potentially also physical. Thus, HYA vs. MCI is both a physical and cognitive difference. Our finding that HYA performed better on both spatial and spatiotemporal trials than MCI suggests that physical and cognitive deficits alone were not sufficient to elicit statistically significant differences between groups (i.e. HYA vs. HOA and HOA vs. MCI) (Figure 5 and Figure 7). However, the combination of cognitive and physical deficits that hinder modifications of spatial components of gait, was sufficient to elicit statistically significant decrease in performance (Figure 5 and Figure 7). This suggests that the combined effects of physical and cognitive deficits are larger than one of the two components. Furthermore, when designing a dance-based therapy for MCI, we would want to decrease the level of difficulty corresponding to physical and cognitive deficits.

Since MCI perform most poorly on temporal trials it is likely that cognitive function is associated with performance deficits during temporal modulation of gait (Figure 6). Since we observed this, but did not observe a statistically significant result, this merits further investigation in a larger study sample. These results aid in characterizing observed group differences. Further RMS data collection could aid in designing a music and dance-based movement therapy that divides movement into spatial and temporal components first, it appears that MCI would need the most temporal training. It would not be expected that based on the observed medians, HYA and HOA would need additional training. Furthermore, if training only takes place for a certain amount of time, then MCI would benefit from less complex rhythms.

Differences were observed in RMS performance across age and function groups; thus, it was tested if those differences can be partially explained by differences in the ability to translate music and dance relationships into task performance. However, there was no statistically significant relationship between music relationship and temporal trial performance (Figure 8) and it is too early to suggest if a participant's relationship to music may or may not aid the participant in learning temporal modifications of gait to inform the difficulty of music-based movement therapies. Similarly, there was no statistically significant correlation between dance relationship and spatial trial performance (Figure 9), and it is likely that a participant's relationship to dance may not be assessed to its full extent via the DRQ. Furthermore, it is too early to suggest that dance relationships are correlated to learning spatial modifications of gait to inform the difficulty of dance-based movement therapies. When using questionnaires to inform music and dance-based movement therapy, relationships to music or dance could be used to determine a level of difficulty given other factors.

In a post-hoc analysis, dance relationships and temporal trial performance were regressed in which there was a significant correlation between dance relationship and performance on temporal trials amongst HYA (Figure 10). Dance requires motor output that is synced to rhythm and in temporal trials, participants need to execute a motor pattern to match the rhythm. Thus, dance relationships may be a better predictor of performance on temporal trials than music relationships which prompted this post-hoc analysis. It is also likely that temporal performance may require more than a strong music relationship. Spatial performance was expected to be related to physical capacity. with weaker dance relationships because these temporal trials require similar coordinated rhythmic motor output. When thinking about the rhythm assessment, temporal performance, and spatiotemporal performance, we might expect people who are more practiced in combining perceiving a rhythm with and executed motor command, they may have higher performance, and this was observed for HYA. Thus, the issue of poor performance during these trials may be due to physical capacity or motor output. Individuals with reduced physical capacity may have trouble transforming their relationship to dance and prior experience into movement performance. All in all, with age and physical and cognitive decline, this relationship may be hindered.

I predicted that group differences in temporal trial performance could be predicted by rhythm assessment scores. It was observed within HYA that there was a statistically significant correlation between higher rhythm assessment score and decreased percent difference in temporal trial performance (Figure 11). It is likely that if someone is more proficient in rhythm, then they can output motor commands that are coordinated with rhythms.

In an exploratory analysis, dance relationship was regressed with rhythm assessment score in which there was no statistically significant correlation between groups (Figure 12). The strength of the correlation suggests the extent of redundancy between tests in which almost half of performance on rhythm assessment cannot be explained by the DRQ in HYA ($R^2 = 0.45$; $y = 0.85x$; $p = 0.067$). Furthermore, this suggests that future music and dance-based therapies that utilize RMS should implement both rhythm assessments and DRQ because they could inform treatment in different ways.

One limitation of our study is that it did not determine if difference in performance was a meaningful difference, however, we can confirm that there was a statistical difference. When interpreting group differences, it is possible that one group did much worse on some modifications than another group despite overall similar performance. Across all the analyses, 9 conditions were tested and trial averages were used. An additional analysis could be to determine which movements within each trials participants did most well on. No R^2 or p-value can account for random variation in small sample sizes. Since this is a small sample, results will be sensitive to interindividual variation. Furthermore, questionnaires that evaluate relationships to music and dance need to be further tested and validated. Assessing QOL in cognitively impaired older adults is complex because it involves many cognitive abilities such as attention, memory, language, and abstract thinking (Logsdon et al., 2002). Self-reports of patients diagnosed with mild AD and MCI versus informants QOL ratings differ substantially. From informants' perspectives, early identification and treatment of neuropsychiatric symptoms in MCI and mild AD may help patients maintain QOL in the context of early cognitive decline (Ready et al., 2004). Participants' self-reported QOL scores were nearly identical for AD, MCI, and control groups.

Tables and Figures

Table 1: Participant Data

ID	age	gender	years since MCI	MoCA
P001	30	Female		29
P002	30	Female		30
P003	24	Female		29
P004	25	Male		
P005	18	Female		30
P006	27	Male		30
P007	21	Female		29
P008	18	Female		28
P101	55	Male		30
P102	78	Female		27
P103	70	Female		24
P104	53	Male		26
P105	75	Male		28
P106	80	Female		
P107	79.5	Female		30
P201	72	Male		25
P202	70	Male	2	
P203	76	Female	3	
P204	58	Female		22
P205	79	Male	2	27
P206	74	Female	4.5	27
P207	67	Female		
P208	72	Female	5	22

Table 2: Swing Modifications

Swing Modifications	Biomechanical targets	Figure
Coupe	• 45 deg knee flexion • maximal plantar flexion • toe at stance LE medial malleolus	
Passe	• 90 deg hip flex at apex • >90 deg knee flexion • plantar flexion • toe at stance LE medial patella	
Attitude	• 90 deg hip flexion • 90 deg knee flexion • plantar flexion • shank perpendicular to floor	
Developpe	• swing foot moves vertically from medial malleolus to medial patella of stance LE • flex hip to maximal 90 deg • extend knee fully so shank is parallel to floor	
Battement	• Full knee extension • Full ankle plantarflexion • Leg swings up to 90 deg of hip flexion (swing leg horizontal)	

Table 3: Stance Modifications

Stance Modifications	Biomechanical targets	Figure
Pique	• Maximal planta flexion • metatarsal contact only	
Tombe	• Mild knee flexion • flat foot	
Exaggerated heel strike	• Maximal dorsi flexion initial stance	
Releve	• flat foot to full plantar flexion	

Table 4: Temporal Modifications

Simple Duple Meter	Complex Duple Meter	Simple Waltz
		

Table 5: Spatiotemporal Trials

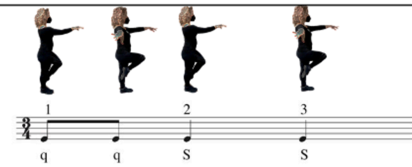
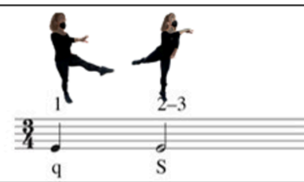
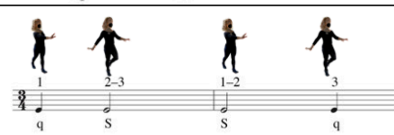
Difficulty	Spatiotemporal Trial	Figure
Easy spatial Easy temporal	coupePasse-qqSS-Duple	
Easy spatial Hard temporal	piqueReleve –SqqqSq-Duple	
Hard spatial Easy temporal	battementPique-qS-Waltz	
Hard spatial Hard temporal	heelReleve-qSSq-Waltz	

Figure 1: Biomechanical target kinematics

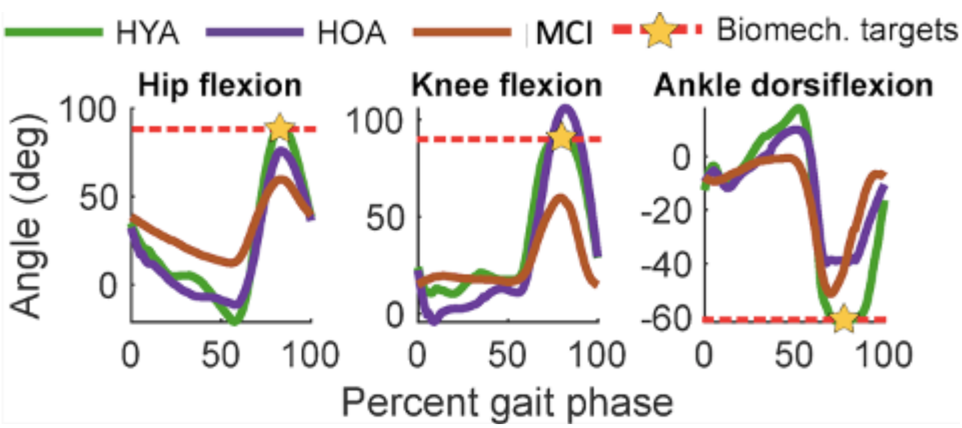


Figure 2: MRQ Average Composite Scores between groups

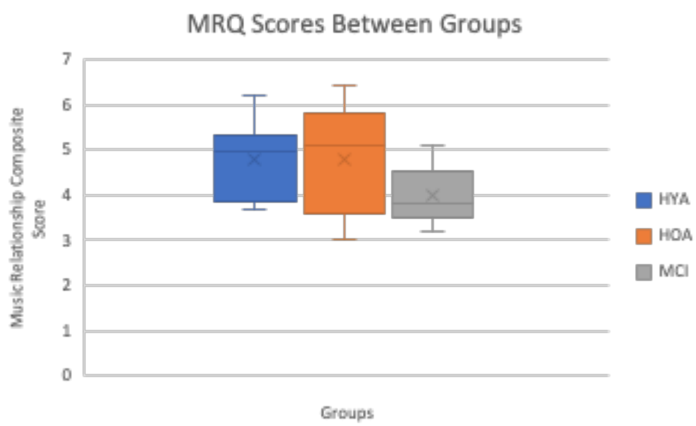


Figure 3: DRQ Average Composite Scores between groups

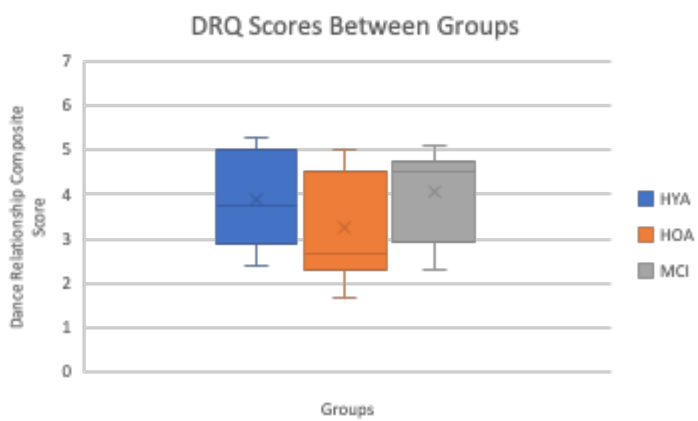


Figure 4: Average Rhythm Assessment Scores between groups

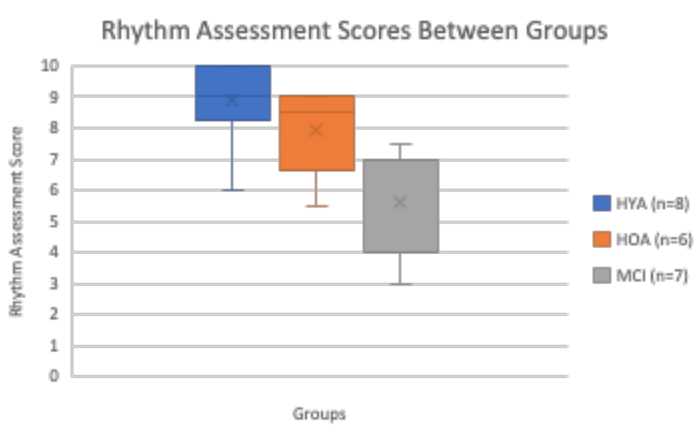


Table 6: Group differences

	HYA vs. HOA		HOA vs. MCI		HYA vs. MCI	
	group difference	p-value	group difference	p-value	group difference	p-value
Spatial	3.49%	0.09	2.22%	0.18	5.71%	0.0048
Temporal	1.48%	0.46	3.05%	0.22	4.54%	0.07
Spatiotemporal	1.28%	0.33	2.14%	0.09	3.42%	0.0081

Figure 5: Spatial trial averages between groups

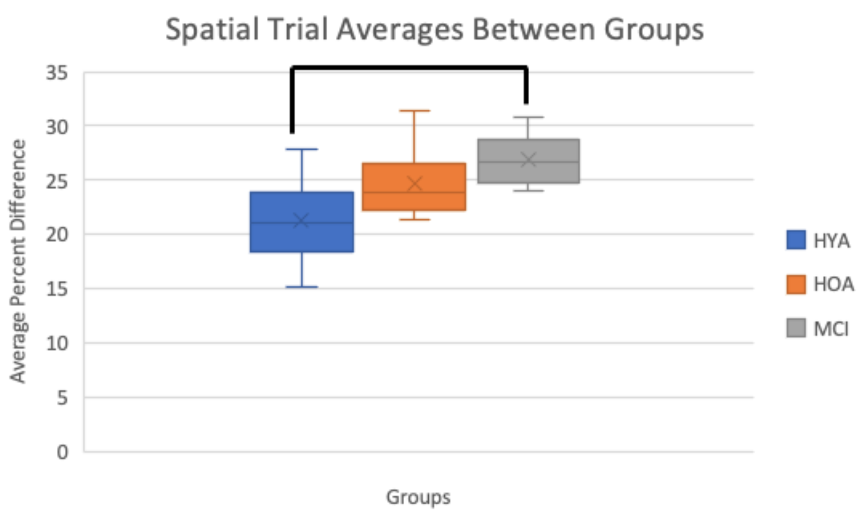


Figure 6: Temporal trial averages between groups

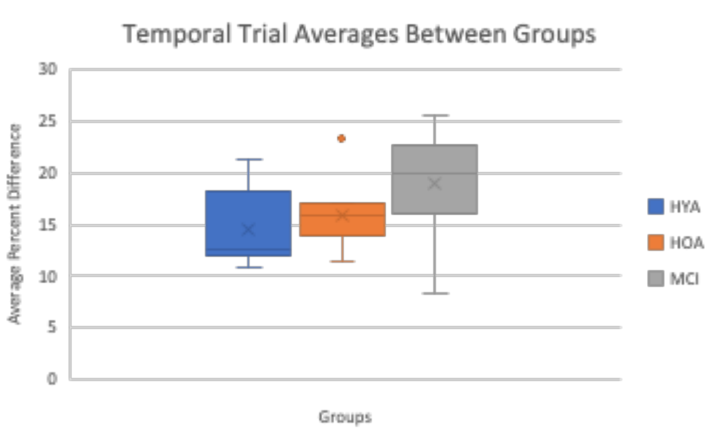


Figure 7: Spatiotemporal averages between groups

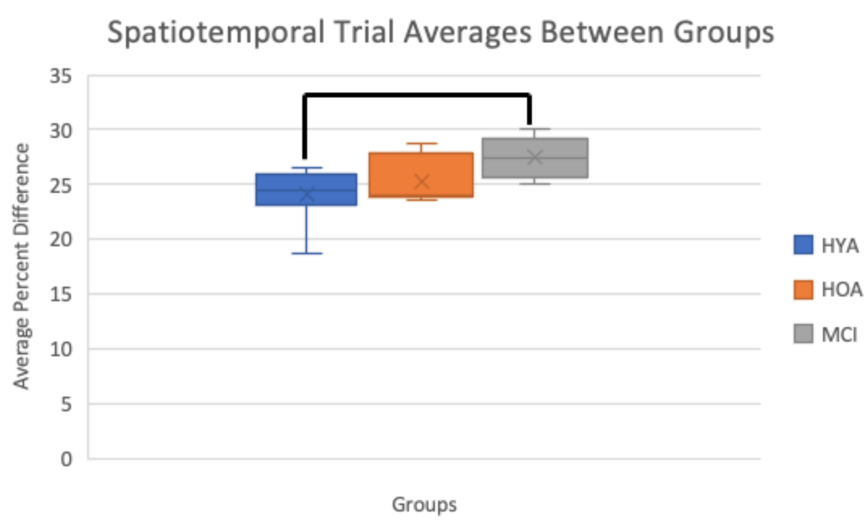


Figure 8: Music relationship versus temporal trial performance

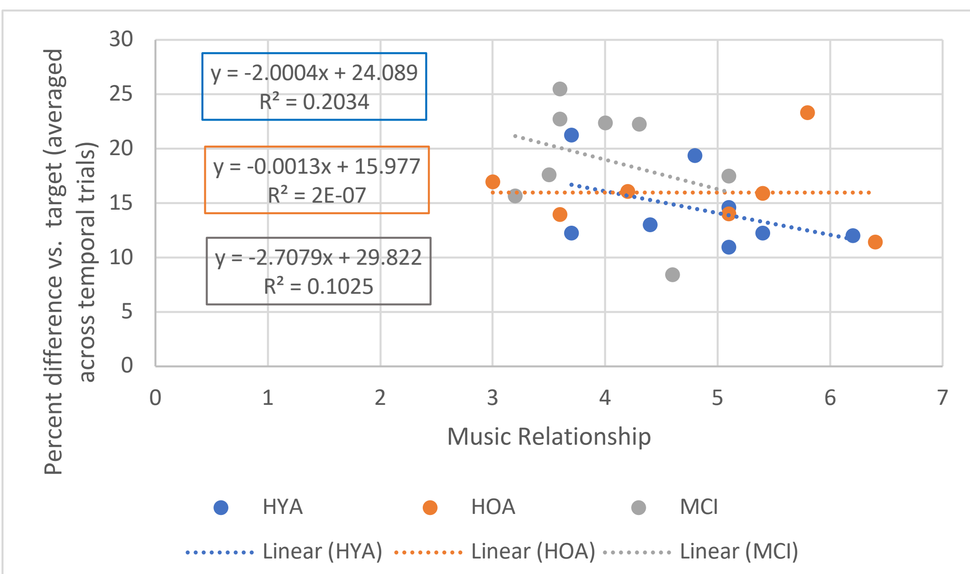


Figure 9: Dance relationship versus spatial trial performance

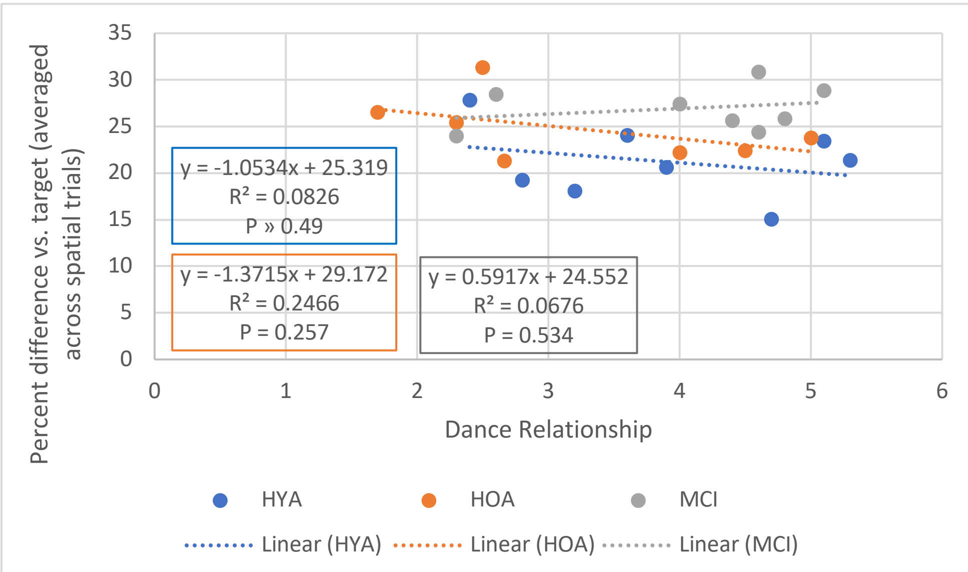


Figure 10: Dance relationship versus temporal trial performance

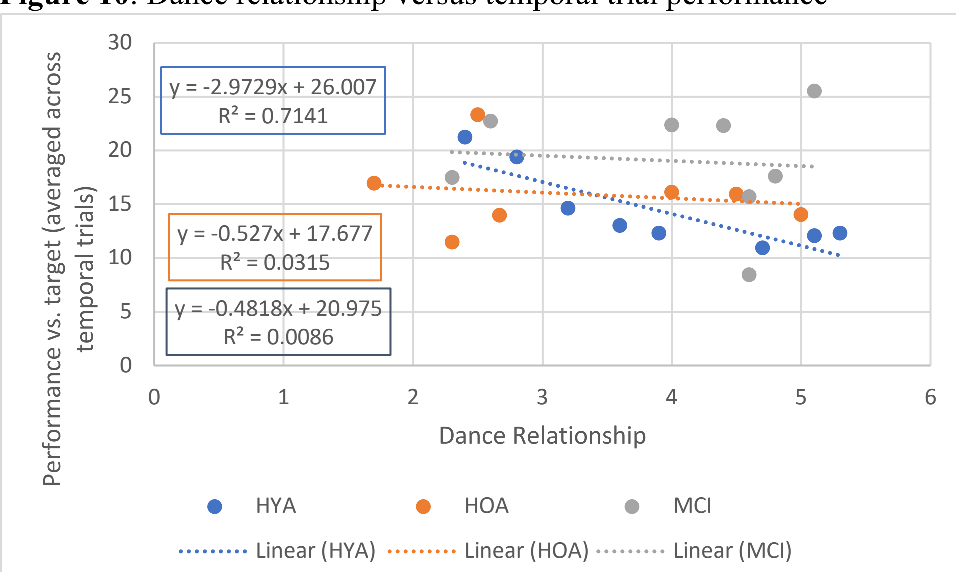


Figure 11: Rhythm Assessment Score and temporal trial performance

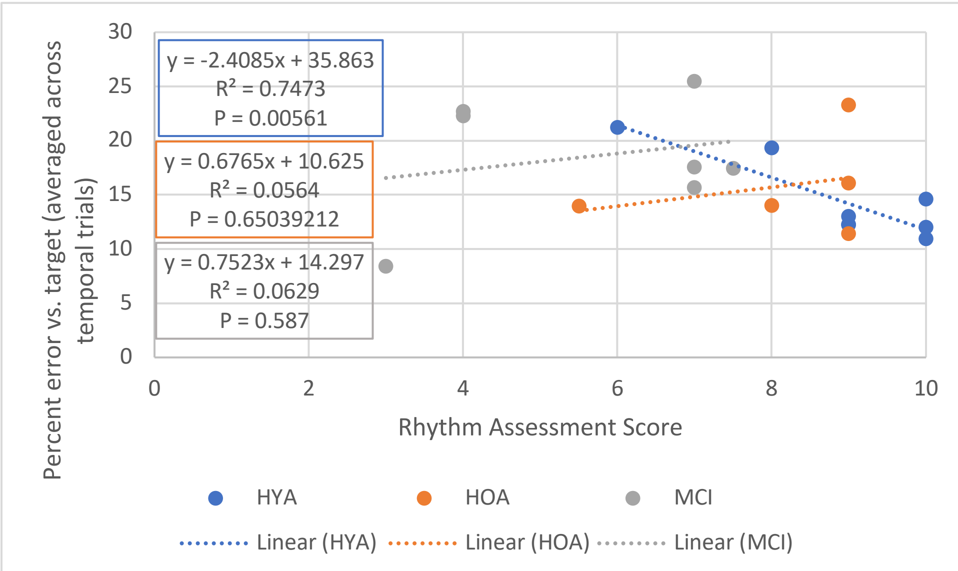
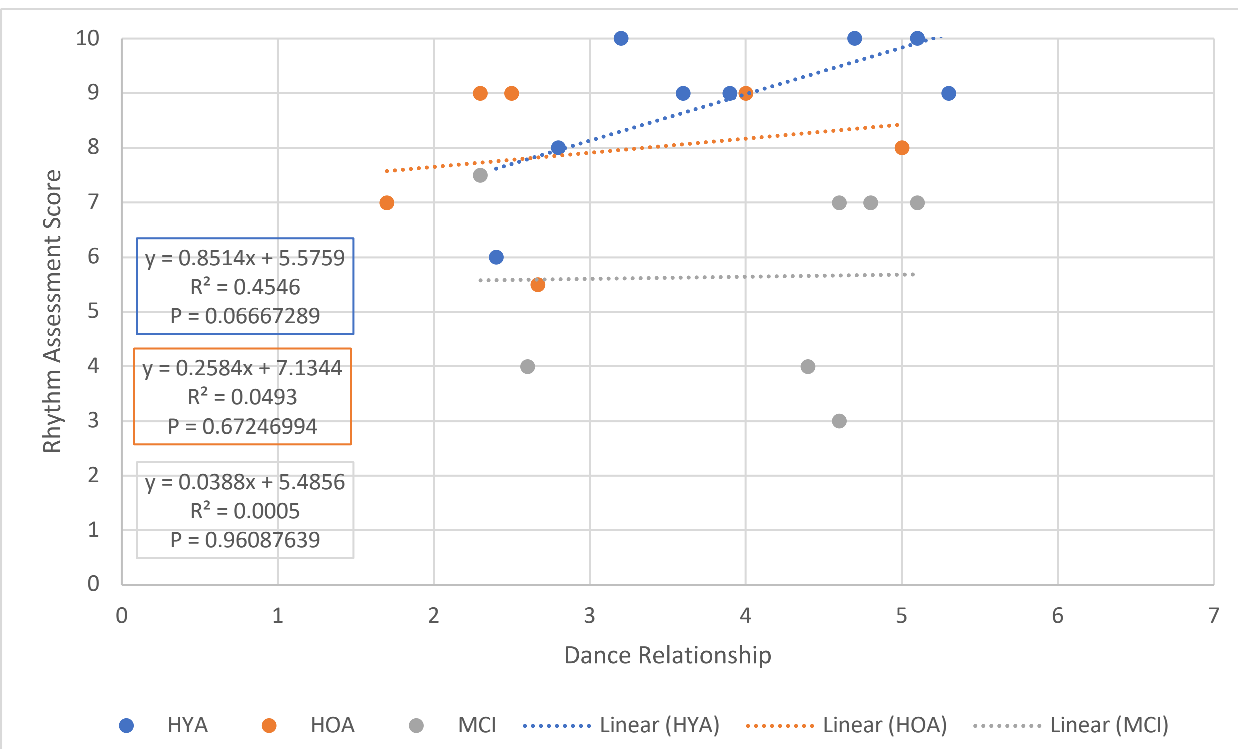


Figure 12: Dance Relationship Composite Score and Rhythm Assessment Score



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