Identifying Ideal Music for Rhythmic Auditory Stimulation: Comparing Subjective Perceptions to Objective Classifications of Groove and Enjoyment on Gait Parameters

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Abstract

The Parkinsonian gait characterized by small, shuffling steps and a stooped posture increases the risk of falling for individuals suffering from this neurodegenerative disease. Rhythmic auditory stimulation (RAS) is a form of physical rehabilitation which involves the synchronization of footsteps to auditory stimuli. RAS produces long term improvements in stride length and stride velocity; attributing to its utility as an alternative treatment to pharmaceuticals and deep brain stimulation for the Parkinsonian gait. However, the success of RAS varies across individuals; therefore, we investigated the potential improvement by selecting music based on personal preference to benefit gait parameters such as stride velocity, stride length, stride time, and stride width. We studied the subjective perception of musical enjoyment and groove by having healthy young adults rate 40 music clips and walk to songs categorized based on three comparison levels; subjective versus objective high groove, subjective versus objective enjoyment, and high versus low enjoyment. In the literature, groove is a musical parameter that is defined by beat strength and is associated with gait improvements. Songs subjectively perceived as high in groove and high in enjoyment were predicted to improve gait significantly more compared to songs objectively categorized for high groove and low enjoyment. We found that walking to objectively categorized low enjoyment songs elicited faster and larger strides, and songs objectively categorized for groove and low in enjoyment reduced the time interval to complete strides. We found no significant effects of enjoyment on gait among neurologically healthy adults. Future studies should investigate the effect of enjoyment directly on the Parkinsonian gait to validate the necessity of selecting music based on personal enjoyment to improve the consistency of RAS and broaden its application as a form of gait rehabilitation.
Keywords: gait rehabilitation, music, rhythmic auditory stimulation, enjoyment, groove.

Introduction

Parkinson's disease (PD) is classified as a severe movement disorder and neurodegenerative disease, exceeded only in incidence by Alzheimer's disease (Hirtz et al., 2007). PD is characterized by the progressive degeneration of the dopamine producing neurons of the substantia nigra pars compacta of the basal ganglia (BG) (Ledger et al., 2008). The BG is primarily involved in motor control and has extensive connections with the supplementary motor area; therefore, many symptoms of PD are motor related (Calabresi et al., 2014). The compromised BG in PD interrupts the ability to control skilled, voluntary actions; therefore, movements become slower and smaller (Morris et al., 2001). The cardinal symptoms include a masklike face, resting "pin rolling" tremor, muscle rigidity, postural instability, and hypokinesia— a reduction in speed and size of movement (Morris et al., 2001). We focused on the distinguishable Parkinsonian gait that compromises the ability of PD patients to walk independently and safely (Grabli et al., 2012; Yogev-Seligmann et al., 2008). The gait consists of a stooped posture, small shuffling steps, reduced arm swing, slight flexion in the hips and knees, flexion of the arms at the elbow and wrist joints, and rigidity or muscle stiffness (Rouse, 2015).

The Parkinsonian gait has been found to be associated with a reduction in the quality of life due to the attenuated locomotion, decreased independence, and increased risk of falls (Grabli et al., 2012; Morris et al., 2001; Bloem et al., 2004). Gait disorders extensively contribute to the financial burdens of the health care system since PD is the second most common neurodegenerative disease and gait disorders are prevalent in about one-third of those over the age of 70 (Hirtz et al., 2007; Cesari et al., 2005; Ostir et al., 2007). Gait disorders are especially a major concern for the health care system because of the other casualties and injuries that can result (de Bruin et al., 2010). Therefore, gait deficiencies often lead to admittance into a long term care facility or the utilization of additional healthcare services (Cesari et al., 2005; Ostir et al., 2007).

In terms of spatiotemporal gait parameters, the Parkinsonian gait has a decreased stride velocity and stride length, and increased stride width and stride time (Morris et al., 2001). A stride is defined as two consecutive steps of the same foot (Leow et al., 2014). Therefore, Parkinson's patients exhibit slower movements and poorer balance control. Slower movements are attributed to decreases in the ratio of stride length to stride time, which defines the gait parameter of stride velocity (Leow et al., 2015). The stride length is the distance covered between the initial contacts of two consecutive steps in the anterior-posterior direction and refers to the step size (Leow et al., 2014). The stride time is the duration of completing one stride (Leow et al., 2014). In early stages of PD the reduced speed is due to the decreased stride length and not the cadence (O'Sullivan et al., 1998). The cadence is defined as the number of steps taken per minute and does not deviate from the healthy range of 100-110 steps per minute until very advanced stages of PD (O'Sullivan et al., 1998). The slower gait in the initial stages of PD is attributed to the smaller step size; therefore, it is particularly beneficial to increase stride length to improve gait. Furthermore, stride width is defined as the horizontal distance between the right and left foot during gait (Leow et al., 2014). Balance control is related to stride width because a wider base of support is achieved through increases in stride width (Charlett et al.,1998).

The more traditional methods of treating PD include pharmaceutical agents, deep brain stimulation, and surgical alterations to the brain. The pharmaceutical precursor of dopamine, Levodopa, maintains dopamine levels by crossing the blood brain barrier to act on appropriate receptors (Laterra et al., 1999). Various nuclei of the BG, in particular the solitary tract nucleus, are treatment targets for deep brain stimulation and surgical approaches (Calabresi P et al., 2014). Deep brain stimulation involves the administration of electric shocks through surgically placed electrodes on a neurological target (Rouse, 2015). Deep brain stimulation and pharmaceutical compounds are effective for relieving most cardinal motor symptoms of PD; however, the benefits on gait are limited and decrease over time (Bella et al., 2015). In a literature review, evidence of the improvement of the Parkinsonian tremor with deep brain stimulation was displayed; however, no significant improvements in gait were elicited by the same treatment (Morris et al., 2001). Therefore, we focused on a form of physical therapy and investigated its utility to serve as an alternative treatment for gait abnormalities in patients with PD (Bella et al., 2015).

Rhythmic auditory stimulation (RAS) is a form of physical rehabilitation that involves the synchronization of footsteps to auditory stimuli (Leow et al., 2015). Metronome tones and musical songs have both been used as auditory stimuli for this music integrated physical therapy (Leow et al., 2015; Berardelli et al., 2001). External cues such as visual, auditory, or other sensory stimuli can be used to guide movement to compensate for deficits of the BG (Berardelli et al., 2001; Morris, 2000). Improvements in gait are manifested through increases in stride length and stride velocity, and decreases in stride time and stride width (Morris et al., 2001). Successful applications of RAS have been found to improve gait through the production of faster movements (Leow et al., 2015). Thus, when RAS is successful, patients walk more quickly by covering the same distance in a shorter amount of time, by taking larger steps, or achieving a combination of both.

The improvements in gait as a result of RAS are long-term and are not restricted to exposure of the sensory stimuli; therefore, the increases in stride length and stride velocity are exhibited in the patients' daily routine (Bella et al., 2015; Leow et al., 2015). The study of RAS is advantageous because it is a non-invasive and less costly alternative to traditional gait treatments (Kwakkel et al., 2007). However, RAS has not been successful when applied to all patients;

therefore, the objective of our study was to identify ideal music to improve the consistency of this treatment, allowing for application to a broader population (Spaulding et al., 2013).

We predicted that personalizing the songs used for RAS would improve the success rate across individuals. We compared how objective classifications to subjective perceptions of musical attributes would impact the spatiotemporal gait parameters—stride velocity, stride length, stride time, and stride width. The songs we used were categorized or perceived to be high in groove, low in familiarity, and high or low in enjoyment. High groove music and familiar music have been determined to elicit faster strides (Leow et al., 2015). Groove is a musical attribute defined as the amount the music induces the desire to move; therefore, the groove level is directly related impulse to move (Madison, 2006). We solely studied high groove songs due to previous evidence of groove improving gait (Leow et al., 2015). In the literature, they found that familiarity may reduce the cognitive requirement necessary for footstep synchronization and that familiarity can induce musical enjoyment (Leow et al., 2015). For a novel investigation, we were more interested in the latter because we wanted to see the effects of enjoyment independent of familiarity. Therefore, we examined low familiarity music to avoid any confounding interactions with musical enjoyment. Furthermore, we studied both spectrums of enjoyment to investigate the finding that music-induced enjoyment can lead to dopamine release impacting motor function (Salimpoor et al., 2011).

We hypothesized that walking to subjectively perceived high groove songs that are highly enjoyed would elicit significant increases in stride length and stride velocity and significant decreases in stride width and stride time, compared to songs objectively categorized for high groove and low enjoyment. Therefore, we expected a main effect of enjoyment such that highly enjoyed songs would elicit better gait. In addition, the enjoyment had to be perceived by the participant in order to improve gait; a song that was collectively enjoyed but not enjoyed by the individual, such as a Billboard song, would not necessarily produce the same gait improvements. We believed that the subjective perception of groove is critical because it is provoking a desire to move; therefore, the amount of movement it is inducing is dependent on the personal qualities of the individual. For instance, some will dance to a high groove song but others may only tap their foot to the beat vigorously because this is the largest movement a high groove song will evoke. Our investigation allowed us to determine the necessity of choosing songs based on the patient's personal ratings or if it is sufficient to use one pool of pre-selected songs that have been classified for the appropriate musical parameters based on collective ratings of a larger sample.

Conclusively, we expected songs subjectively perceived to be high in groove and highly enjoyed by the individual to improve gait significantly more compared to when walking to music objectively categorized to be high in groove but low in enjoyment. Therefore, we believed that it is necessary and effective to have patients rate multiple songs before implementing RAS; in order to increase the likelihood of improving gait. Improving the consistency of RAS is opportune because it is a non-invasive and less expensive treatment that provides lasting gait improvements (Kwakkel et al., 2007).

Materials and Methods

Participants

An ethics proposal number of 106385 was administered by the Human Research Ethics Committee of the University of Western Ontario permitted the execution of this study. The approval allowed us to recruit participants through SONA, the psychology department's research participant pool. We recruited 30 undergraduate students enrolled in a psychology class to participate in studies for monetary compensation or course credit. Participants received half a credit for each half hour of participation. This sample size is similar to a previous study conducted in our lab, which found significant results through a similar paradigm. Only 16 participants were included in data analysis due to incomplete data or technical errors. Consent was obtained from our volunteers only after they were adequately informed. We excluded individuals under the age of 17 and those with hearing or visual impairments that would interfere with the procedure. We chose to examine the potential benefit of personalizing the songs used for RAS on neurologically healthy young adults first. Working with a more feasible population allowed us to see if this treatment modification is worth applying to PD patients. In addition, we followed the standard protocol of our lab, which begins with data collection from neurologically healthy young adults first, followed by Parkinson's patients. Due to the voluntary nature of SONA, we did not aim for any sex specific ratios but we did keep track of biological sex for potential sex differences in the resulting data. The experimental protocol began with participants completing a questionnaire that provided information about their sex, educational background, current mood, psychotropic drug use, psychiatric or neurological health, dance or music training, and past participation in gait studies.

Design

To compare the effects of objective classifications and subjective perceptions of enjoyment and groove, we created eight experimental groups, depicted in Figure 1, based on a three level comparison between: (1) objective versus subjective groove, (2) objective versus subjective enjoyment, and (3) high versus low enjoyment. The assigning of three songs to eight experimental groups resulted in 24 trials that required participants to walk to musical stimuli. Only high groove songs were examined, unless specified, further mention of groove in regards to the experimental conditions refers to high groove. Therefore, objective groove, implies objective high groove.

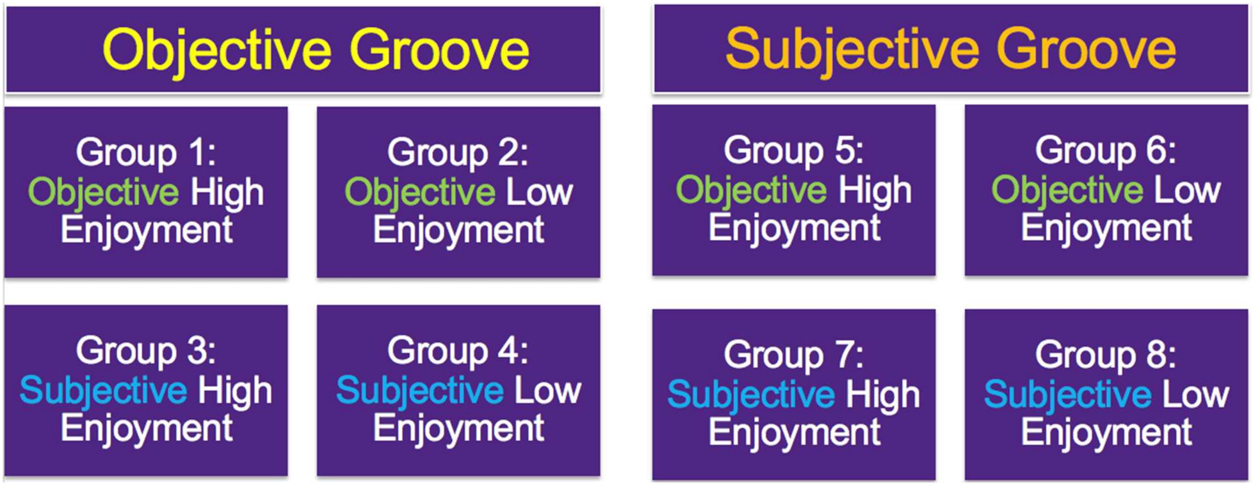

Figure1. Study design. Eight experimental groups were formulated from the three levels of comparison; objective versus subjective groove, objective versus subjective enjoyment, and high versus low enjoyment.

Song Selection

Prior to the study 40 songs were selected for investigation. Songs were selected based on ratings given in previous studies conducted in the lab. We averaged the ratings for familiarity, groove, and enjoyment given by previous participants to deem objective categorizations of songs of high groove, low familiarity, and high or low enjoyment. However, some songs that were selected were not used in previous studies; therefore, they were piloted for familiarity, groove, and enjoyment ratings, which were then averaged for assigning into the appropriate musical parameter categorizations. A 100- point rating scale was used and a value of 50 determined if songs were high or low in a given category. Thus, all 40 songs were given an objective rating prior to the experimental protocol based on averaged ratings collected from a variety of people. These averaged ratings determined the objective classification of the songs.

All 40 songs were objectively categorized to be high in groove and low in familiarity, along with half the songs objectively categorized as highly enjoyed and the other half as lowly enjoyed. Using MixMeister BPM version 1.0 (Ft. Lauderdale, FL) the tempo was calculated to ensure that all the songs were within the range of 100-135 beats per minute, which is matched to the range of a healthy cadence. These 40 songs were then separated into four different lists, each list contained five songs rated high in enjoyment and five songs of low enjoyment. Statistical analyses such as, un-paired t-tests and measures of standard deviation, ensured that there were similar averages in groove, enjoyment, and familiarity across the four lists. This avoided the use of songs that could be distinctively identified as a better song because of an excessively high rating for a parameter identified to improve gait. This was necessary because we were interested in identifying general musical patterns that can be applied to personalize RAS to improve the consistency. Our objective was not to find individual songs that improve gait.

Experimental Protocol

Ratings Task

Participants listened to 10 second music clips of the 40 preselected songs played in random order. Ratings were based on a 100-point Likert scale using the LABVIEW Evaluation Software version 14.0f1 (Austin, TX). The rating scales used for the different parameters are as follows: (1) familiarity: How familiar are you with this piece of music? 1 = never heard this song before, 100 = know this song so well, can predict what happens next; (2) groove: How much does this piece of music make you want to move to it? 1 = no desire to move, 50 = moderate desire to move, 100 = strong desire to move; (3) enjoyment: How much do you enjoy listening to this piece of music? 1 = strongly dislike this song and 100 = strongly like this song; and (4) beat salience: How strong is the beat in this piece of music? 1= very week and 100 = very strong.

Assigning musical stimuli to an experimental trial

Based on the participant number, a MATLAB version 8.6 (Natick, MA) designed algorithm used the Latin square method to assign an experimental condition to each of the four lists. One of the four lists was assigned to represent a combination of objective or subjective groove or enjoyment. For instance, one list for a given subject represented the condition of objective groove-subjective enjoyment. The algorithm then proceeded to select three songs of high enjoyment and three songs of low enjoyment from each of the four lists to satisfy the high or low enjoyment categorizations to create the eight experimental groups.

In the odd case of the MATLAB script failing to work entirely, the songs were assigned to the eight experimental groups by the experimenter. The experimenter would sort through the participant's ratings to assign songs to match the subjective element of the experimental group. Only high groove songs were examined; therefore, the experimenter would only select for songs rated above 50 for groove to satisfy the requirement. To satisfy the subjective enjoyment classifications, the experimenter would select for high enjoyment songs when the ratings were above 50 and select for low enjoyment songs when the ratings were below 50. To satisfy the objective enjoyment and objective groove classifications, the songs were matched according to the averaged ratings collected prior to the experiment. In an ideal situation, four songs would not be selected from the list because one list provides songs to two experimental groups. This was done purposely to ensure that each participant would have enough songs to satisfy each experimental group.

In some instances, the ratings did not extend across a wide enough range to have at least one song assigned to every experimental group. High classifications of musical parameters were determined with values above 50 and low classifications for values below 50. In order to satisfy the experimental condition of subjective groove, this entailed that we needed at least six songs from the list to be rated above 50 for groove by the participant to satisfy the subjective high groove component. Satisfying the experimental condition of subjective enjoyment required at least three songs from that one list to be rated above 50 and three songs rated below 50 for enjoyment by the participant. If these requirements were not met, we conducted the song selection without the use of the script and used the median value of the participant's ratings for the list specific musical parameter as the cut-off point to assign high and low classifications. For instance, we would find the median value of groove for list three to determine the high and low groove classifications.

Walking Trials

The walking trials began with participants walking at their preferred cadence to constitute the baseline walk. The following trials were conducted with the participant walking to music freely as the musical stimuli induced. Participants walked to three songs for each of the eight experimental groups and two metronome tones to account for a total of 26 walks to auditory stimuli. The auditory stimuli were played in a random order to avoid confounding effects. Neither the research or participant was aware of what song was being walked to and which experimental condition that song belonged to, constituting a double blind study.

For each walking trial, the subject walked eight lengths of the pressure sensitive Zeno walkway (Peekskill, NY), which collected data to be analyzed by the ProtoKinetics Movement Analysis Software Version 5.06C2i3 (PKMAS) (Havertown, PA). Reliable measurements were obtained by informing subjects to begin and finish their walks at a point of 1.78m off the mat and to gradually change direction by widening their turns at the same speed, instead of making sharp abrupt turns (Leow et al., 2015).

The ProtoKinetics Movement Analysis Software processed the gait information from the Zeno walkway and calculated the stride velocity, stride length, stride time, and stride width for every subject. Stride length (cm) was measured between the initial point of contact of two consecutive steps of the same foot (Leow et al., 2015). Stride time (s) was measured as the time duration between the initial contact of two consecutive steps of the same foot (Leow et al., 2015). Therefore, stride velocity (cm/s) was measured as the ratio of stride length to stride time, defined as the distance moved by two consecutive steps per unit time (Leow et al., 2015). Stride width (cm) was measured perpendicular to the anterior-posterior direction of the stride; it is the horizontal distance between the right and left foot that connects the initial heel contact of two consecutive steps (Leow et al., 2014).

Statistical Analyses

We investigated how the gait parameters changed in relation to baseline walking. Therefore, we calculated a normalized change score for statistical analysis. The purpose of this calculation was to reduce individual differences for factors such as leg length. The following equation was used: normalized change score = (gait parameter—baseline gait parameter) /

baseline gait parameter. Therefore, all statistical analyses were conducted on gait parameters that were normalized to baseline gait parameters.

We compared the effects in which the objective and subjective attributes of enjoyment and groove have on stride velocity, stride length, stride time, and stride width, by using a three-way, repeated-measures ANOVA followed by a Bonferroni Post- hoc test. We identified significance with an alpha criterion of ≤ 0.05 using SPSS. We chose this type of statistical analysis because we were conducting a three pairwise interaction with every subject exposed to all comparisons, hence the repeated measure. The three pairwise interaction was between: (1) subjective versus objective enjoyment, (2) subjective groove versus objective groove, and (3) high enjoyment versus low enjoyment. Paired student t-tests were applied when necessary to identify any significant between factor interactions with an alpha criterion of ≤ 0.05, after significance with the three-way, repeated measures ANOVA was found.

Results

Stride Velocity

Figure 2 exhibits a normalized change score for stride velocity; therefore, positive data represents increased stride velocity compared to baseline and negative data represents a decrease compared to baseline. A significant interaction between objective versus subjective enjoyment and high versus low enjoyment was found [$F(1,16) = 4.720$, $P = 0.046$, $\eta_p 2 = 0.239$].

After finding significance with the three-way, repeated measures ANOVA we performed student's paired t-tests and found significant differences in stride velocity between musical conditions of objective high enjoyment and objective low enjoyment ($P = 0.049$). The percent change in stride velocity from baseline was significantly greater when walking to low enjoyment songs compared to high enjoyment songs, categorized objectively for enjoyment. Walking to objectively categorized lowly enjoyed songs elicited faster strides.

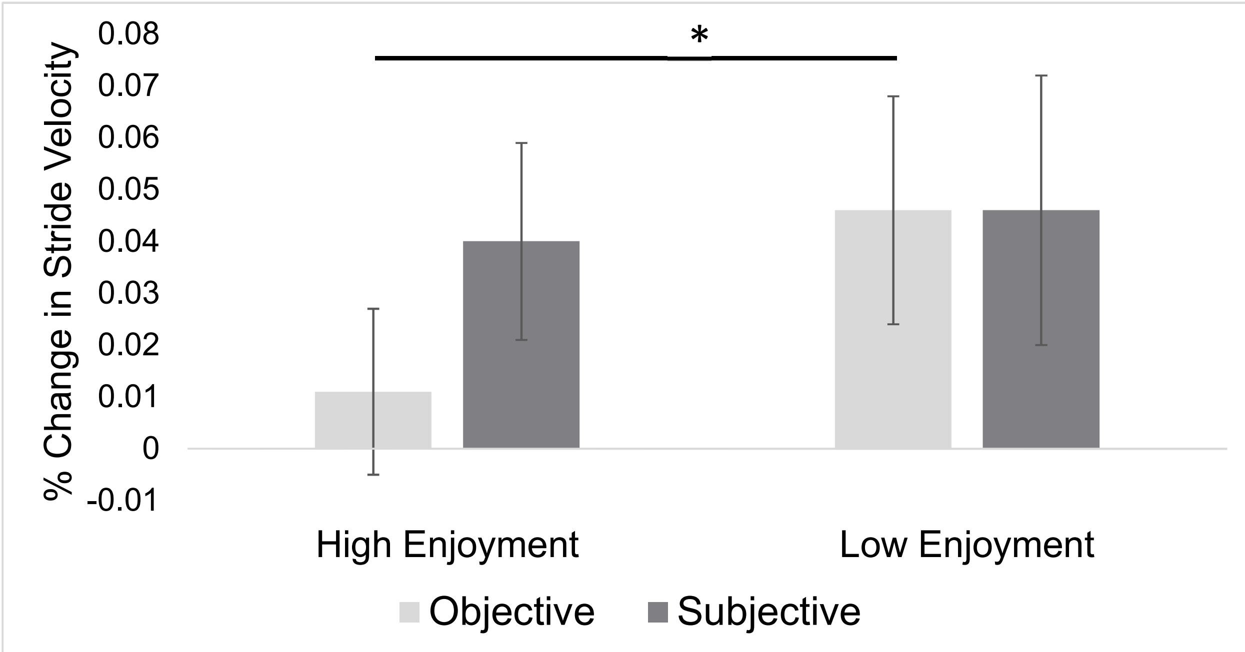

Figure2. % Change in stride velocity was calculated from the walking to music trials to compare the effects of objective versus subjective enjoyment and high versus low enjoyment on gait. Averages of the stride velocity normalized to baseline ± SEM with N=16. Significant increases in % change of stride velocity when walking to songs of objective-low enjoyment compared to songs of objective-high enjoyment (*, $p<0.05$; three-way, repeated measures ANOVA, student's paired t-tests).

Stride Length

Figure 3 displays normalized changed scores for stride length; therefore, positive results display an increase in stride length compared to baseline and negative results show a decrease compared to baseline. A significant interaction between objective versus subjective enjoyment and high versus low enjoyment was identified [$F(1,16) = 6.081$, $P = 0.026$, η_p2 = 0.288].

We conducted student's paired t-tests after finding significance with the three-way, repeated measures ANOVA and found significant differences in stride length between objective high enjoyment and objective low enjoyment stimuli ($P = 0.0022$). The percent change in stride length from baseline was significantly greater when walking to low enjoyment songs compared to high enjoyment songs, categorized objectively for enjoyment. Walking to objectively categorized lowly enjoyed songs elicited larger strides.

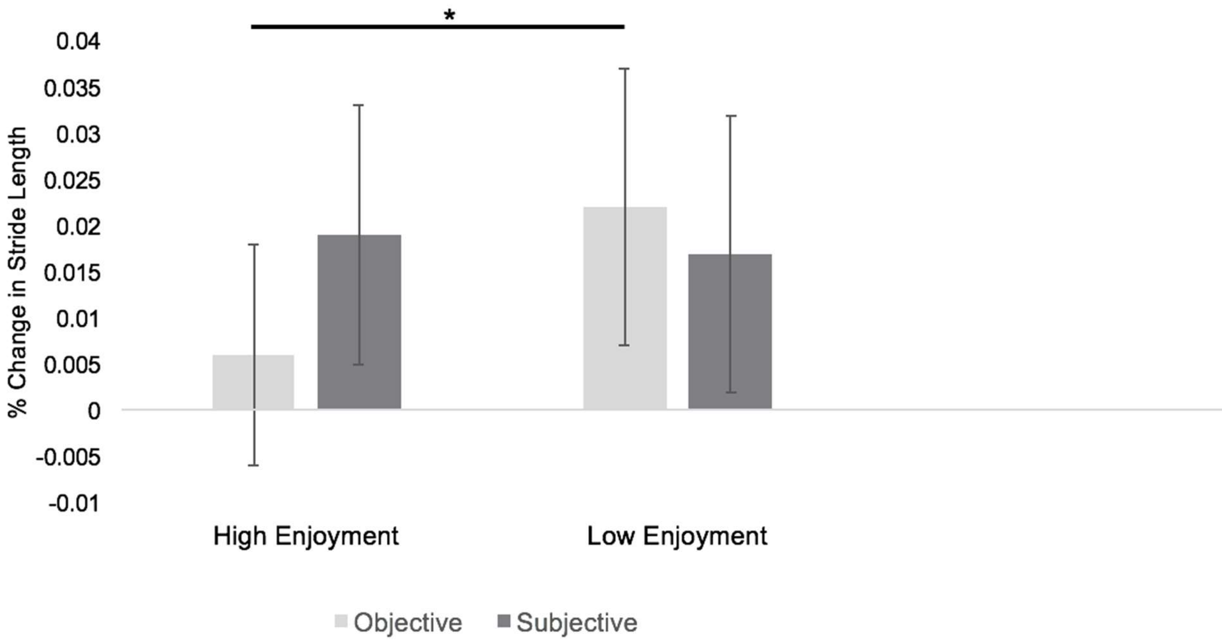

Figure3. % Change in stride length was calculated from the walking to music trials to compare the effects of objective versus subjective enjoyment and high versus low enjoyment on gait. Averages of the stride length normalized to baseline ± SEM with N=16. Significant increases in % change of stride length when walking to songs of objective-low enjoyment compared to songs of objective-high enjoyment (*, $p<0.05$; three-way, repeated measures ANOVA, student's paired t-tests).

Stride Time

Figure 4 shows the normalized changed scores for stride time; therefore, positive values show increases in stride time compared to baseline and negative values show decreases compared to baseline. Significance for the interaction between objective versus subjective groove and high versus low enjoyment was found [$F(1,16) = 5.191$, $P = 0.038$, $\eta_p 2 = 0.257$].

We used student's paired t-tests to identify significant differences between specific musical conditions, after finding significance with the three-way, repeated measures ANOVA. We found significant differences in stride time between the high enjoyment and low enjoyment stimuli, both categorized objectively for groove ($P = 0.0094$). The % change in stride time from baseline was significantly reduced when walking to low enjoyment songs compared to high enjoyment songs, categorized objectively for groove. Walking to lowly enjoyed songs, objectively categorized for groove elicited shorter stride times.

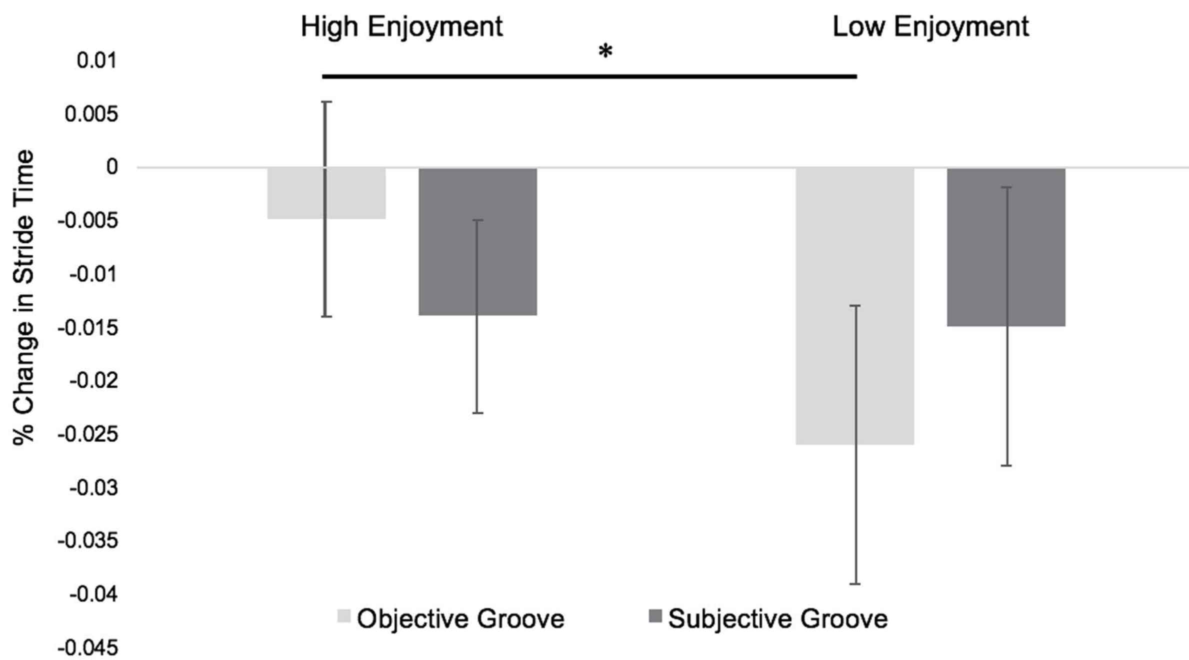

Figure4. % Change in stride time was calculated from participants' walking to music trials to compare the effects of objective versus subjective enjoyment and high versus low enjoyment on gait. Averages of the stride time normalized to baseline ± SEM with N=16. Significant decreases in % change of stride time when walking to songs of low enjoyment versus high enjoyment, both objectively categorized for groove (*, $p<0.05$; three-way, repeated measures ANOVA, student's paired –tests).

Discussion

Our study displayed no effect of enjoyment on gait contrary to our hypothesis. We found significant increases in stride velocity and stride length from baseline when walking to songs objectively categorized for low enjoyment. In addition, we found significant decreases in stride time from baseline when walking to songs objectively categorized for groove and for low enjoyment. As stated, gait improvements are manifested through increases in stride length and stride velocity and decreases in stride width and stride time (Morris et al., 2001). Subjective manipulations of enjoyment did not result in any significant differences in gait and it was the objective manipulations of low enjoyment that improved stride velocity, stride length, and stride time. Therefore, our results displayed that there was no significant effect of musical enjoyment on gait, contrary to our prediction that subjective manipulations of high groove and enjoyment would improve gait. Lastly, there were no significant interactions between the musical parameters to produce significant differences in stride width from baseline.

We initially predicted that in regards to music, the subjective perception of enjoyment would significantly improve gait more than music objectively categorized for enjoyment. This prediction was based on a RAS study that instructed participants to walk to a personalized playlist of music tailored to their musical preference for three times a week (de Bruin et al., 2010). This investigation of personalizing RAS improved gait velocity, stride time, and cadence; and reduced the severity of motor symptoms accompanying PD (de Bruin et al., 2010). Abstract rewards including music are largely cognitive in nature and are very specific to cultural and personal preferences (Salimpoor et al., 2001). Therefore, it was unexpected to find that the subjective manipulation of enjoyment would not significantly effect gait and lead to no improvements in our study.

Similar to the personalized RAS study, we selected songs based on personal preferences but we did not see the same gait improvements. It is probable that the improvements they saw were attributed to familiarity or an interaction with familiarity since familiarity can lead to increased enjoyment (van den Bosch et al., 2013; Schellenberg et al., 2008). Since the songs were tailored to the participant's preference of genre, artist, and song; it is likely that the songs were familiar. If the songs were not familiar initially, the repetitive exposure would eventually establish it. However, we chose to study enjoyment independent of familiarity and this could contribute to the different results despite the similar paradigm of tailoring songs to the individual.

Further, we predicted that music of high enjoyment would elicit significant improvements in gait compared to using music of low enjoyment. We based our prediction on the finding that the pleasure related to listening to enjoyable music is associated with dopamine activity (Salimpoor et al., 2011). Music is a rewarding stimuli that can directly stimulate dopaminergic neurotransmission within the mesolimbic system (Salimpoor et al., 2011). Dopamine release induced by musical enjoyment is associated with the production of faster movements (Mazzoni et al., 2007). The literature has investigated that the dopamine released by musical enjoyment of unfamiliar music is due to positive prediction errors (Salimpoor et al., 2015; Saunders et al., 2013; Schultz, 2013). Positive prediction errors are unexpected stimuli that induce dopamine release (Glimcher, 2011). Positive prediction errors contribute to the idea that musical pleasure is believed to be dependent on the production of expectations (Rohrmeier and Koelsch, 2012). When individuals initially listen to a song, they cannot store all the aspects; therefore, re-exposure allows the prediction of an initially un-expected reward and the generation of an expectation will coincide with musical pleasure (Salimpoor et al., 2015).

Thus, we did not anticipate that songs objectively categorized for low enjoyment would produce significant improvements in stride velocity, stride length, and stride time. If there is no musical pleasure, faster movements should not be elicited because there is no stimulation of dopamine activity. The association between low enjoyment music and faster, larger strides contradicted our prediction based on musical pleasure inducing dopamine release (Salimpoor et al., 2011).

We predicted that songs subjectively perceived to be high in groove would elicit improvements in gait. Therefore, we did not expect songs objectively categorized for groove that were low in enjoyment to result in significant decreases in stride time. Contrary to our initial prediction, groove may be more of an objective measure due to its direct association with beat salience, a musical parameter that can be calculated with algorithms (Janata et al., 2012). The association between groove and beat salience remains whether, groove is compared to a computed or perceived measure of beat salience (Janata et al., 2012). It is possible that groove is more of an inherent property of the music and less related to the individual's perception, explaining the promotion of faster stride times when walking to music objectively categorized for groove.

We predicted that songs subjectively perceived to be high in groove and high in enjoyment would produce decreases in stride width. This prediction followed the principle that increases in stride width allow for a wider base for support, serving as an indicator of compromised balance (Martin et al., 2016). Furthermore, it has been found that during faster walking speeds an individual's center of mass is less displaced in the mediolateral direction, resulting in a decreased stride width (Orendurff et al., 2004). Since we predicted that the subjective perception of enjoyment and groove should elicit faster strides and improve balance, it was unexpected that the participants did not display significant decreases in stride width. However, our participant pool consisted of neurologically young healthy adults that displayed non-significant decreases in stride width when walking to musical stimuli. Older adults, the typical group affected by PD, tend to walk slower and this is associated with increases in stride width (Morris et al., 2001; Orendurff et al., 2004). It is possible that significant decreases in stride width were not exhibited from baseline because younger people tend to have faster gait and their balance is not as compromised, compared to older adults (Martin et al., 2016). Therefore, increases in stride width are not as significant among younger adults who do not need to compensate as much for speed and balance deficits.

Limitations

The protocol for song selection prior to the beginning of the study may have limited our selection of songs that truly constitute high or low enjoyment songs. Previously mentioned in the materials and methods, unpaired t-tests and measures of standard deviation were used to ensure that songs within the four lists were consistently low in familiarity, consistently high in groove, and consistent for enjoyment across all lists. However, significant differences of enjoyment within the lists was necessary to satisfy the high and low conditions. We identified significance with an alpha criterion of ≤ 0.1; therefore, consistencies were determined with p-values above 0.1.

For post-analysis purposes, we averaged the objective high enjoyment values, collected from averages of ratings conducted before the study, for every song and found an average of 59.85. The same was conducted for the objective low enjoyment songs and we found a value of 41.07. This lead us to believe that these are not the best representations of high and low enjoyment song, considering a value of 50 was used to determine high and low enjoyment. None of the songs represented either end of the enjoyment spectrum, which was necessary to keep the lists consistent but perhaps our alpha criterion was too stringent resulting in a poor representation of enjoyment.

In addition, we averaged all the ratings, from the 16 participants, for the 20 songs objectively categorized for low enjoyment and the 20 songs objectively categorized for high enjoyment. There was only a difference of two between these averages, allowing us to confirm that these songs were not effective gauges of high and low enjoyment.

Therefore, the stringent alpha criterion that permitted the selection of songs and the number of songs that were rated and potentially walked to, resulted in poor representations of contrasting musical enjoyment. If we lower the alpha criterion, expand the number of songs selected, or carry out both actions we can obtain better representations of high and low enjoyment music.

Future Studies

The largely cognitive nature of music makes it heavily influenced by personal and cultural preferences; therefore, a particular song can have vastly varying influences across individuals (Salimpoor et al., 2011). The impacts of enjoyment on gait should be further studied with the limitations of this study improved upon. The recruitment of patients with gait disorders, particularly Parkinson's patients, is necessary to determine the utility of manipulating enjoyment when selecting songs for RAS. The investigation of enjoyment independent of familiarity should be further analyzed to confirm if there is an interaction between enjoyment and familiarity or if each can independently improve gait. Both are relevant findings because if the former is confirmed, it is sufficient to rely on familiar music for RAS protocols. This can be enforced by using mainstream music or repeating exposure to songs even if they are not initially recognizable. If the latter is confirmed, independent musical manipulations of enjoyment and familiarity are sufficient to improve gait but a combination can produce additive benefits to gait.

Another musical parameter that can be investigated is beat strength. One study displayed that metronome tones did not produce significant differences in gait compared to familiar and high-groove music (Leow et al., 2015). Perhaps, manipulations of beat salience can elicit improvements in gait during RAS. One of the potential explanations for RAS refers to the improved motor ability due to the additional activation of the BG caused by beat-based rhythms (Grahn and Watson, 2013).

Studies in the literature have shown that the BG responds during perceptions of beat-based rhythms (Grahn and Brett, 2007). During beat perception, the BG is more activated and there is greater communication between the BG and cortical motor areas including the supplementary motor cortex and the pre-motor cortex (Grahn and Rowe, 2009; Grahn and Watson, 2013). Therefore, it is possible that the beat salience of the auditory cue can be related to the activation level of the BG. A more prominent beat could be associated with increased activation of the BG or an amount of activation necessary to surpass the increased threshold of a defective BG. A study to investigate these speculations with a neuroimaging portion can be valuable. The neuroimaging portion can identify cortical areas that are responsive to the external auditory stimuli and the coupled motor areas responsible for the improvements in motor abilities when implementing RAS.

Conclusion

In conclusion, we find that musical enjoyment has no benefits on gait. Further investigations of musical enjoyment independent of familiarity should be considered, to confirm the interaction between such parameters or the distinctive role each parameter plays to benefit gait. Beat strength is another musical factor that can be examined to conclude if music with greater beat salience can elicit improvements in gait. Neuroimaging studies and recruitment of individuals with gait disorders should be incorporated into future studies to validate the utility of applying the effort to select music based on certain criteria to improve RAS.

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