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Musical enjoyment does not enhance walking speed in healthy adults during music-based auditory cueing

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ABSTRACT

Background: Rhythmic Auditory Stimulation (RAS) involves synchronizing footsteps to music or a metronome to improve gait speed and stability in patients with neurological disorders, such as Parkinson's disease. However, responses to RAS vary across individuals, perhaps because of differences in enjoyment of the music or in musical abilities.
Research question: Intuitively, musical enjoyment may influence gait responses to RAS, but enjoyment has not been systematically manipulated nor the effects empirically assessed. In addition, differences in beat perception ability are likely to influence gait responses to music, particularly when synchronizing to the beat. Therefore, we asked: how does music enjoyment alter gait, and do gait parameters differ between individuals with good versus poor beat perception ability, specifically when instructed to 'walk freely' versus 'synchronize to the beat'?
Method: Young adults and older adults walked on a pressure sensor walkway in silence and to music that they had rated as either high or low in enjoyment, as well as a metronome. All stimuli were presented at 15 % faster than baseline cadence. Participants either walked freely to the music or synchronized to the beat.
Results: Music enjoyment had no significant effects on gait in either younger or older adults. Compared to baseline, younger adults walked faster (by taking longer strides) to music than the metronome, whereas older adults walked faster (by taking more steps per minute) to the metronome than music. When instructed to synchronize vs. walk freely, young adults walked faster, but older adults walked slower. Finally, regardless of instruction type, young adults with poor beat perception took shorter and slower strides to the music, whereas older adults with poor beat perception took slower strides to the music.
Significance: Beat perception ability, instruction type, and age affect gait more than music enjoyment does, and thus should be considered when optimizing RAS outcomes.

1. Introduction

Moving in time to a musical beat, e.g., foot tapping, is a spontaneous human behavior [1], which has been harnessed by Rhythmic Auditory Stimulation (RAS): a therapeutic technique for improving gait impairments by asking individuals to synchronize steps to a beat [2]. In patients with Parkinson's disease, RAS can improve stride velocity, stride length, cadence, and gait stability [3].

RAS may affect gait because the regular beat in music activates motor regions of the brain [5]. Moreover, music subjectively rated as inducing a greater urge to move, a characteristic termed 'groove' [6], elicits faster movement in tapping and walking tasks [7–9] than music rated lower in groove [7].

One factor that has not been assessed in the context of RAS is enjoyment of music, despite that fact that enjoyment correlates closely with groove [6], and individuals anecdotally report that music makes them want to move and dance. Listening to enjoyed, or rewarding, music increases dopamine levels in the basal ganglia [9]. Furthermore, reward increases speed of movement, even in patients with Parkinson's disease [10]. Musical reward may therefore account for the spatial and temporal gait changes observed previously with high vs. low groove music [11]. Thus, the aim of this paper is to isolate how high vs. low music enjoyment alters gait independently of groove during RAS.

Enjoyment may interact with another factor that accounts for variability in RAS responses: beat perception ability [12,13]. Musical enjoyment may drive gait responses to a greater degree in poor than

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good beat perceivers, as reward-based responses to music may be intact whereas beat-related motor responses may be reduced [14]. Moreover, beat perception ability may interact with task instructions: poor beat perception ability may make finding the beat in music difficult, and synchronizing may create a dual task that slows gait [15]. Dual-task effects are also larger in older than young populations [16]. Walking freely, without a requirement to synchronize, reduces the dual task, and may benefit poor beat perceivers, particularly if they are older.

To assess the effect of enjoyment on gait during RAS, healthy young and older adults walked to music that they rated as either high or low in enjoyment. Beat perception ability was assessed to determine differences in gait responses between good and poor beat perceivers. Finally, instructions to synchronize were manipulated to assess interactions with musical properties and beat perception ability observed in previous research [8]. Enjoyable music was hypothesized to produce faster stride velocity, longer stride length, higher cadence, and shorter double support time (DST) than unenjoyable music in both young and older adults. In addition, poor beat perceivers were hypothesized to show greater improvements with high-enjoyment music while freely walking than when instructed to synchronize.

2. Method

2.1. Participants

Of the 173 participants, 82 healthy young adults (18 to 31 years old, 35 males, 47 female), and 86 healthy older adults (49 to 90 years old, 26 males, 60 females) were analyzed (see Table 1). All participants were able to walk unaided and reported normal hearing. Three older adults were excluded from analyses due to missing data (not consistently walking on active area of walkway). After calculating the mean of each gait parameter across all walking trials, two additional participants, one younger and one older adult, were excluded for falling two standard deviations below the mean for each gait parameter. Participants were compensated 10$/hour. Western University's Human Research Ethics Board approved the study (106385).

2.2. Materials

Two separate lists of 32 instrumental songs were used for young and older adults, based on pilot data ratings indicating they were reliably rated low in familiarity, high in groove, and consistently high or low in enjoyment (see *Supplemental 1*). Music clips rated high in beat salience were selected to support participants in walking to the beat. Using Audacity (http://audacity.sourceforge.net), a range of tempos (beats per minute; bpm) for each stimulus was produced which were normalized to the same relative volume while preserving pitch (music clips are available at http://www.jessicagrahn.com/RobertsReadyGrahnEnjoyment.html). The stimulus tempo was matched to a rate 15 % faster than each participant's walking cadence (steps per minute), in line with clinical practice [17] as well as previous studies in young [11] and older adults [18].

A 16-foot pressure sensor walkway (Zeno™) was used to measure spatiotemporal gait parameters. During walking trials, wireless headphones (Sennheiser HRD 160) were used to present stimuli. To measure beat perception ability, participants completed the Beat Alignment Test (BAT) perception subtest. This validated test has high test-retest reliability (Cronbach's alpha = .87–.92) and the average test accuracy typically ranges from 50 to 100% correct (norms from n = 134,984 sample yielded mean accuracy of 77 % [SD = 16 %]) [19]. Participants also completed a demographic questionnaire on music/dance training and music preference.

2.3. Procedure

2.3.1. Beat alignment test and baseline gait trial

Participants first completed the BAT perception test, in which they identified whether beeps superimposed on music clips were 'on' or 'off' the beat of the music [19], then a silent (baseline) walking trial. Participants walked eight continuous passes of the walkway at a self-selected walking pace. To capture steady state walking and minimize recording of accelerating/decelerating gait, participants walked to floor markings 1.78 m past the end of the walkway before turning to re-enter the walkway.

2.3.2. Rating task & stimulus selection

Participants rated, on a 100-pt scale, 10-second stimulus excerpts, adjusted to 15 % faster than baseline cadence, from the older adult or young adult databases on enjoyment, familiarity, groove, and beat salience. Using each participant's ratings, individualized stimulus lists were created for the walking task (each list had 18 stimuli: eight low enjoyment, eight high enjoyment, two metronome) since music enjoyment differs between individuals (see Table 2). To minimize differences between the high and low enjoyment lists in familiarity, beat salience, and groove, a custom MATLAB R2015b (https://www.mathworks.com/products/matlab/student.html) script performed a series of t-tests to select songs rated low in familiarity (rated < 50), high in beat salience (rated > 50), and that differed minimally in groove between low and high enjoyment conditions (see *Supplemental 2*). Full-length versions of the music clips, as well as two metronome clips, were then used for Cued Gait Trials (see Fig. 1).

2.3.3. Cued gait trials

Participants were randomized to either free walking (walk

Table 1
Demographics of younger and older adults.

Population	Age	N	Free Walking Group: Average Beat perception score [*SD*]	Free Walking Group: Years of Music training [*SD*]	N	Synchronized Group: Average Beat perception score [*SD*]	Synchronized Group: Years of Music training [*SD*]
Young Adults							
Poor Beat perceiver		19	.51 [*.11*]	2.37 [*3.89*]	21	.56 [*.06*]	3.93 [*5.07*]
Good beat perceiver		21	.82 [*.09*]	8.60 [*5.57*]	20	.80 [*.09*]	9.48 [*7.12*]
Average	22 [*2.88*]		.67 [*.18*]	5.64 [*5.73*]		.68 [*.14*]	6.63 [*6.34*]
Older Adults							
Poor beat perceiver		21	.48 [*.11*]	5.86 [*9.04*]	19	.53 [*.10*]	5.37 [*7.06*]
Good beat perceiver		27	.76 [*.10*]	5.91 [*6.66*]	27	.75 [*.10*]	5.80 [*5.88*]
Average	66 [*9.14*]		.63 [*.17*]	5.88 [*7.71*]		.66 [*.14*]	5.21 [*6.36*]

Table 2
Means and standard deviations of the individualized song list ratings in young and older adults.

Stimuli	Enjoyment[1]	Familiarity[2]	Groove[3]	Beat Salience[4]
Young Adults				
High Enjoyment	59[5] [18]	19 [16]	47 [18]	66 [19]
Low Enjoyment	15 [10]	11 [12]	23 [14]	56 [22]
Average	37 [14]	15 [14]	35 [16]	61 [21]
Older Adults				
High Enjoyment	59 [23]	20 [20]	52 [23]	71 [24]
Low Enjoyment	14 [17]	9 [14]	19 [18]	51 [24]
Average	36 [20]	14 [17]	36 [20]	61 [24]

[1] **How much do you enjoy this piece of music?** 1 = strongly dislike, 100 = strongly like.
[2] **How familiar are you with this piece of music?** 1 = never heard it before, 100 = I have heard this song multiple times before and can predict what happens next.
[3] **How much does this piece of music make you want to move to it?** 1 = no desire to move, 100 = strong desire to move.
[4] **How strong is the beat in this piece of music?** 1 = very weak, 100 = very strong.
[5] 75 on the enjoyment scale was 'I enjoy this piece of music' and 50 was 'neutral'. Thus, a rating between 50 and 75 (e.g., 59) reflects a positive rating of the music.

comfortably to the music) or synchronized walking (walk to the beat of the music). Participants completed two practice trials with stimuli playing over loudspeakers to enable the experimenter to confirm the participant understood the instructions. Then, participants put on wireless headphones and walked to the 18 selected stimuli (1 stimulus per trial) in random order. Each trial consisted of eight continuous passes of the walkway, as in the baseline trial. Volume was preset but adjusted if uncomfortable, and breaks were permitted. Two silent trials were completed to assess changes in gait across the experiment: once after eight stimulus trials, and once after all 18 stimulus trials.

3. Data processing and analysis

3.1. Beat perception ability

Beat perception ability was quantified by the proportion of trials correctly identified as 'on' or 'off' the beat. For graphing purposes, participants were categorized as good beat perceivers if they scored at or above the sample median (.67) and poor if below the median (.64), but in the statistical analyses beat perception ability was included as a continuous variable.

3.2. Gait analysis

PKMAS (ProtoKinetic Movement Analysis Software, https://www.protokinetics.com/pkmas/) was used to record and process each gait trial. Stride velocity (cm/second), stride length (cm), cadence (steps per minute), stride width (cm), and DST (seconds) were assessed. Longer DST, reduced gait speed, and shorter strides are associated with attempts to stabilize gait [20], and are increased in older adults at risk for falls [21]. Proportional change scores from baseline were calculated, normalized to account for individual differences, such as in leg length, as follows [22]:

$$\text{Proportion change score} = \frac{\text{Cued gait parameter} - \text{Initial baseline gait parameter}}{\text{Initial baseline gait parameter}}$$

Average gait parameter change scores in the high enjoyment, low enjoyment, and metronome conditions were analyzed using a 3-way mixed-design ANCOVA, with between-subject variables instruction type (free, synchronized) and age (younger, older), and musical stimulus as a within-subject variable (high enjoyment, low enjoyment, metronome). The BAT perception scores and years of musical training were included as continuous variables.

4. Results

4.1. Song ratings

The aim of the study was to examine differences between high and low enjoyment music that was similar in familiarity, groove, and beat salience. However, paired t-tests revealed that the average ratings of familiarity, groove, and beat salience were significantly higher in the high enjoyment music than the low enjoyment music for both the young and older adults. Young adult statistics: familiarity [$t(81) = 6.88$, $p < .001$], groove [$t(81) = 13.31$, $p < .001$], and beat salience [$t(81) = 3.98$, $p < .001$]. Older adult statistics: familiarity [$t(84) = 8.85$ $p < .001$],

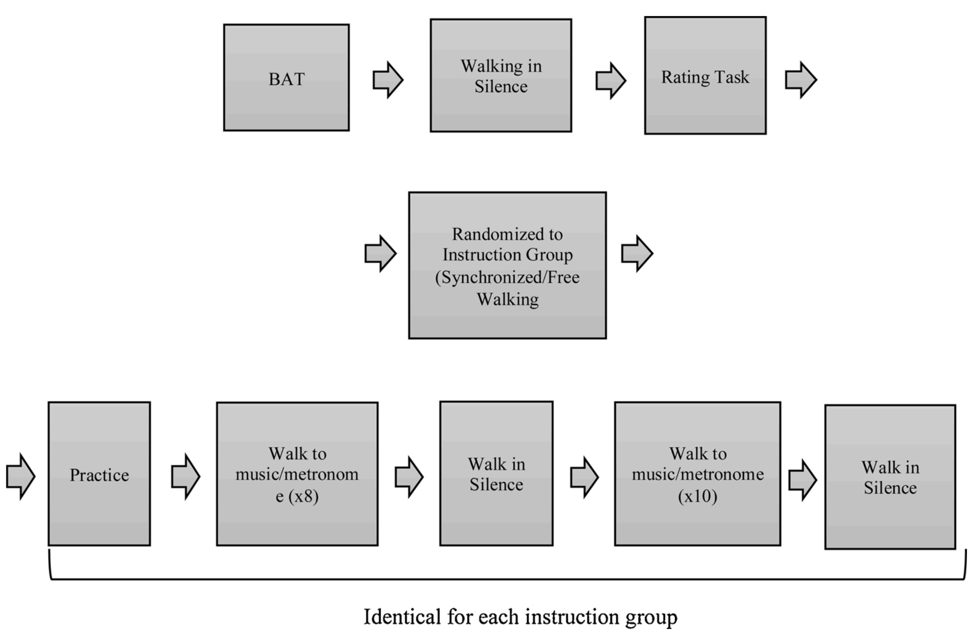

Fig. 1. Protocol. After completing the beat perception task, baseline walks in silence, and the ratings task, participants were assigned to either synchronize to the beat or to freely walk to the music for rest of the experiment.

groove [t(84) = 17.09, p < .001], and beat salience [t(84) = 10.71, p < .001]. As intended, high and low enjoyment songs differed on enjoyment for both young [t(81) = 19.68, *p* < .001] and older adults [t (84), 20.86, p < .001]. On average, all songs were rated low in familiarity (*M* = 15) and moderately high in beat salience (*M* = 61.5; see Table 2). The difference between the songs rated high in enjoyment (M_{HE} = 59[*22*]) and the songs rated low in enjoyment (M_{LE} = 14[*15*]) was 45 points on the 100-point scale, which was larger than all other differences between high and low enjoyment music in other ratings (see *Supplementary 2*).

4.2. Beat perception and musical training

Beat perception scores in young adults ranged from 29 % to 100 % (*M* = 67 % [16 %]) with the median being 68 %. Poor beat perceivers had significantly fewer years of music training than the good beat perceivers (*M* = 3.1 [*4.0*] vs. *M* = 9.0 [*6.3*]; t(80) = -5.06, *p* < 0.001). The older adults' scores ranged from 17 % to 100 % (*M* = 64 % [16 %]) with the median being 64 %. Unlike the young adults, poor and good beat perceivers did not significantly differ in years of formal music training (*M* = 5.3 [*10.1*] vs. *M* = 5.4 [*6.2*]; t(96) = -.05, *p* = .96). Similarly, older adults differed from younger adults in that beat perception and formal music training did not have a significant relationship among older adults (r(94) = .10, p > .05 vs r(82) = .53, p < .001). See Table 1 for beat perception and music training summary.

4.3. Gait changes: music enjoyment and metronome

No gait parameter for either age group showed differences between high and low enjoyment music (see *Supplemental 3*). However, both music conditions (high and low enjoyment) differed from metronome, but with different patterns between younger and older adults. In young adults, music produced longer [*F*(1.67, 123.56) = 5.80, *p* = .004, n^2_p = .07], and faster strides [*F*(1.64, 121.11) = 3.48, *p* = .04, n^2_p = .04] compared to the metronome. In older adults, music conditions elicited slower strides [*F*(1.70, 153.02) = 25.80, *p* < .001, n^2_p = .22], with fewer steps per minute [*F*(1.63, 146.78) = 21.32, *p* < .001, n^2_p = .19] compared to the metronome (see Fig. 2). In addition, both music conditions elicited longer DST compared to the metronome among older adults [*F*(1.64, 147.55) = 9.98, *p* < .001, n^2_p = .10]; whereas younger adults did not differ in DST (see Fig. 3). There were no significant main effects of music enjoyment on any other gait parameters (see Table 3).

4.4. Gait changes: instruction

Both young and older adults showed larger gait changes between walking instructions. Young adults had faster strides [*F*(1, 74) = 11.78, *p* = .001, n^2_p = .14], with more steps per minute [*F*(1, 74) = 6.21, *p* = .01, n^2_p = .08], when synchronizing than when walking comfortably. In contrast, older adults took shorter [*F*(1, 90) = 24.77, *p* < .001, n^2_p = .22] and slower strides [*F*(1, 90) = 8.60, *p* = .004, n^2_p = .09] when synchronizing than when walking comfortably (*see* Fig. 2). In addition, young adults had shorter DST [*F*(1, 74) = 5.14, *p* = .03, n^2_p = .06] when synchronizing than when walking comfortably; whereas, older adults did not differ in DST (see Fig. 3). There were no significant main effects of instruction on any other gait parameters (see Table 3).

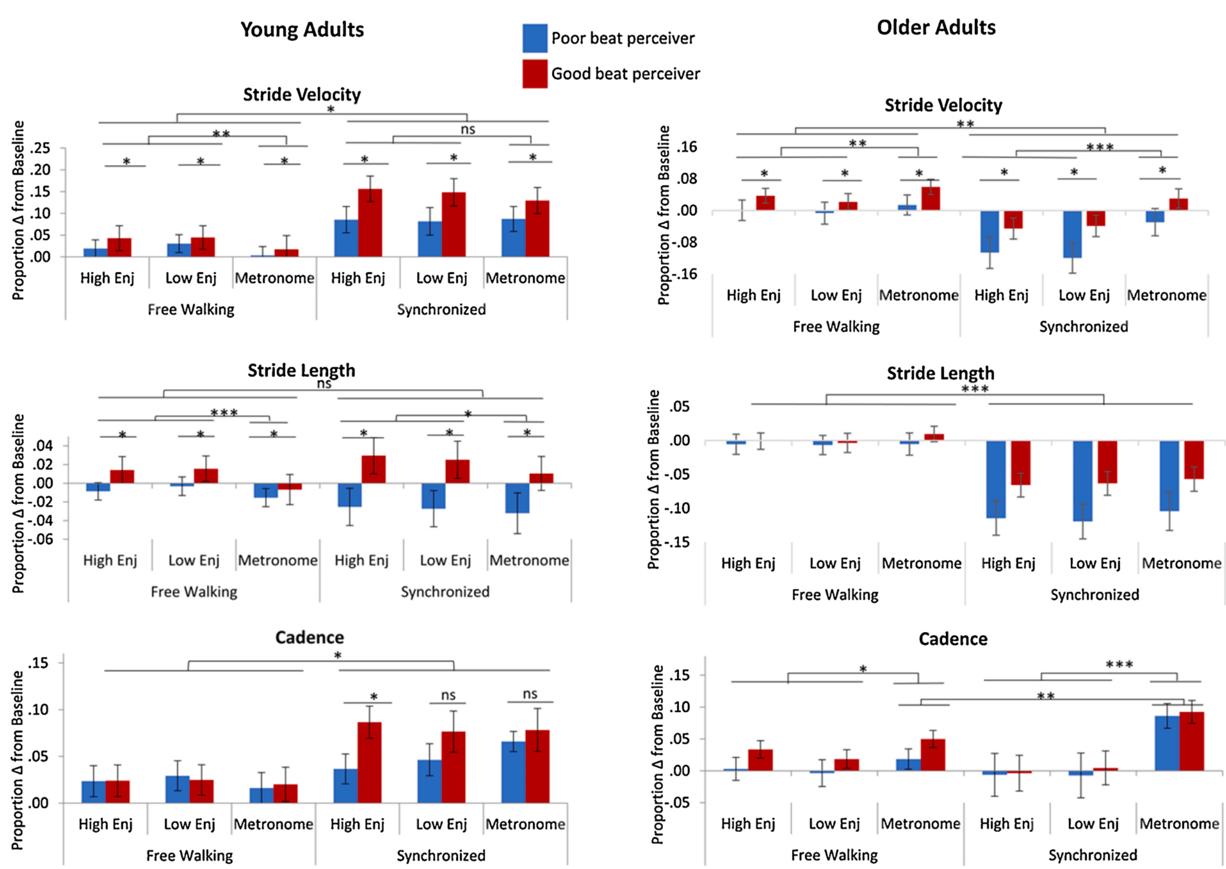

Fig. 2. Effects of beat perception ability on gait in healthy younger and older adults. "High Enj" = high enjoyment stimuli and "Low Enj" = low enjoyment stimuli. Error bars represent standard error of the mean. *p < .05, **p < .01, ***p < .00, and ns = not significant. Synchronized instructions elicited longer and faster strides in young adults, but shorter and slower strides in older adults. Poor beat perceivers showed shorter and slower strides compared to good beat perceivers, regardless of age.

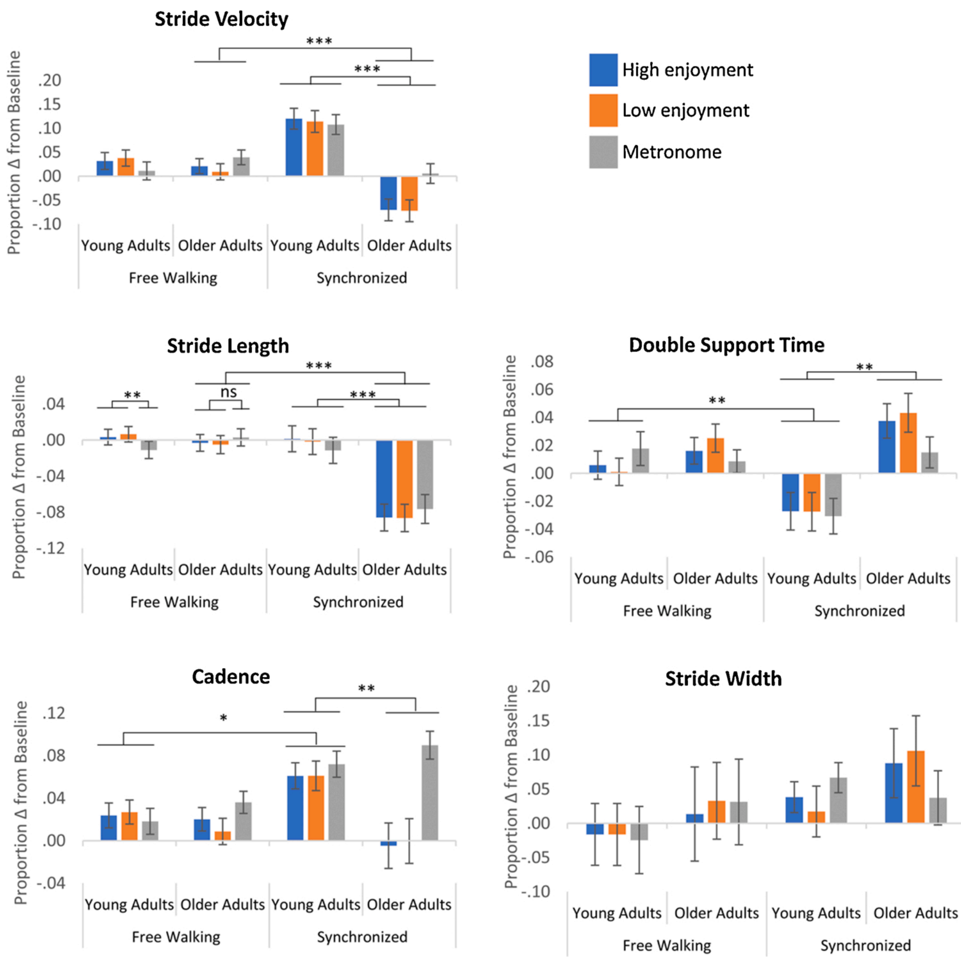

Fig. 3. Effects of instruction and stimulus type on gait in healthy young and older adults. Error bars represent standard error of the mean. *p < .05, **p < .01, ***p < .001, and ns = not significant. Music elicited longer and faster strides with more steps per minute compared to metronome in young adults, whereas music elicited shorter and slower strides with fewer steps per minute in older adults.

Table 3
ANOVA table of main effects and interactions for each gait parameter in young and older adults. p = p-value, n^2p = partial eta squared.

Young Adults	Stimulus[1]		BAT score		Instruction		Stimulus x Instruction		Stimulus x BAT score		Stimulus x BAT score x Instruction		BAT score x Instruction	
Gait Parameter	p	n^2p	p	n^2p	p	n^2p	p	n^2p	p	n^2p	p	n^2p	p	n^2p
Stride Velocity (cm/s)	.04*	0.04	.04*	0.06	.001***	0.14	.09	.03	.42	.01	.65	.006	.43	.008
Stride Length (cm)	.004**	0.07	.02*	0.07	.84	0.001	.36	.01	.39	.01	.76	.004	.63	.003
Cadence (steps per minute)	.95	0.001	.15	0.03	.01**	.08	.08	.03	.13	.02	.12	.03	.57	.004
Stride Width (cm)	.47	0.01	.49	.006	.31	.01	.23	.02	.54	.008	.35	.01	.54	.005
Double Support Time (s)	.10	0.03	.77	0.001	.03*	0.06	.004**	.07	.60	.007	.96	<.001	.17	.03

Older Adults	Stimulus[1]		BAT score		Instruction		Stimulus x Instruction		Stimulus x BAT score		Stimulus x BAT score x Instruction		BAT score x Instruction	
	p	n^2p	p	n^2p	p	n^2p	p	n^2p	p	n^2p	p	n^2p	p	n^2p
Stride Velocity (cm/s)	<.001***	.22	.04*	0.04	.004**	0.09	.002**	.07	.28	.01	.93	.001	.24	.01
Stride Length (cm)	.161	0.02	.08	.03	<.001***	0.22	.95	.001	.94	.001	.79	.003	.26	.01
Cadence (steps per minute)	<.001***	0.19	.53	0.004	.771	0.001	<.001***	.08	.23	.02	.85	.002	.75	.001
Stride Width (cm)	.19	0.02	.08	.03	.43	0.007	.14	.02	.74	.003	.83	.002	.16	.02
Double Support Time (s)	<.001***	.10	.05*	.04	.21	0.02	.31	.01	.51	.008	.95	.001	.35	.01

* p < .05.
** p < .01.
*** p < .001.
[1] Stimulus refers to the type of stimulus (i.e., high enjoyment, low enjoyment, metronome).

4.5. Gait changes: beat perception ability

Lastly, regardless of stimulus, in young adults, poor beat perceivers had shorter [$F(1, 74) = 5.89$, $p = .02$, $n^2_p = .07$] and slower strides [$F(1, 74) = 4.1$, $p = .04$, $n^2_p = .06$] than good beat perceivers (*see* Fig. 2). In contrast, in older adults, poor beat perceivers had slower strides [$F(1, 90) = 4.11$, $p = .04$, $n^2_p = .04$] and longer DST [$F(1, 90) = 3.87$, $p = .05$, $n^2_p = .04$] than good beat perceivers. There were no significant main effects of beat perception ability on any other gait parameters (see Table 3).

5. Discussion

This study examined how music enjoyment influences gait in healthy adults during accelerated RAS, both with and without instructions to synchronize. We compared older and younger adults with good and poor beat perception abilities to understand the impact of these factors across the lifespan. Contrary to our hypothesis and previous work [11], highly enjoyable music, compared to unenjoyable music, did not enhance gait speed or stride length. Therefore, controlling for enjoyment may not be necessary to optimize gait outcomes during RAS with unfamiliar music. In contrast, instructions to synchronize did appear to maximize gait outcomes, but with caveats noted previously [7], instructions to synchronize elicited compensatory gait patterns in poor beat perceivers and older adults.

5.1. Enjoyment and gait

Walking to enjoyable music did not alter gait, regardless of instructions, beat perception ability, or age. Although enjoyable music may stimulate dopaminergic pathways and elicit faster movements [9], this did not translate into faster gait for either age group in our study. One recent study indicated that pleasurable music affected gait only when familiar, but not unfamiliar [23]. This may support that the unfamiliar stimuli in our study contributed to the lack of enjoyment effect, perhaps because the experience of pleasure is somewhat lower with unfamiliar than highly familiar music. Although we attempted to keep groove and familiarity similar between high and low enjoyment conditions, the high enjoyment songs were rated slightly higher on familiarity, and substantially higher on groove; this may support that these experiences are closely linked and that controlling one (e.g., familiarity) can constrain the effect of another (e.g., enjoyment). Importantly, despite these small differences in groove/familiarity for high and low enjoyment songs, no effect of enjoyment was observed. One alternative explanation for the absence of effect is the possibility that enjoyment during listening does not correspond to identical enjoyment during walking. In future work, evaluating if people enjoy walking with the music help to better capture the role of music enjoyment during RAS.

Nevertheless, these findings do support that high and low enjoyment music have similar outcomes when using music that is only unfamiliar. Therefore, interventions that do not tailor stimuli based on what is familiar to the patient may not need control for enjoyment to optimize outcomes unless the intention is to improve RAS adherence through enjoyment.

5.2. Synchronizing and beat perception ability

Instructions to synchronize and beat perception ability influenced overall gait speed, suggesting that these factors influence RAS outcomes [5], despite rarely being accounted for in clinical populations. Both young and older adults with poor beat perception demonstrated cautious walking patterns when instructed to synchronize, as demonstrated by slower velocity and shorter strides relative to good beat perceivers. This supports previous conclusions that synchronizing may be more cognitively demanding for poor beat perceivers, creating dual-tasking interference with gait as participants shift cognitive resources toward synchronizing [11].

5.3. The influence of age

Importantly, synchronizing affected young and older adults differently. When young adults were instructed to synchronize, stride velocity and cadence increased, while DST decreased from baseline. In contrast, older adults slowed their velocity and cadence while DST increased, despite both groups being cued at tempi 15 % faster than their natural walking rate. This suggests that older adults may have found synchronizing challenging, leading to compromised gait, similar to the pattern observed for poor beat perceivers while synchronizing. Previous work has reported that movements that must be coordinated in time, such as synchronizing to a beat, become more difficult and less accurate over the lifespan [24]. Thus, synchronizing gait to a beat may be harder for older adults and, leading to dual-task interference that slows gait and shortens strides [25].

5.4. Conclusion

In this study, higher enjoyment music did not enhance gait outcomes when walking to unfamiliar songs. This is one of the first studies to directly study the effects of subjective music enjoyment on RAS-cued gait while taking into consideration age, synchronization demands, and beat perception ability. Enjoyment did not appear to influence gait outcomes by modifying speed or stride length. As with previous work, instructions to synchronize influenced good and poor beat perceivers differently and synchronization demands did not always elicit optimal gait changes. This study adds to the literature by demonstrating differential effects of stimulus type and instructions in healthy older adults when compared to young adults who are not experiencing age-related gait changes. In particular, older adults were more likely to slow gait speed and shorten strides when synchronizing than young adults were, and also when walking with music compared to metronome cues. Therefore, age, instructions, and beat perception ability are important factors to account for in both clinical application and further empirical study of music-based RAS. The results suggest that subjective enjoyment of stimuli does not reliably affect gait when using unfamiliar music. Future studies should examine the relationship among these factors with high familiarity stimuli and with longitudinal cueing interventions in both healthy and clinical populations.

Declaration of Competing Interest

The authors report no declarations of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2021.04.008.

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