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Beat perception ability and instructions to synchronize influence gait when walking to music-based auditory cues

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ABSTRACT

Synchronizing gait to music-based auditory cues (rhythmic auditory stimulation) is a strategy used to manage gait impairments in a variety of neurological conditions, including Parkinson's disease. However, knowledge of how to individually optimize music-based cues is limited. The purpose of this study was to investigate how instructions to synchronize with auditory cues influences gait outcomes among healthy young adults with either good or poor beat perception ability. 65 healthy adults walked to metronome and musical stimuli with high and low levels of perceived groove (how much it induces desire to move) and familiarity at a tempo equivalent to their self-selected walking pace. Participants were randomized to instruction conditions: (i) synchronized: match footsteps with the beat, or (ii) free-walking: walk comfortably. Participants were classified as good or poor beat perceivers using the Beat Alignment Test. In this study, poor beat perceivers show better balance-related parameters (stride width and double-limb support time) when they are not instructed to synchronize their gait with cues (versus when synchronization was required). Good beat perceivers, in contrast, were better when instructed to synchronize gait (versus when no synchronization was required). Changes in stride length and velocity were influenced by musical properties, in particular the perceived 'groove' (greater stride length and velocity with high- versus low-groove cues) and, in some cases, this interacted with beat perception ability. The results indicate that beat perception ability and instructions to synchronize indeed influence spatiotemporal gait parameters when walking to music- and metronome-based rhythmic auditory stimuli. Importantly, these results suggest that both low groove cues and instructing poor beat perceivers to synchronize may interfere with performance while walking, thus potentially impacting both empirical and clinical outcomes.

1. Introduction

Gait impairments in Parkinson's disease (PD), such as reduced speed, stride length and stability, are debilitating and difficult to manage pharmaceutically [1–4]. These deficits interfere with safe mobility and independence, consequently hindering quality of life [5] and increasing fall risk [6,7]. One highly recommended strategy for mitigating gait impairment in PD is Rhythmic Auditory Stimulation (RAS), which involves synchronizing footsteps to a steady metronome or musical beat while walking [8–14].

Importantly for clinical application, the impact of instructions to synchronize during RAS may be influenced by individual differences in beat perception ability and rhythmic skills; however, this is rarely assessed in clinical interventions. When healthy young adults with poor beat perception ability synchronize to the beat of the music, they show reduced velocity and stride length compared to silence; however, good beat perceivers show faster velocity [15]. Among mild PD patients, greater rhythmic timing skills are predictive of velocity improvements with RAS [16]. Thus, rhythmic ability alters individual responses to RAS in both healthy and PD populations.

Cautious gait patterns, such as those observed during synchronized walking in poor beat perceivers, may result from 'dual-task' interference elicited by task instructions [17,18]. Specifically, poor beat perceivers may require more attention to identify and synchronize with

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Table 1
Demographic data by subgroup.

	Free-Walking		Synchronized-Walking	
	Poor BP (n = 15)	Good BP (n = 14)	Poor BP (n = 24)	Good BP (n = 12)
Baseline Cadence	111.2 (7.8)	111.4 (6.6)	112.6 (7.2)	114.2 (8.0)
Age (years)	18.7(.96)	18.6(.5)	18.8(.86)	18.8(.87)
Gender				
Female/Male	8/7	6/7	20/4	4/4
Unidentified	0	1	0	0
Training (Years)				
Music	3.7 (3.2)	6.1 (4.6)	5.0 (4.5)	7.3 (3.6)
Dance	1.6 (2.2)	0.8 (2.0)	3.0 (5.38)	2.7 (3.0)

Note. Data presented as means (standard deviations) for age, baseline (uncued) cadence, music training, and dance training. Sums are presented for gender.

a beat than good beat perceivers, resulting in slower gait. We hypothesize that removing instructions to synchronize may reduce attentional costs of RAS among poor beat perceivers and may reflect a more appropriate strategy for people prone to dual-tasking interference, such as people with cognitive or mobility impairment.

Here, we investigate how RAS alters gait when healthy participants are or are not instructed to synchronize. We also manipulated the musical domains of groove (how much music makes a person want to move) and familiarity to replicate previous research on the beneficial effects of these characteristics on stride length and velocity [15,19,20], and to determine whether their effects differed for good and poor beat perceivers.

2. Methods

2.1. Participants

102 healthy young adults were recruited from the University of Western Ontario (see Table 1 for demographic data). Eighteen participants were excluded (two due to abnormal gait patterns [shuffling, foot drag], 14 for technical error [computer/headphone malfunction], and three due to language barrier). The final sample consisted of 84 participants (45 female, 1 unidentified) with a mean age of 18.59 (SD = .72). Participants were compensated with 1.5 course credits. Written informed consent was obtained, and the study was approved by the University's Nonmedical Research Ethics Board.

2.2. Procedures

2.2.1. Baseline gait & demographics

Prior to hearing any music, participants walked the length of a 16-foot pressure sensitive walkway eight consecutive times at a comfortable pace to measure baseline gait (see Fig. 1 for procedures). Afterward, participants completed a demographic questionnaire.

2.2.2. Auditory stimuli

Stimuli for gait trials were selected from a database of 27 non-lyrical music clips (30 s each, Supplementary material 1) that were high or low familiarity and high or low groove (as rated by young adults in pilot testing). Stimuli were digitally altered (TwistedWave© 2015) to match the music tempo (beats per minute) to each participant's baseline cadence (steps per minute). Pitch was preserved. Participants heard the music clips over noise-cancelling headphones (Bose® Quiet Comfort 3) in random order and rated familiarity, groove, enjoyment, and beat salience on 100-pt Likert scales (see Table 2). Enjoyment and beat salience ratings were included as filler ratings and were not analysed. Participants completed all four ratings before moving to the next stimulus. Individual ratings were then used to select a tailored set of eight stimuli for each participant's cued gait trials. Two songs each were selected for: high groove/high familiarity, high groove/low familiarity, low groove/high familiarity, and low groove/low familiarity conditions. A metronome stimulus (www.reztronics.com) was also set to each participant's baseline cadence and played independently (without music) for two metronome trials.

2.2.3. Cued walking trials

After being randomized to an instruction condition, participants completed a total of 10 cued gait trials (two per condition) in a randomized order (see Fig. 1). Stimuli were played at a comfortable level over wireless headphones (Sennheiser® HDR 160), preventing experimenter influence. Five gait parameters were measured: stride length, stride time (cadence), stride velocity, stride width, and double limb support time.

2.2.4. Music/dance questionnaire and beat alignment test

After cued trials, participants completed a demographic questionnaire about music and dance history (e.g., years of training, age started, etc.), and the Perception subtest of the Beat Alignment Test (BAT) from the Goldsmiths Musical Sophistication Index v1.0 [30] to measure beat perception ability.

3. Data analysis

For this study, only good and poor beat perceivers were analysed (N = 65), as BAT data were distributed bimodally. Participants scoring at/above the higher mode (M = 76.47) or at/below the lower mode (M = 58.82) were considered good (range = 76.47–100) and poor beat perceivers (range = 29.41–58.82), respectively.

3.1. Gait performance

Data were analyzed using a three-way mixed-design analysis of variance (ANOVA) using SPSS (version 22). Separate models were run for stride length, stride time (cadence), stride velocity, stride width, and double-limb support time. Initial analyses used the within-subject variables groove (high, low) and familiarity (high, low), and the between subject variables beat perception ability (good, poor) and instruction (synchronized-walking, free-walking). No significant and interpretable effects of familiarity were found, therefore, reported analyses are collapsed across levels of familiarity (see Supplementary material 2 for analyses). Spearman's correlations for years of dance and music experience indicated no significant relationship with gait measures (all $ps > .12$), thus were not included in gait ANOVAs. Greenhouse-Geisser adjusted values are reported for all gait measures.

3.2. Tempo matching

To assess whether participants' step rates differed across cue type or group, a three-way mixed-design ANOVA (Cue Type × Instruction × Beat Perception) was conducted on cadence (steps per minute). One-sample t-tests indicated how accurately participants matched cadence to cue tempo (the target rate, if synchronizing).

3.3. Normalization

To account for individual differences (e.g., in leg length), gait analyses were conducted on normalized change scores [21] indicating proportion of change: the individual's baseline gait parameter was subtracted from the gait parameter for a given condition; then divided by the baseline parameter:

$$\text{Normalized Change Score} = \frac{(\text{cued gait parameter-baseline gait parameter})}{\text{baseline gait parameter}}$$

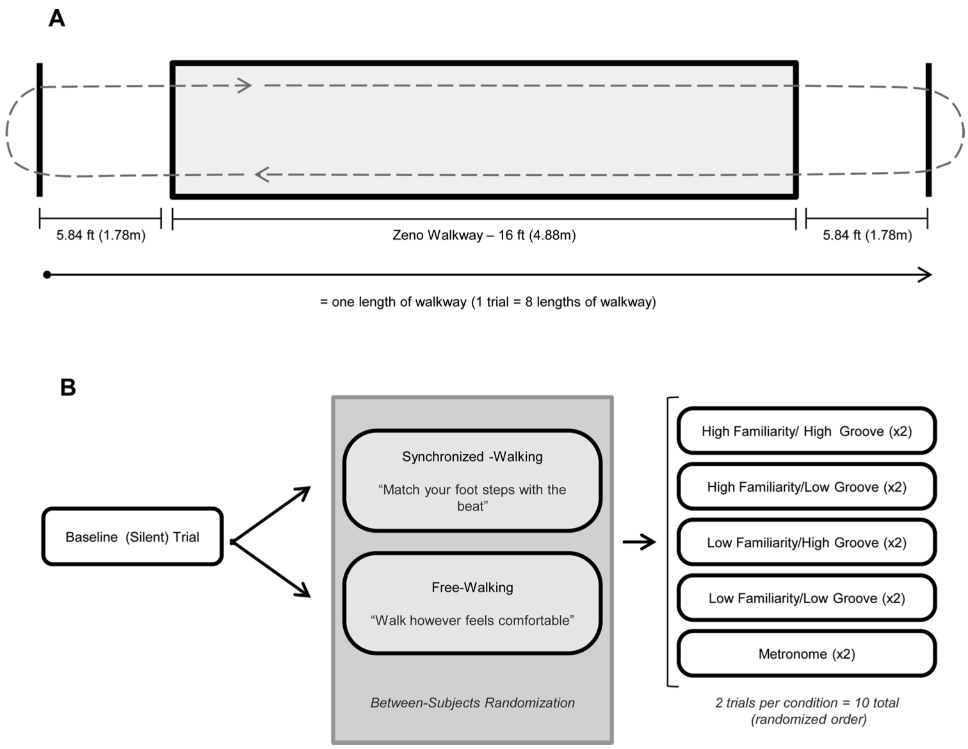

Fig. 1. Gait procedures. **1A**: Illustration of pressure sensitive Zeno™ walkway procedures. All gait trials (baseline and cued) consisted of 8 consecutive passes of the 16 ft walkway (shaded grey rectangle). To reduce acceleration/deceleration effects, participants walked to a floor marking 1.78 m beyond the edge of the walkway (solid black lines) before turning and re-entering the walkway. **1B**: Protocol for gait trials. Gait was evaluated in silence (baseline – no RAS) and during five randomly ordered RAS conditions: listening to music that was rated by the participant as (1) high groove/high familiarity, (2) high groove/low familiarity, (3) low groove/high familiarity, (4) low groove/low familiarity, and (5) a metronome. Two trials occurred for each condition with distinct stimuli, with the exception of metronome which was identical in both trials. Participants were randomized to either synchronized-walking (instructed to match their steps with the beat in the auditory cue) or free-walking (instructed to walk however was comfortable, with the cue in the background).

Table 2
End anchors for familiarity, groove, enjoyment, and beat salience ratings. Boldface text was not provided to participants.

Familiarity: "How familiar is the piece of music to you?"	
1 = Never heard it before	100 = Know this song so well that I can predict what happens next
Groove: "How much does this piece of music make you want to move?"	
1 = Would definitely not move to this	100 = Would move a lot to this
Enjoyment: "How much do you enjoy listening to this piece of music?"	
1 = I strongly dislike this song	100 = I strongly enjoy this song
Beat Salience: "How strong is the beat in this piece of music to you?"	
1 = Very weak	100 = Very strong

4. Results

Separate one-way ANOVAs confirmed that equivalent groups were achieved for age [F (3, 61) = 0.06, $p > .05$], music/dance training [F (3, 61) = 1.96, $p > .05$; F (3, 61) = 1.15, $p > .05$], and baseline cadence [F (3, 61) = 0.43, $p > .05$]. However, Pearson Chi-Square analysis indicated uneven gender across subgroups [$\chi2$ = 8.94, $p < .05$] (see Table 1). All spatiotemporal gait parameter results are reported as proportion of change from baseline.

4.1. Stride length (centimeters)

Overall, strides tended to shorten during cueing compared to baseline. A significant main effect of cue type [F (1.52, 92.69) = 33.11, $p < .001$, $\eta_p^2 = .35$] for stride length indicated that strides shortened less with high groove [$M = -.008$, $SD = .049$] versus low groove [$M = -.045$, $SD = .035$] and metronome [$M = -.032$, $SD = -.038$] cueing. This was qualified by a significant cue type by beat perception interaction [F (1.52, 92.69) = 5.90, $p < .01$, $\eta_p^2 = .088$]. Follow-up t-tests indicated that the groups did not differ in stride length for metronome and low groove music, but did for high groove music: Good beat perceivers took significantly shorter strides [M = .002, SD = .003] than poor beat perceivers [M = −.02, SD = .001] [t(63) = 2.24, $p < .05$] (Fig. 2A).

4.2. Stride time (seconds)

A significant main effect of cue type [F (1.21, 73.40) = 15.34, $p < .001$, $\eta_p^2 = .20$] indicated that both high groove music [$M = -.001$, $SD = .028$] and metronome [$M = .0005$, $SD = .025$] elicited faster strides than low groove music [$M = .029$, $SD = .054$] (Fig. 2B).

4.3. Stride velocity (centimeters/second)

Overall, velocity tended to decrease during cueing compared to baseline. A significant main effect of cue type [F (1.85, 112.9) = 27.97, $p < .001$, $\eta_p^2 = .31$] indicated significantly smaller velocity decreases in high groove [$M = -.006$, $SD = .073$] than low groove [$M = -.065$, $SD = .063$] and metronome conditions [$M = -.029$, $SD = .048$]. Velocity decreases with metronome cues were also significantly less than with low groove cues. There was a significant interaction between cue type and beat perception [F (1.85, 112.9) = 4.95, $p < .01$, $\eta_p^2 = .075$]. Follow-up t-tests indicated that for good beat perceivers, stride velocity decreased significantly less for both high groove [t (25) = 3.58, $p < .001$] and metronome [t(25) = 2.91, $p < .001$] compared low groove, but high groove and metronome did not differ [t (25) = 1.22, $p = .12$]. For poor beat perceivers, stride velocity decreased significantly less for high groove and metronome compared to low groove [HG: t(38) = −6.59, $p < .001$; Metr: t(38) = −4.86, $p < .001$], but high groove also decreased less than metronome. [t (38) = 3.18, $p < .01$] (Fig. 2C).

4.4. Stride width (centimeters)

A significant interaction between instruction and beat perception was observed [F (1, 61) = 6.09, $p < .05$, $\eta_p^2 = .091$]. Follow-up t-tests indicate that good beat perceivers take significantly narrower strides when synchronizing than walking freely [t(73) = 2.66, $p < .01$], whereas poor beat perceivers take significantly wider strides [t (103) = −2.89, $p < 0.01$] (Fig. 2D).

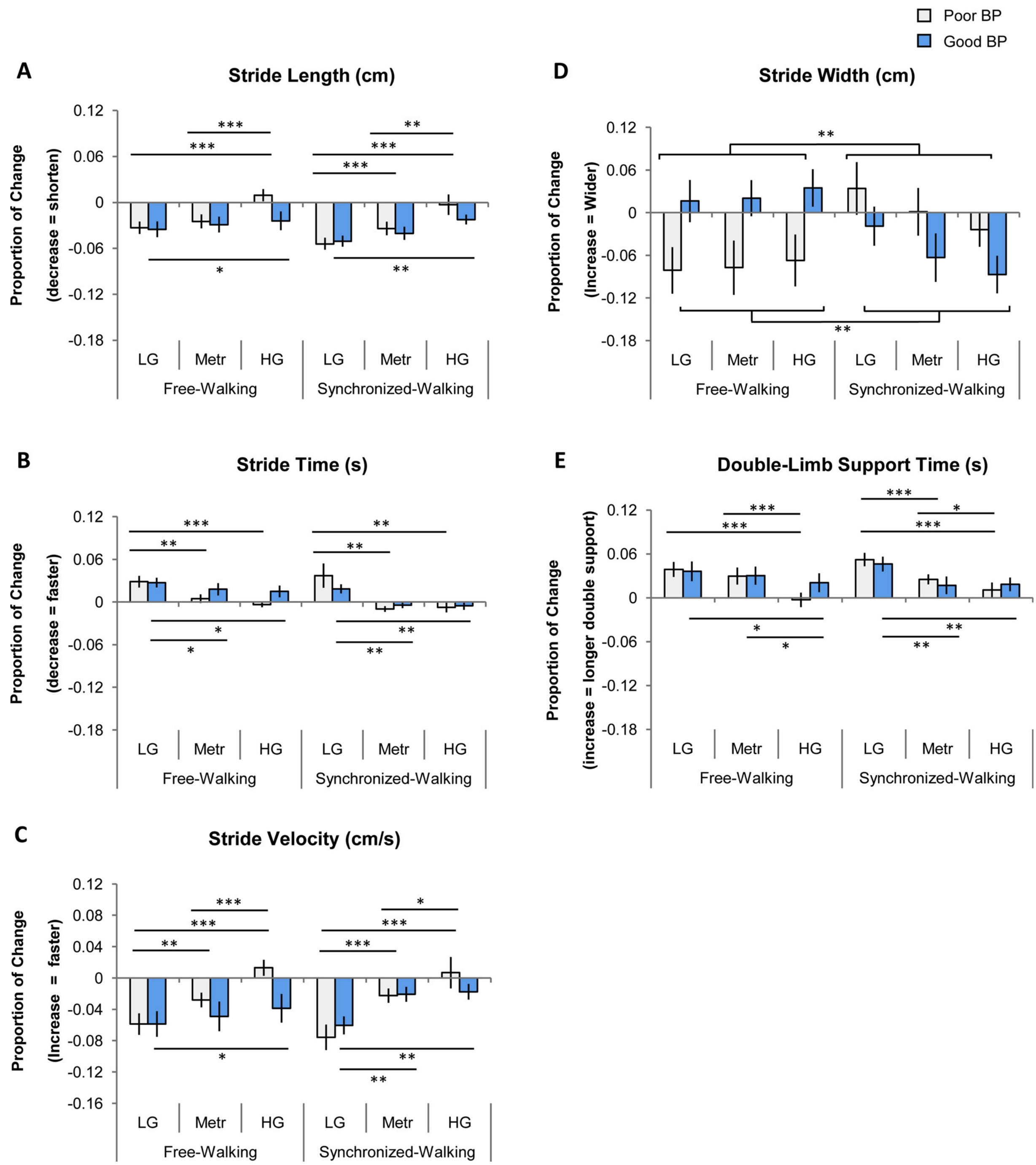

Fig. 2. Normalized change scores (proportion of change from baseline). Analyses of variance indicate a significant difference between instruction type for stride width (**2D**) and double-limb support time (**2E**), but not for stride length (**2 A**), stride time (**2B**), or stride velocity (**2C**). Metr = Metronome Cue; LG = Low Groove Cue; HG = High Groove Cue; BP = Beat Perception. * $p < .05$, ** $p < .01$, *** $p < .001$. Astricks over graph indicate significance among poor beat perceivers (grey); astericks under graph indicate significance among good beat perceivers (blue). Stride width graph denotes interaction between beat perception ability and instruction type (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article).

4.5. Double-Limb Support Time (DLST; seconds)

A significant main effect of cue type [F (1.91, 116.24) = 34.69, $p < .001$, $\eta_p^2 = .36$] indicated that DLST increased significantly with low groove [$M = .044$, $SD = .043$] compared to high groove [$M = .011$, $SD = .044$] and metronome cues [$M = .026$, $SD = .040$]. However, this main effect was qualified by a significant cue type by instruction interaction [F (1.91, 116.24) = 3.89, $p < .05$, $\eta_p^2 = .060$]. Follow-up t-tests indicated that, regardless of instruction, high groove cues produced smaller increases in DLST than both metronome [Synchronizing: $t(35) = -1.70$, $p < .05$; Free-Walking: $t(28) = -4.50$, $p < .001$] and low groove cues [Synchronizing: $t(35) = -6.16$, $p < .001$; Free-Walking: $t(28) = -5.06$, $p < .001$]. However, only when synchronizing (not walking freely) did metronome cues also produce smaller DLST increases than low groove cues [Synchronizing: $t(25) = -5.67$, $p < .001$; Free-Walking: $t(28) = 1.68$, $p > .05$] (Fig. 2E)

A cue type by beat perception interaction was also present [F (1.9, 116.24) = 4.41, $p < .05$, $\eta_p^2 = .067$]. Follow-up t-tests indicated that high groove and metronome elicited significantly smaller increases in

Table 3
Raw means and standard deviations for gait parameters in all cueing conditions, averaged across participants and trials within each condition.

	Free-Walking		Synchronized-Walking	
	Poor BP	Good BP	Poor BP	Good BP
Stride Length (cm)				
Uncued	129.45 (10.7)	128.45 (9.7)	129.45 (9.7)	127.83 (12.0)
Metronome	126.27 (11.9)*	124.71 (11.3)*	124.94 (9.7)*	122.70 (12.7)*
Low Groove	125.18 (11.5)*	123.89 (10.7)*	122.35 (8.8)*	121.35 (11.8)*
High Groove	130.58 (10.7)	125.31 (10.7)*	128.75 (9.0)	125.04 (13.0)*
Stride Time (sec)				
Uncued	1.08 (.07)	1.09 (.06)	1.08 (.07)	1.05 (.07)
Metronome	1.09 (.07)	1.11 (.08)*	1.07 (.06)*	1.05 (.08)
Low Groove	1.11 (.08)*	1.12 (.07)*	1.12 (.12)*	1.07 (.08)*
High Groove	1.08 (.07)	1.10 (.08)*	1.07 (.07)	1.04 (.07)
Stride Velocity (cm/sec)				
Uncued	120.34 (12.7)	118.71 (11.1)	120.78 (10.4)	122.50 (14.8)
Metronome	116.99 (13.6)*	112.86 (14.0)*	117.89 (9.6)*	119.94 (15.1)*
Low Groove	113.34 (14.4)*	111.70 (13.1)*	111.45 (12.1)*	115.09 (14.6)*
High Groove	121.83 (13.3)	114.05 (13.5)*	121.04 (10.2)	120.46 (16.2)
Stride Width (cm)				
Uncued	7.40 (2.4)	9.28 (2.7)	8.36 (2.8)	8.21 (2.1)
Metronome	6.96 (2.9)*	9.16 (2.4)	8.36 (3.1)	7.82 (2.5)*
Low Groove	6.89 (2.7)*	9.11 (2.5)	8.64 (3.1)	8.14 (2.3)
High Groove	6.94 (2.6)*	9.35 (2.6)	8.19 (2.8)	7.59 (2.4)*
Double-Limb Support Time (sec)				
Uncued	11.49 (1.1)	12.28 (0.9)	12.02 (1.0)	12.08 (1.4)
Metronome	11.82 (1.2)*	12.65 (1.2)*	12.33 (1.2)*	12.28 (1.4)
Low Groove	11.94 (1.3)*	12.73 (1.2)*	12.65 (1.2)*	12.62 (1.4)*
High Groove	11.45 (1.1)	12.53 (1.1)	12.15 (1.2)	12.30 (1.5)*

Note. Asterisks (*) indicate conditions that differed significantly (at $p < .05$) from baseline (uncued) walking.

DLST than low groove among both good [High Groove: $t(25) = 3.75$, $p < .001$; Metronome: $t(25) = 3.30$, $p < .01$] and poor beat perceivers [High Groove: $t(38) = 7.48$, $p < .001$; Metronome: $t(38) = 4.06$, $p < .001$]. However, metronome compared to high groove increased DLST only among poor beat perceivers (not good beat perceivers) [Poor Beat perceivers: $t(38) = -4.21$, $p < .001$; Good Beat perceivers: $t(25) = -0.98$, $p = .17$].

4.6. Tempo matching

A significant main effect of cue type [$F(2, 61) = 23.43$, $p < .001$, $\eta_p^2 = .278$] indicated that cadence significantly slowed during low groove more than high groove and metronome cues (see Table 3 for descriptive statistics). In addition, Bonferroni-corrected *t*-tests were conducted to compare cadence in each cueing condition to the target cadence (the beats per minute of the cue). Cadence was significantly slower than the music tempo with low groove cues only [$t(64) = -4.95$, $p < .001$] (Fig. 3A), suggesting poor tempo-matching. With high groove and the metronome cues, cadence was not significantly different from the stimulus tempo [HG: $t(64) = .585$, $p = .56$; Metr: $t(64) = -.491$, $p = .63$], indicating successful tempo-matching.

A significant interaction between instruction (synchronize or walk freely) and beat perception (good, poor) was also present [$F(1, 61) = 6.13$, $p < .05$, $\eta_p^2 = .091$], indicating that good beat perceivers took significantly fewer steps per minute [$t(69) = -4.09$, $p < .001$] when not explicitly instructed to synchronize [$M = -.019$, $SD = .04$] than when they were instructed to synchronize [$M = .005$, $SD = .02$]. Follow-up Bonferroni-corrected *t*-tests indicated that cadence was significantly slower than target cadence (beats per minute of the cue) when good beat perceivers were not instructed to synchronize [$t(68) = -4.03$, $p < .001$] (Fig. 3B). This was not the case with poor beat perceivers, who did not differ from target tempo in either the free-walking or synchronized conditions.

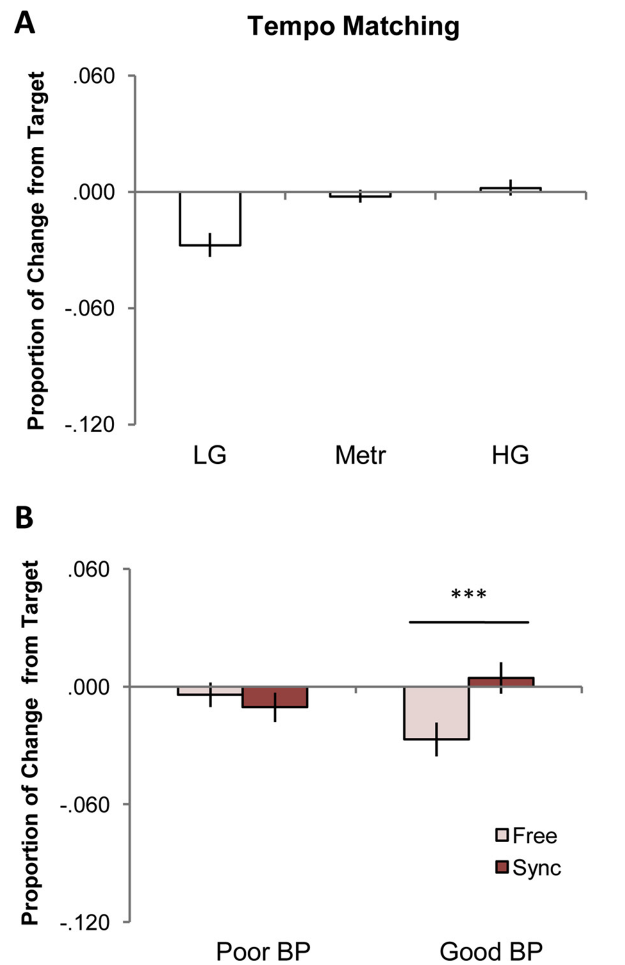

Fig. 3. Tempo matching (cadence vs. stimulus beats per minute). **3 A** illustrates main effect of cue type. **3B** illustrates interaction between beat perception ability and instruction type. Metr = Metronome Cue; HG = High Groove Cue; LG = Low Groove Cue; BP = Beat Perception; Free = Free-Walking Instruction; Sync = Synchronized-Walking Instruction. *** Free vs. Sync = significant at $p < .001$.

5. Discussion

The current study examined how instructions to synchronize and individual beat perception abilities affected gait patterns during high groove, low groove, and metronome RAS among healthy young adults. Overall, RAS slowed participants down, mainly through shortening of strides. The only exception to this was high groove music, in which strides were less shortened relative to baseline, particularly in poor beat perceivers. The results replicate previous work that high groove music generally produces faster velocity and longer strides than low groove music, and sometimes metronome cues [15]. The narrowing of strides for poor beat perceivers during free-walking but not synchronized-walking (and vice versa for good beat perceivers) further suggests that beat perception does indeed interact with instructions to synchronize, perhaps by supporting greater stability through individualized instruction that minimize attentional cost.

Although gait slowed, high levels of groove elicited less slowing and shortening than low levels of groove or metronome cues. Strikingly, this finding holds true for RAS at a person's natural walking pace, as in the current study; previously, high and low groove cues were delivered at

22.5% faster than natural walking pace [15]. Groove may therefore be helpful regardless of rate, which may be promising during clinical RAS when cues are often set at different proportions of a person's natural walking rate [22]. We and others find that high groove music may also be better than metronome cues [23], although this finding is not consistently observed. Leow et al. [15] found that metronomes increased velocity and stride length more than high groove music at accelerated tempi (+22.5%). Here, however, at natural walking rate, high groove and metronome cues elicited similarly increased stride velocity and step length compared to low groove cues, particularly among poor beat perceivers.

In addition to negatively affecting velocity and stride length, low groove music hindered participants' ability to match their walking rate to the music rate. The capacity to walk in synchrony with the beat was expected with all cues, as stimuli were played at natural walking pace. However, participants slowed their step rate significantly with low groove cues. Thus, despite all stimuli (high groove, low groove, and metronome) being played at identical rates that matched each participant's natural walking rate, low groove music slowed cadence. This supports that all cues cannot be used interchangeably and that synchronization accuracy is influenced by musical groove, regardless of cue pace.

5.1. Groove & beat perception

A previous study by Leow et al. [15] found that poor beat perceivers slowed cadence and stride length relative to good beat perceivers when instructed to synchronize, particularly to low groove cues. Contrarily, in this study both good and poor beat perceivers demonstrated similar slowing and shortening of strides during low groove cueing. High groove cues reduced some of these effects for poor beat perceivers, but not good beat perceivers in the free-walking condition. While this finding was unexpected, it may demonstrate that poor beat perceivers respond more to other musical properties, instead of the musical beat, that are linked to perceived groove.

5.2. Beat perception & instruction

Importantly, the current results suggest that RAS does not reduce stability in healthy young adults, as indicated by the consistency of stride width across cued and silent (baseline) trials. Reduced balance or stability should increase stride width to compensate by increasing the base of support. However, the only change in stride width was a narrowing, observed when poor beat perceivers were free-walking to high groove music and when good beat perceivers were synchronizing to any cues. These narrowed strides during RAS, suggest that additional rhythmic information may have supported greater stability. A caveat of these findings may be the healthy nature of this sample, as younger adults are not as susceptible to dual-tasking interference as older adults and clinical populations [24]. This may support the notion that instructions to synchronize do not elicit enough cognitive interference to produce dual-tasking gait patterns in a young, healthy group.

Surprisingly, poor beat perceivers' ability to match tempo (or walk in synchrony) was overall good and unaffected by instructions to synchronize. Perhaps poor beat perceivers sense that tempo matching is challenging and respond similarly regardless of instructions. Alternatively, they may not sense discrepancy between the pace of their gait and the cues and may not adjust their gait from natural walking pace when synchronizing. Good beat perceivers, in contrast, slowed their step rate from baseline (and the target rate) when permitted to walk freely.

5.3. Conclusion

Currently, it is uncommon for beat perception ability or different musical properties to be incorporated into therapeutic recommendations regarding RAS (c.f. [25]). Our findings support recommendations from previous studies that beat perception ability and musical groove may be important factors to consider when using music for rehabilitation. Low groove stimuli consistently produce a detriment in both spatial and temporal parameters of gait when compared to high groove stimuli, while high groove stimuli lead to more stable gait. In some cases, these effects were dependent on the task instructions given and the individual's beat perception ability. Furthermore, the present study highlights the potential capacity of RAS to increase stability when the appropriate instructions are paired with one's beat perception ability, even among healthy walkers, as demonstrated by the narrowing of strides for poor beat perceivers when walking freely and good beat perceivers when synchronizing. This suggests that walking with RAS does not increase cognitive load among healthy young adults to a degree that impacts stability but supports that RAS instructions may impact good and poor beat perceivers differently. Future studies should investigate if these trends persist through healthy ageing and in clinical populations.

Conflict of interest

All authors declare no financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.gaitpost.2018.12.038.

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