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Corey A. Lohnes
Washington University School of Medicine in St. Louis

Gammon M. Earhart
Washington University School of Medicine in St. Louis

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The Impact of Attentional, Auditory, and Combined Cues on Walking During Single and Cognitive Dual Tasks in Parkinson Disease

Corey A. Lohnes[1], Gammon M. Earhart [1-3]

1 Program in Physical Therapy, Washington University in St. Louis, St. Louis, MO, USA
2 Department of Anatomy & Neurobiology, Washington University in St. Louis, St. Louis, MO, USA
3 Department of Neurology, Washington University in St. Louis, St. Louis, MO, USA

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Corresponding Author:
Gammon M. Earhart, PhD, PT
Program in Physical Therapy, Washington University School of Medicine
Campus Box 8502
4444 Forest Park Blvd.
St. Louis, MO, 63108
Ph: 314-286-1425
Fax: 314-286-1410
earhartg@wusm.wustl.edu

Abstract

Auditory and attentional cues improve gait in Parkinson disease (PD), but it is unclear if combining the two cueing strategies offers additional benefit. Further, the effect of a secondary cognitive task on cue efficacy is unknown. Therefore, this study aimed to assess the effects of cue type and task complexity on gait in PD. 11 participants with PD,11 age-matched controls, and 11 young controls performed 3 walking trials on a GAITRite walkway under the following cueing conditions: no cue (baseline), rhythmic auditory cue at 10% below (AUD-10) and 10% above (AUD+10) self selected cadence, attentional cue (ATT; "take long strides"), and a combination of AUD and ATT (COM-10, COM+10). Each condition was also performed concurrently with a secondary word generation task (dual task, DT). Baseline gait velocity and stride length were less for those with PD and age-matched controls compared to young controls, and the ability of those with PD to use cues differed from the other groups. Gait velocity and stride length increased in PD with ATT, but not with auditory cues. Similar increases in gait velocity and stride length were observed with the combined cues, but additional benefit beyond ATT alone was not observed. Cues did not improve gait velocity during dual task walking, although stride length did increase with COMB+10. It appears persons with PD are able to benefit from attentional cueing and can combine attentional and auditory cues, but do not gain additional benefit from such a combination. During walking while performing a secondary cognitive task, attentional cues may help facilitate a longer stride length.

Keywords: Parkinson Disease, Gait Disorders, Rehabilitation, Cueing, Attention

INTRODUCTION

Impaired gait is common in Parkinson disease (PD) and is characterized by reduced velocity and step amplitude and increased step frequency, placing individuals with PD at a greater risk for falls and a loss of independence.[1] Evidence exists to support the use of spatial and rhythmic external cues to increase stride length and regulate cadence.[2-9] Spatial cues, most commonly delivered using lines on the floor, direct the individual to take steps with larger and more regular spacing. As spatial cues are often unavailable outside the laboratory setting, an attentional strategy ("think about taking larger steps") may be more practical and has been shown to be equally effective as external spatial cues for improving step size and gait velocity[4]. Another portable and practical means of cueing is the generation of auditory rhythmic cues using a metronome with instruction to match step frequency to the auditory rhythm. The ideal frequency of such cues has yet to be fully elucidated, but auditory cues ranging from 90% to125% of preferred cadence have shown benefit in terms of gait velocity[3, 5-7, 9], stride length[3, 6, 9, 10], and cadence[3, 5-7, 9, 10].

Combining an auditory cue to prompt step frequency with a spatial cue to normalize step amplitude has been proposed to address both the temporal and spatial components of gait impairment in people with PD.[5, 11] In one study, however, improvements in step amplitude with visuals cues alone were lost when auditory cues at 25% above preferred stepping frequency were added.[5] Proposing that an attentional strategy may be less demanding than using 2 different external cue types, Baker at al. combined an attentional strategy with auditory rhythmic cues at 10% below preferred stepping frequency.[11] While subjects were able to effectively combine the two cue types during both single and dual motor task walking, improvements in gait velocity and step amplitude did not exceed those obtained with the attentional strategy alone. These findings are not surprising as the auditory cues alone did not improve gait, possibly due to the lower than preferred cueing frequency.

Individuals with PD experience exacerbated gait impairments when required to perform a concurrent task.[4, 12-16] There is strong support for the use of external cues and internally generated attentional strategies to reduce the interference effect of a secondary motor task on gait performance.[15-17] However, only one study has examined the effectiveness of cueing to reduce the interference effect of a concurrent cognitive task on gait in PD[4]. Following visual and attentional cue training, PD gait performance improved to that of healthy controls, even when subjects were instructed to concentrate on reciting a sentence. However, as the complexity of the recited sentence increased, stride length and velocity greatly deteriorated proportional to the complexity of the secondary task.

Therefore, we sought to determine if individuals with PD are able to combine a higher frequency auditory rhythmic cue with an attentional cueing strategy, and to determine if the combination improves gait performance above and beyond that observed with either cue type alone. Secondly, we sought to determine if the effectiveness of rhythmic auditory cueing, attentional spatial cueing, and a combined cueing strategy holds when performing a concurrent cognitive task. To separate the effects of age versus disease status, we chose to also include a sample of young, healthy adults. By comparing PD and aged controls, we could examine the effects of PD on the ability to use cues, and by comparing differences between young and aged controls, we could determine how the ability to use cues is affected by age. We hypothesized that those with PD would walk slower and with a smaller stride length and higher cadence than those without PD. Secondly, we hypothesized that all groups would increase their gait velocity with attentional cues and with the higher frequency auditory cues due to increases in stride length and cadence, respectively. Further, we hypothesized that all groups would be able to combine the two cueing strategies, and that combining the higher frequency auditory cue with the attentional cue would result in larger increases in gait velocity than with either cue type alone. Finally, we hypothesized that when performing a secondary cognitive task while walking, the gait of young and age-matched controls would benefit from cueing in a similar manner as during single task walking, but that those with PD would not gain additional benefit from a combined cueing strategy.

METHODS

Participants

Eleven individuals with PD, 11 age- and gender-matched controls, and 11 young healthy controls participated in this investigation. Individuals with PD were recruited from a convenience sample of subjects who were participating in a separate study in the (x-blinded-x) Laboratory, as well as from the (x-blinded-x) database. Age-matched controls were recruited from a volunteer database at (x-blinded-x) as well by offering enrollment to spouses of participants with PD. Young controls were recruited from the Program in (x-blinded-x) at (x-blinded-x) University. Inclusion criteria for the PD group included: diagnosis of idiopathic PD, as performed by a board certified neurologist using diagnostic criteria for “definite PD” [18] ability to ambulate independently indoors without an assistive device, absence of any other neurologic disorder or dementia, absence of any orthopedic injury or other comorbidity that may affect gait, and adequate vision and hearing (with or without a hearing aid). Eligibility criteria for control subjects included a lack of any neurologic disorder, dementia, or other disease or injury that may affect gait, and adequate vision and hearing. Inclusion age for the young control group was 18-35 years. All subjects gave informed consent to perform experimental procedures approved by the Human Research Protection Office at (x-blinded-x).

Experimental Protocol

All testing was performed in the (x-blinded-x) laboratory at (x-blinded-x) University School of Medicine. For those subjects with PD, testing was performed during the ‘on’ state of their anti-Parkinson medication. All groups performed walking trials across a 5 meter instrumented, computerized GAITRite walkway (CIR systems, Inc, Havertown, PA) under the following cueing conditions: no cues, auditory cues at 10% below and above preferred cadence

(AUD-10, AUD+10, respectively), attentional cueing strategy (“think about taking large strides”, ATT), and combined auditory and attentional cues performed at both auditory cueing frequencies (COM-10, COM+10). Auditory cues were delivered using a stationary metronome located no further than 10 meters from the subject at any time during the walking trials. Subjects were asked to synchronize each step with the auditory tones. Each of the walking conditions was performed alone (single-task) and while performing a secondary cognitive task (dual-task, word generation based on letter of the alphabet). The cognitive task required subjects to generate and say words beginning with a letter of the alphabet. Subjects were encouraged to generate as many words as possible during each trial, and a new letter was used for each trial. Cognitive performance was monitored and quantified for each trial by dividing the number of correct words by ambulation time.

Prior to performing the walking protocol, subjects were familiarized with the GAITRite walkway and each cue modality, and were directed to attend equally to the cues and word generation task when performing dual task walking. Participants then performed three trials under each condition for a total of 36 trials. Participants were given as much time as they wished to rest between trials, and fatigue did not appear to limit any subjects. Task complexity order (single-task, dual-task) was counterbalanced and cue presentation order was randomized. For each trial, participants began walking prior to reaching the GAITRite mat and were instructed to walk completely across and off the mat before stopping. From the three initial baseline walking trials, an average value for preferred walking cadence was determined for each individual. This was used to calculate the +10% and -10% auditory cueing frequencies. Gait variables of primary interest were gait velocity, stride length, and cadence.

Data Analysis

An average value from the three trials of each condition was calculated for each variable of interest. SPSS v17.0 was used for statistical analysis. Baseline gait velocity, stride length, and cadence were compared across groups using a 1-way analysis of variance, with pairwise comparisons identifying significant differences between conditions. Gait velocity, stride length, cadence, and cognitive performance were compared between groups and across conditions using repeated measures, two way analysis of variance. Pairwise comparisons identified significant differences between conditions, and Bonferroni corrections were used during all analyses to adjust for multiple comparisons. Criteria for statistical significance was set at p<0.05.

RESULTS

Demographic data for the three groups are shown in table 1. PD and age-matched controls did not differ by age (p=.169) and there were no differences in leg length between any of the groups (p=.06). Baseline gait velocity and stride length were greater for young controls compared to PD and age-matched controls (F=5.45, p=.01, F=7.512, p=.002, respectively). PD and age-matched controls did not differ statistically in terms of baseline gait velocity, stride length, or cadence.

Effects of Cues on Single Task Walking

There was a significant main effect of group for gait velocity (F=6.011, p=.006) and stride length (F=8.858, p=.001) with the PD and age-matched controls walking slower and with a shorter stride length than the young controls. There was also an interaction effect of group and cue type for gait velocity (F=3.066, p=.001), stride length (F=2.416, p=.011) and cadence (F=2.057, p=.031), indicating the groups used the cues differently. Gait velocity, stride length, and cadence data are shown for all groups in Table 1.

Pairwise comparisons revealed that gait velocity increased for young controls with ATT (p=.004), AUD+10 (p<.001), COMB-10 (p=.003), and COMB+10 (p<.001), for age-matched controls with COMB+10 (p=.003), and for PD with ATT (p=.004), COMB-10 (p=.031), and COMB+10 (p=.029) (Figure 1A). Stride length increased above baseline for all three groups with ATT and Comb+10 (p<.011), and for young controls and PD with COMB-10 (p<.002) (Figure 1B). Significant changes in cadence were noted for age-matched controls with AUD-10 (p=.025, decreased cadence), and for young controls with AUD-10 (p=.011, decreased cadence), Aud+10 (p<.001, increased cadence), and COMB-10 (p<.001, decreased cadence). Cadence was not different across cue types in PD (Figure 1C).

Effect of a Secondary Cognitive Task on Walking

Age-matched controls and PD experienced a significant decrease in gait velocity when required to walk and perform a secondary cognitive task as compared with uncued, single task walking. This dual task interference effect was also evident for young controls but was not statistically significant (p=.056). Stride length during dual task walking did not decrease significantly below baseline walking, and cadence decreased significantly for age-matched controls only. There was a significant main effect of group for cognitive performance during the dual task trials, with young controls performing better than PD and age-matched controls (F=3.31, p=0.05). Additionally, cognitive performance differed across cue types (F=3.96, p=.002) in a similar manner for all groups as evidenced by the lack of interaction (F=1.45, p=.251, Figure 2).

Effect of Cues on Dual Task Walking

There was a significant main effect of group for gait velocity (F=13.616, p<.001), stride length (F=9.901, p<.001) and cadence (F=6.659, p=.004) with the PD and age-matched controls walking slower and with a smaller stride length and cadence than the young controls. There was also an interaction effect of group and cue type for stride length (F=1.921, p=.046) and cadence (F=3.769, p<.001), indicating the groups used the cues differently under dual task conditions as well.

Dual task gait velocity increased for young and age-matched controls with COMB+10 (p<.01) (Figure 3A). Stride length during dual task walking increased for young controls, age-matched controls, and PD with ATT (p=.001,p=.017,p=.004, respectively) and Comb+10 (p=.001, p=.012, p=.039, respectively), and for young controls and age-matched controls with COMB-10 (p=.007, p=.022, respectively) (Figure 3B). Significant changes in cadence during dual task walking were noted for only for aged matched controls with AUD+10 (p=.046, increased cadence, Figure 3C).

DISCUSSION

The main findings of this investigation are that persons with PD were able to effectively combine an attentional cueing strategy with an external auditory cue to improve gait performance during simple straight forward walking. A combined cueing strategy was not, however, more effective than using an attentional strategy alone. When required to perform a concurrent cognitive task while walking, persons with PD were able to improve their stride length by using the attentional cueing strategy, but this did not translate into an increase in gait velocity. Additionally, PD did not gain any further benefit from combining cue types during dual task walking.

Effects of Cues on Single Task Walking

During single-task walking, persons with PD were able to improve their gait velocity and stride length with the attentional strategy. This agrees with previous work showing that focusing on longer strides is effective for improving gait performance in PD.[4, 11] The relative magnitude of improvement was similar to that observed with the young and age-matched healthy controls (although the improvement in gait velocity for age-matched controls did not reach statistical significance). Auditory cueing did not improve gait velocity or stride length in PD, regardless of the cueing frequency, even though such improvements were observed for young controls when cued at 10% above preferred cadence. This is in contrast to some previous work showing that auditory cues presented at a higher than preferred cadence improve gait velocity[3, 5-7, 9] and stride length.[3, 5, 6] It is unclear why we did not observe improvements in PD gait performance with auditory cueing. It appears as though all groups were able to attend to the auditory cue whenever it was present during single task walking, since measured step frequency relative to baseline walking trended in the expected direction for all groups with auditory cueing.

Baker et al.[11] combined an attentional strategy with auditory cueing at 10% below preferred cadence but found no additional benefit with the combined cueing strategy.[11] We proposed that using a higher than self-selected auditory cueing cadence for the combined strategy may allow for an additive benefit, as the lower than preferred cadence auditory cues alone did not improve gait velocity in the Baker et al.[11] study. When we combined auditory cues at 10% above self selected cadence with the attentional strategy, all groups were able to effectively utilize both cues, as evidenced by an increase relative to baseline in gait velocity and stride length. However, only the young and age-matched controls experienced further improvements in gait performance with the COMB+10 condition beyond that observed with the attentional strategy alone. Similar to the study of Baker et al., we did not observe improvements in gait velocity in PD with AUD+10, so it is not entirely surprising that an additive benefit was not observed.

Effect of Cues on Dual Task Walking

While young and age-matched controls were able to improve dual task gait velocity by using the COMB+10 strategy, none of the cueing strategies were effective in improving dual task gait velocity for those with PD. While both control groups used cues in a similar fashion under single-task walking, young controls did not experience as much gait interference during dual task walking as did the age-matched controls, and young controls were able to use the combined cueing strategy (COM+10) to improve gait velocity more than the age-matched group. Therefore, while age-matched controls were able to use the cues more effectively than those with PD under dual task walking, they were still limited in their ability to do so, suggesting an age effect on the ability to use cues during dual task gait. Bloem et al.[19] suggest that during difficult dual task walking, healthy controls focus their attention on gait at the expense of cognitive performance, but that individuals with PD are less inclined to do so and are thus less likely to use a safe gait pattern. During dual tasks walking, we measured no difference between PD and age-matched controls in terms of cognitive task performance across conditions.

Therefore, it is unlikely that a difference in the amount of attention allocated to the secondary task would account for this finding A trend toward a decrease in cadence was, however, observed for all groups during dual task walking when the attentional strategy was used, which would counter the effects of improved stride length on gait velocity. Regardless, the limited effect of cueing on dual task walking for those with PD is contrary to some previous work. Rochester et al. [16] demonstrated improvements in dual task gait velocity, step amplitude, and cadence with auditory cueing, while Baker et al.[11] showed similar improvements with attentional and combined cues. In a similar study, only a combined cue strategy improved step time variability.[20] The authors suggest that cues reduce the attentional costs associated with walking, freeing up cognitive resources which can be used to perform the secondary task. These studies, however, used a secondary motor task, consisting of carrying a tray with cups of water. While it may be the case that cognitive and motor secondary tasks affect gait differently, O'Shea et al.[12] had subjects walk while performing a coin transference task (secondary motor) or a number subtraction task (secondary cognitive) and found that dual task gait decrements were similar regardless of the type of secondary task. Therefore, the effect of a secondary task on gait may be more dependent on task difficulty than task type. In the only study using cues during walking while performing a cognitive task, Morris et al.[4] found when subjects with PD were required to recite difficult sentences while walking, decreases in stride length and gait velocity were proportional to the difficulty of the sentence recited. We propose that the cognitive task chosen herein may be more attention demanding than the secondary motor tasks chosen in previous cueing studies (carrying a tray with cups of water)[11, 16] and that this may explain why cueing did not improve gait velocity during dual tasking in PD. It is argued that the role of cues is to direct attention to gait, thus bypassing the defective basal ganglia and allowing cortical regions to control gait.[21] When performance of a simple secondary task is required, attention may be divided between both the concurrent task and gait. However, if cortical resources are fully engaged by an attention demanding secondary task, control of the more automatic movement, gait, may revert back to the diseased basal ganglia.

Limitations

A limitation of this study is the ability to generalize to a wider population due to the small sample size and narrow range of PD disease severity. We observed no statistical difference in baseline gait characteristics between PD and age-matched controls. However, it must be highlighted that average baseline stride length was 9.3 cm greater in the PD group as compared with age-matched controls. Participants were tested ON medication and were aware they were being monitored, which can lead to improved performance on gait tasks, possibly explaining such unexpected findings although subjects were also aware of being monitored in previous studies with dissimilar results. Additionally, our sample included seven participants at Hoehn & Yahr stage 2 and only one participant at stage 3. As such, disease severity in our sample was relatively mild. Regardless, the lack of deficits in baseline gait characteristics of those with PD as compared with age-matched controls was unexpected and it is possible that the amount of benefit realized by those with PD in response to cues may have been limited by this. However, we do not think that this detracts from our findings, as one would expect that the observations we have noted with this group of people with mild PD would be amplified in individuals with more advanced disease.

Clinical Implications and Conclusions

As walking is often accompanied by a secondary cognitive task such as participating in a conversation, an understanding of strategies for optimizing gait during such contexts is essential. The data presented herein point to an attentional strategy as being most effective and robust in terms of normalizing Parkinsonian gait. An attentional cueing strategy allows for an increase in gait velocity and stride length during simple walking and appears to improve stride length when a secondary cognitive task is being performed. While gait velocity may not increase with attentional cueing under cognitive dual task conditions, the increased stride length may allow for a more normal gait pattern that is further removed from the “shuffling gait” often described in those with PD. As a progressive reduction in stride length, as well as festination, has been associated with freezing of gait,[22, 23] increasing stride length using cues may also help reduce the risk of freezing-related falls in PD. Further work is needed to determine if these findings are consistent across cognitive tasks of varying type and difficulty, and in persons at different stages of PD progression.

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Figures

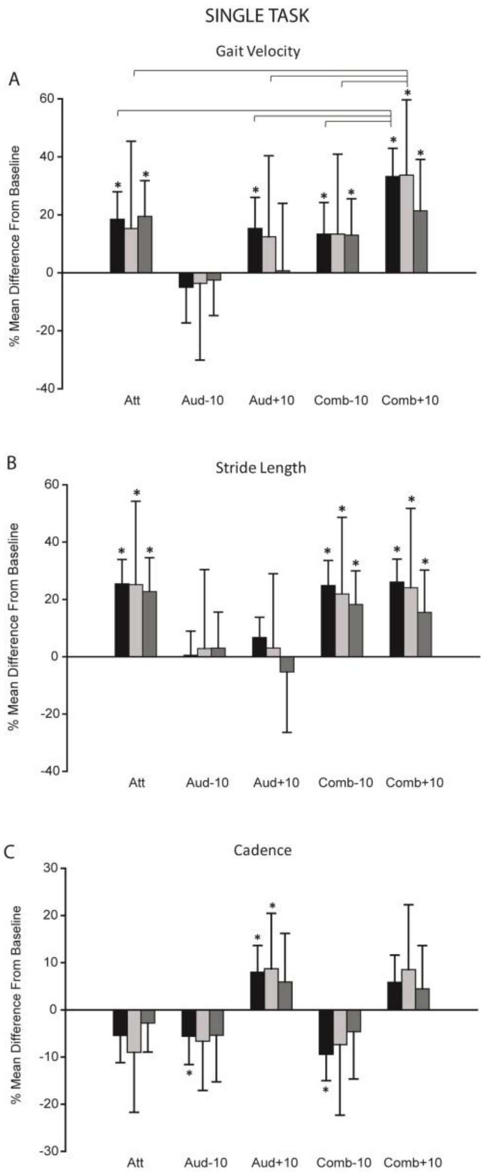

Figure 1. Gait velocity (A), stride length (B), and cadence (C) during walking. Data are represented as the percent mean difference from baseline walking (mean ± SEM). Black bars indicate young healthy controls, light grey bars indicate age-matched controls, and dark grey bars indicate PD. Only selected pairwise comparisons between experimental conditions within a group based on our specific research questions are displayed, with significant (p<0.05) pairwise comparisons indicated by brackets.

* Significantly different from non-cued baseline walking, (p<0.05)

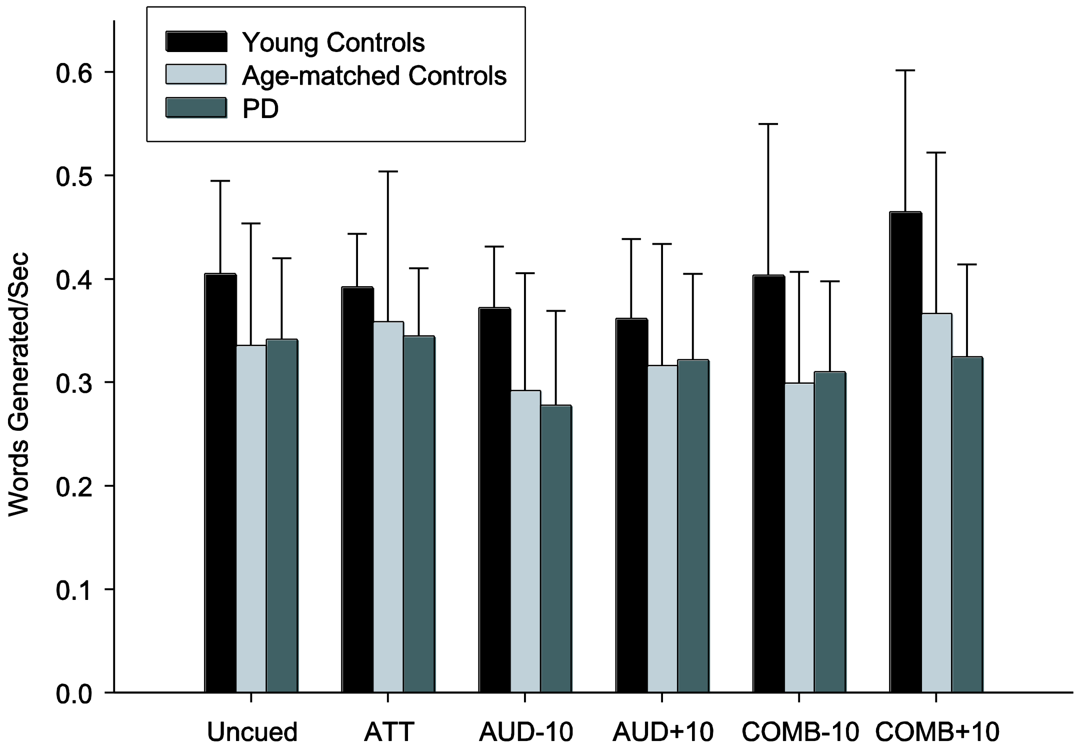

Figure 2. Graph representing cognitive performance during the dual task walking conditions. Black bars indicate young healthy controls, light grey bars indicate age-matched controls, and dark grey bars indicate PD. The number of correct words generated in each trial was normalized to the length of the trial (ambulation time) Data are represented as mean ± SD.

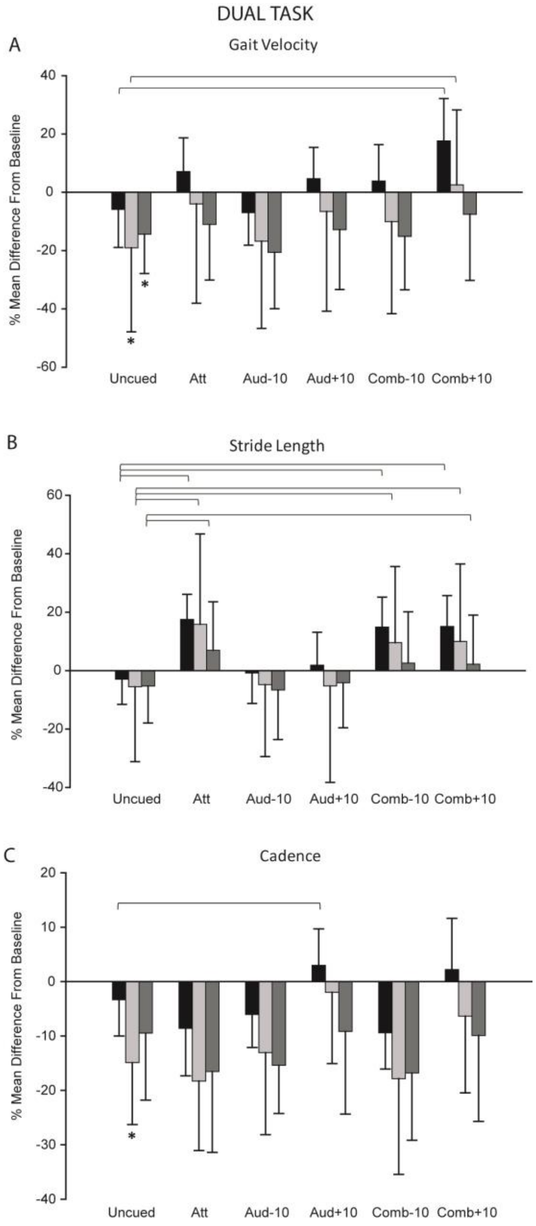

Figure 3. Gait velocity (A), stride length (B), and cadence (C) during walking while performing a secondary cognitive task. Data are represented as the percent mean difference from baseline walking (mean ± SEM). Black bars indicate young healthy controls, light grey bars indicate age-matched controls, and dark grey bars indicate PD. Only selected pairwise comparisons between experimental conditions within a group based on our specific research questions are displayed, with significant ($p<0.05$) pairwise comparisons indicated by brackets.

* Significantly different from non-cued baseline walking, ($p<0.05$)

Table 1. Subject Demographics

	PD	Controls	Young
Age (years)	70.27 ± 6.80	70.82 ± 10.44	24.09 ± 0.83
Male/Female	4/7	4/7	4/7
Averaged Leg Length	87.64 ± 6.21	83.68 ± 8.14	80.36 ± 6.07
PD Characteristics			
Disease Duration	9.09 ± 5.39		
Hoehn & Yahr Stage (# in each stage)	2 = 7		
	2.5 = 3		
	3 = 1		
Freezing of Gait Score	6.91 ± 5.54		
UPDRS Motor Score	21.55 ± 6.71		
ABC-16	65.17 ± 23.48		

Values are means ± standard deviations.

Table 2. Mean Values ± SEM in PD, Age-matched Controls, and Young Controls for Gait Velocity, Stride Length, and Cadence.

Gait Parameter	Task	Condition	PD	Age-Matched Controls	Young Controls
Gait Velocity (cm/s)	Walking	Baseline	117.5 ± 4.3	116.0 ± 7.8	140.6 ± 5.1
		ATT	140.4 ± 5.2	133.7 ± 12.1	166.6 ± 4.7
		AUD -10	114.5 ± 4.2	111.7 ± 8.9	133.6 ± 4.9
		AUD +10	118.3 ± 8.3	130.4 ± 11.0	162.2 ± 5.2
		COMB -10	132.7 ± 5.0	131.5 ± 10.9	159.4 ± 5.2
		COMB +10	142.6 ± 7.6	155.1 ± 12.1	187.4 ± 5.5
	Dual-Task	Uncued	100.6 ± 4.1	93.9 ± 8.2	132.4 ± 5.2
		ATT	104.5 ± 6.0	111.4 ± 11.4	150.6 ± 5.3
		AUD -10	93.3 ± 5.4	96.5 ± 8.7	130.8 ± 4.4
		AUD +10	102.4 ± 6.4	108.4 ± 11.2	147.2 ± 4.8
		COMB -10	99.7 ± 5.5	104.3 ± 9.9	146.1 ± 5.5
		COMB +10	108.6 ± 7.4	119.0 ± 9.2	165.4 ± 7.2
Stride Length (cm)	Walking	Baseline	129.1 ± 5.2	119.8 ± 8.7	153.1 ± 4.0
		ATT	158.5 ± 5.6	150.0 ± 13.1	192.1 ± 4.9
		AUD -10	133.0 ± 5.0	123.2 ± 10.2	153.9 ± 3.9
		AUD +10	122.3 ± 7.8	123.4 ± 9.7	163.4 ± 3.5
		COMB -10	152.7 ± 5.4	146.0 ± 11.8	191.2 ± 5.0
		COMB +10	149.1 ± 6.6	148.6 ± 12.4	193.0 ± 4.7
	Dual-Task	Uncued	122.3 ± 4.7	113.2 ± 8.7	148.6 ± 3.9
		ATT	138.1 ± 6.9	138.8 ± 12.9	180.0 ± 4.6
		AUD -10	120.5 ± 6.2	114.1 ± 8.5	151.9 ± 4.8
		AUD +10	123.7 ± 5.8	113.5 ± 11.3	156.0 ± 5.3
		COMB -10	132.5 ± 7.0	131.2 ± 10.3	175.9 ± 5.4
		COMB +10	132.0 ± 6.7	131.8 ± 10.5	176.3 ± 5.6
Cadence (steps/sec)	Walking	Baseline	110.0 ± 2.9	110.7 ± 3.0	110.3 ± 2.2
		ATT	106.9 ± 2.0	110.8 ± 3.9	104.3 ± 1.8
		AUD -10	104.0 ± 3.1	103.4 ± 3.2	104.1 ± 1.9
		AUD +10	116.5 ± 3.6	120.4 ± 4.3	119.1 ± 2.0
		COMB -10	104.9 ± 3.2	102.6 ± 4.6	99.9 ± 1.7
		COMB +10	114.9 ± 3.2	120.2 ± 5.0	116.7 ± 2.0
	Dual-Task	Uncued	99.5 ± 3.7	94.2 ± 3.2	106.6 ± 2.1
		ATT	91.8 ± 4.1	90.5 ± 3.5	100.8 ± 2.7
		AUD -10	93.0 ± 2.5	96.3 ± 4.4	103.6 ± 1.9
		AUD +10	99.9 ± 4.6	108.6 ± 4.3	113.6 ± 2.3
		COMB -10	91.5 ± 3.4	91.0 ± 4.8	99.9 ± 2.0
		COMB +10	99.1 ± 4.7	103.7 ± 4.4	112.7 ± 3.2