

3-2011

The impact of attentional, auditory, and combined cues on walking during single and cognitive dual tasks in Parkinson disease

Corey A. Lohnes

Washington University School of Medicine in St. Louis

Gammon M. Earhart

Washington University School of Medicine in St. Louis

Follow this and additional works at: http://digitalcommons.wustl.edu/pt_facpubs

Recommended Citation

Lohnes, Corey A. and Earhart, Gammon M., "The impact of attentional, auditory, and combined cues on walking during single and cognitive dual tasks in Parkinson disease" (2011). *Physical Therapy Faculty Publications*. Paper 40.
http://digitalcommons.wustl.edu/pt_facpubs/40

This Article is brought to you for free and open access by the Program in Physical Therapy at Digital Commons@Becker. It has been accepted for inclusion in Physical Therapy Faculty Publications by an authorized administrator of Digital Commons@Becker. For more information, please contact engeszer@wustl.edu.

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

3

4 Corey A. Lohnes¹, Gammon M. Earhart¹⁻³

5

6 1 Program in Physical Therapy, Washington University in St. Louis, St. Louis, MO, USA

7 2 Department of Anatomy & Neurobiology, Washington University in St. Louis, St. Louis, MO,
8 USA

9 3 Department of Neurology, Washington University in St. Louis, St. Louis, MO, USA

10

11 Running Title: Cueing during single and dual task walking in PD.

12 Word Count: Abstract = 259, Body = 3462

13

14

15 Corresponding Author:

16 Gammon M. Earhart, PhD, PT

17 Program in Physical Therapy, Washington University School of Medicine

18 Campus Box 8502

19 4444 Forest Park Blvd.

20 St. Louis, MO, 63108

21 Ph: 314-286-1425

22 Fax: 314-286-1410

23 earhartg@wusm.wustl.edu

24

25

26

27 **Abstract**

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

47

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

49

50

51

52

53 INTRODUCTION

54 Impaired gait is common in Parkinson disease (PD) and is characterized by reduced
55 velocity and step amplitude and increased step frequency, placing individuals with PD at a
56 greater risk for falls and a loss of independence.¹ Evidence exists to support the use of spatial
57 and rhythmic external cues to increase stride length and regulate cadence.²⁻⁹ Spatial cues,
58 most commonly delivered using lines on the floor, direct the individual to take steps with larger
59 and more regular spacing. As spatial cues are often unavailable outside the laboratory setting,
60 an attentional strategy (“think about taking larger steps”) may be more practical and has been
61 shown to be equally effective as external spatial cues for improving step size and gait velocity⁴.
62 Another portable and practical means of cueing is the generation of auditory rhythmic cues
63 using a metronome with instruction to match step frequency to the auditory rhythm. The ideal
64 frequency of such cues has yet to be fully elucidated, but auditory cues ranging from 90%
65 to 125% of preferred cadence have shown benefit in terms of gait velocity^{3, 5-7, 9}, stride length^{3, 6, 9,}
66 ¹⁰, and cadence^{3, 5-7, 9, 10}.

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

78 Individuals with PD experience exacerbated gait impairments when required to perform
79 a concurrent task.^{4, 12-16} There is strong support for the use of external cues and internally
80 generated attentional strategies to reduce the interference effect of a secondary motor task on
81 gait performance.¹⁵⁻¹⁷ However, only one study has examined the effectiveness of cueing to
82 reduce the interference effect of a concurrent cognitive task on gait in PD⁴. Following visual and
83 attentional cue training, PD gait performance improved to that of healthy controls, even when
84 subjects were instructed to concentrate on reciting a sentence. However, as the complexity of
85 the recited sentence increased, stride length and velocity greatly deteriorated proportional to the
86 complexity of the secondary task.

87 Therefore, we sought to determine if individuals with PD are able to combine a higher
88 frequency auditory rhythmic cue with an attentional cueing strategy, and to determine if the
89 combination improves gait performance above and beyond that observed with either cue type
90 alone. Secondly, we sought to determine if the effectiveness of rhythmic auditory cueing,
91 attentional spatial cueing, and a combined cueing strategy holds when performing a concurrent
92 cognitive task. To separate the effects of age versus disease status, we chose to also include a
93 sample of young, healthy adults. By comparing PD and aged controls, we could examine the
94 effects of PD on the ability to use cues, and by comparing differences between young and aged
95 controls, we could determine how the ability to use cues is affected by age. We hypothesized
96 that those with PD would walk slower and with a smaller stride length and higher cadence than
97 those without PD. Secondly, we hypothesized that all groups would increase their gait velocity
98 with attentional cues and with the higher frequency auditory cues due to increases in stride
99 length and cadence, respectively. Further, we hypothesized that all groups would be able to
100 combine the two cueing strategies, and that combining the higher frequency auditory cue with
101 the attentional cue would result in larger increases in gait velocity than with either cue type
102 alone. Finally, we hypothesized that when performing a secondary cognitive task while walking,
103 the gait of young and age-matched controls would benefit from cueing in a similar manner as

104 during single task walking, but that those with PD would not gain additional benefit from a
105 combined cueing strategy.

106

107 **METHODS**

108 **Participants**

109 Eleven individuals with PD, 11 age- and gender-matched controls, and 11 young healthy
110 controls participated in this investigation. Individuals with PD were recruited from a
111 convenience sample of subjects who were participating in a separate study in the (x-blinded-x)
112 Laboratory, as well as from the (x-blinded-x) database. Age-matched controls were recruited
113 from a volunteer database at (x-blinded-x) as well by offering enrollment to spouses of
114 participants with PD. Young controls were recruited from the Program in (x-blinded-x) at (x-
115 blinded-x) University. Inclusion criteria for the PD group included: diagnosis of idiopathic PD, as
116 performed by a board certified neurologist using diagnostic criteria for “definite PD”¹⁸ ability to
117 ambulate independently indoors without an assistive device, absence of any other neurologic
118 disorder or dementia, absence of any orthopedic injury or other comorbidity that may affect gait,
119 and adequate vision and hearing (with or without a hearing aid). Eligibility criteria for control
120 subjects included a lack of any neurologic disorder, dementia, or other disease or injury that
121 may affect gait, and adequate vision and hearing. Inclusion age for the young control group was
122 18-35 years. All subjects gave informed consent to perform experimental procedures approved
123 by the Human Research Protection Office at (x-blinded-x).

124 **Experimental Protocol**

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

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

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

152 **Data Analysis**

153 An average value from the three trials of each condition was calculated for each variable
154 of interest. SPSS v17.0 was used for statistical analysis. Baseline gait velocity, stride length,
155 and cadence were compared across groups using a 1-way analysis of variance, with pairwise

156 comparisons identifying significant differences between conditions. Gait velocity, stride length,
157 cadence, and cognitive performance were compared between groups and across conditions
158 using repeated measures, two way analysis of variance. Pairwise comparisons identified
159 significant differences between conditions, and Bonferroni corrections were used during all
160 analyses to adjust for multiple comparisons. Criteria for statistical significance was set at
161 $p < 0.05$.

162 **RESULTS**

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

169 **Effects of Cues on Single Task Walking**

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

176 Pairwise comparisons revealed that gait velocity increased for young controls with ATT
177 ($p = .004$), AUD+10 ($p < .001$), COMB-10 ($p = .003$), and COMB+10 ($p < .001$), for age-matched
178 controls with COMB+10 ($p = .003$), and for PD with ATT ($p = .004$), COMB-10 ($p = .031$), and
179 COMB+10 ($p = .029$) (Figure 1A). Stride length increased above baseline for all three groups
180 with ATT and Comb+10 ($p < .011$), and for young controls and PD with COMB-10 ($p < .002$)
181 (Figure 1B). Significant changes in cadence were noted for age-matched controls with AUD-10

182 (p=.025, decreased cadence), and for young controls with AUD-10 (p=.011, decreased
183 cadence), Aud+10 (p<.001, increased cadence), and COMB-10 (p<.001, decreased cadence).
184 Cadence was not different across cue types in PD (Figure 1C).

185 **Effect of a Secondary Cognitive Task on Walking**

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

196 **Effect of Cues on Dual Task Walking**

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

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

208 dual task walking were noted for only for aged matched controls with AUD+10 ($p=.046$,
209 increased cadence, Figure 3C).

210

211 **DISCUSSION**

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

220 **Effects of Cues on Single Task Walking**

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

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

246 **Effect of Cues on Dual Task Walking**

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

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

285 fully engaged by an attention demanding secondary task, control of the more automatic
286 movement, gait, may revert back to the diseased basal ganglia.

287 **Limitations**

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

303 **Clinical Implications and Conclusions**

304 As walking is often accompanied by a secondary cognitive task such as participating in a
305 conversation, an understanding of strategies for optimizing gait during such contexts is
306 essential. The data presented herein point to an attentional strategy as being most effective
307 and robust in terms of normalizing Parkinsonian gait. An attentional cueing strategy allows for
308 an increase in gait velocity and stride length during simple walking and appears to improve
309 stride length when a secondary cognitive task is being performed. While gait velocity may not
310 increase with attentional cueing under cognitive dual task conditions, the increased stride length

311 may allow for a more normal gait pattern that is further removed from the “shuffling gait” often
312 described in those with PD. As a progressive reduction in stride length, as well as festination,
313 has been associated with freezing of gait,^{22, 23} increasing stride length using cues may also help
314 reduce the risk of freezing-related falls in PD. Further work is needed to determine if these
315 findings are consistent across cognitive tasks of varying type and difficulty, and in persons at
316 different stages of PD progression.

317 **Acknowledgements**

318 This work was supported by a grant from the Center for Programs at (x-blinded-x). Additional
319 support was provided by the American Parkinson Disease Association (APDA) Advanced
320 Center for PD Research at (x-blinded-x) and the Greater (x-blinded-x) Chapter of the APDA.

321

322

323

324

325

326

327

328

329

330

331

332

333

334

335

336

337 **REFERENCES**

- 338 1. Morris ME, Iansek R, Matyas TA, Summers JJ. The pathogenesis of gait hypokinesia in
339 Parkinson's disease. *Brain* 1994;117 (Pt 5):1169-81.
340
- 341 2. Nieuwboer A, Kwakkel G, Rochester L, Jones D, van Wegen E, Willems AM et al. Cueing
342 training in the home improves gait-related mobility in Parkinson's disease: the RESCUE trial. *J*
343 *Neurol Neurosurg Psychiatry* 2007;78(2):134-40.
344
- 345 3. McIntosh GC, Brown SH, Rice RR, Thaut MH. Rhythmic auditory-motor facilitation of gait
346 patterns in patients with Parkinson's disease. *J Neurol Neurosurg Psychiatry* 1997;62(1):22-6.
347
- 348 4. Morris ME, Iansek R, Matyas TA, Summers JJ. Stride length regulation in Parkinson's
349 disease. Normalization strategies and underlying mechanisms. *Brain* 1996;119 (Pt 2):551-68.
350
- 351 5. Suteerawattananon M, Morris GS, Etnyre BR, Jankovic J, Protas EJ. Effects of visual and
352 auditory cues on gait in individuals with Parkinson's disease. *J Neurol Sci* 2004;219(1-2):63-9.
353
- 354 6. Thaut MH, McIntosh GC, Rice RR, Miller RA, Rathbun J, Brault JM. Rhythmic auditory
355 stimulation in gait training for Parkinson's disease patients. *Mov Disord* 1996;11(2):193-200.
356
- 357 7. Howe TE, Lovgreen B, Cody FW, Ashton VJ, Oldham JA. Auditory cues can modify the gait
358 of persons with early-stage Parkinson's disease: a method for enhancing parkinsonian walking
359 performance? *Clin Rehabil* 2003;17(4):363-7.
360
- 361 8. Lewis GN, Byblow WD, Walt SE. Stride length regulation in Parkinson's disease: the use of
362 extrinsic, visual cues. *Brain* 2000;123 (Pt 10):2077-90.
363
- 364 9. Willems AM, Nieuwboer A, Chavret F, Desloovere K, Dom R, Rochester L et al. The use of
365 rhythmic auditory cues to influence gait in patients with Parkinson's disease, the differential
366 effect for freezers and non-freezers, an explorative study. *Disabil Rehabil* 2006;28(11):721-8.
367
- 368 10. Arias P, Cudeiro J. Effects of rhythmic sensory stimulation (auditory, visual) on gait in
369 Parkinson's disease patients. *Exp Brain Res* 2008;186(4):589-601.
370
- 371 11. Baker K, Rochester L, Nieuwboer A. The immediate effect of attentional, auditory, and a
372 combined cue strategy on gait during single and dual tasks in Parkinson's disease. *Arch Phys*
373 *Med Rehabil* 2007;88(12):1593-600.
374
- 375 12. O'Shea S, Morris ME, Iansek R. Dual task interference during gait in people with Parkinson
376 disease: effects of motor versus cognitive secondary tasks. *Phys Ther* 2002;82(9):888-97.
377
- 378 13. Camicioli R, Oken BS, Sexton G, Kaye JA, Nutt JG. Verbal fluency task affects gait in
379 Parkinson's disease with motor freezing. *J Geriatr Psychiatry Neurol* 1998;11(4):181-5.
380
- 381 14. Rochester L, Hetherington V, Jones D, Nieuwboer A, Willems AM, Kwakkel G et al.
382 Attending to the task: interference effects of functional tasks on walking in Parkinson's disease
383 and the roles of cognition, depression, fatigue, and balance. *Arch Phys Med Rehabil*
384 2004;85(10):1578-85.
385

386 15. Rochester L, Hetherington V, Jones D, Nieuwboer A, Willems AM, Kwakkel G et al. The
387 effect of external rhythmic cues (auditory and visual) on walking during a functional task in
388 homes of people with Parkinson's disease. Arch Phys Med Rehabil 2005;86(5):999-1006.
389

390 16. Rochester L, Nieuwboer A, Baker K, Hetherington V, Willems AM, Chavret F et al. The
391 attentional cost of external rhythmical cues and their impact on gait in Parkinson's disease:
392 effect of cue modality and task complexity. J Neural Transm 2007;114(10):1243-8.
393

394 17. Rochester L, Rafferty D, Dotchin C, Msuya O, Minde V, Walker RW. The effect of cueing
395 therapy on single and dual-task gait in a drug naive population of people with Parkinson's
396 disease in northern Tanzania. Mov Disord 2010;25(7):906-11.
397

398 18. Racette BA, Rundle M, Parsian A, Perlmutter JS. Evaluation of a screening questionnaire
399 for genetic studies of Parkinson's disease. Am J Med Genet 1999;88(5):539-43.
400

401 19. Bloem BR, Grimbergen YA, van Dijk JG, Munneke M. The "posture second" strategy: a
402 review of wrong priorities in Parkinson's disease. J Neurol Sci 2006;248(1-2):196-204.
403

404 20. Baker K, Rochester L, Nieuwboer A. The effect of cues on gait variability--reducing the
405 attentional cost of walking in people with Parkinson's disease. Parkinsonism Relat Disord
406 2008;14(4):314-20.
407

408 21. Cunnington R, Iansek R, Bradshaw JL. Movement-related potentials in Parkinson's disease:
409 external cues and attentional strategies. Mov Disord 1999;14(1):63-8.
410

411 22. Giladi N, Shabtai H, Rozenberg E, Shabtai E. Gait festination in Parkinson's disease.
412 Parkinsonism Relat Disord 2001;7(2):135-8.
413

414 23. Nieuwboer A, Dom R, De Weerd W, Desloovere K, Fieuws S, Broens-Kaucsik E.
415 Abnormalities of the spatiotemporal characteristics of gait at the onset of freezing in Parkinson's
416 disease. Mov Disord 2001;16(6):1066-75.
417
418

419

420

421

422

423

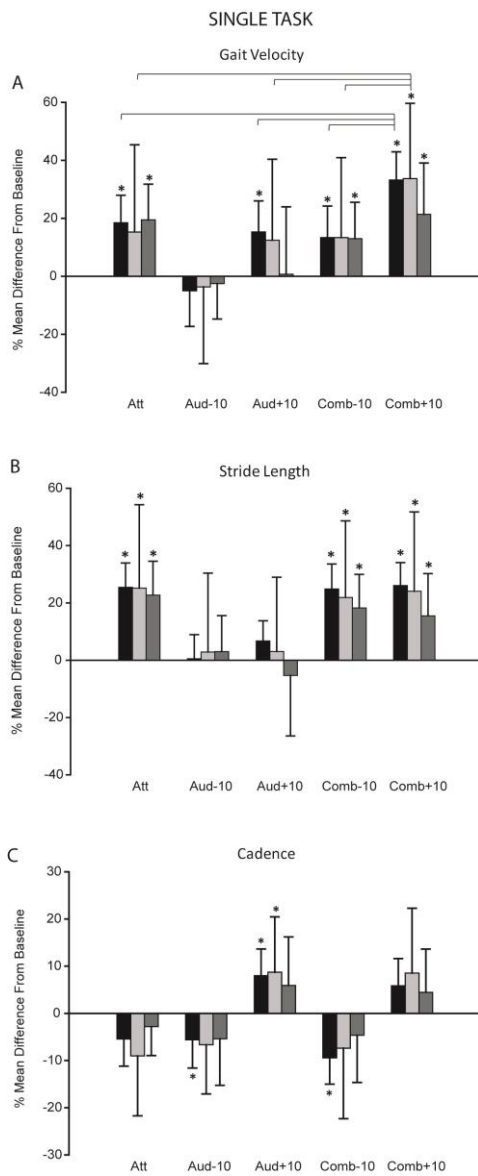
424

425

426

427

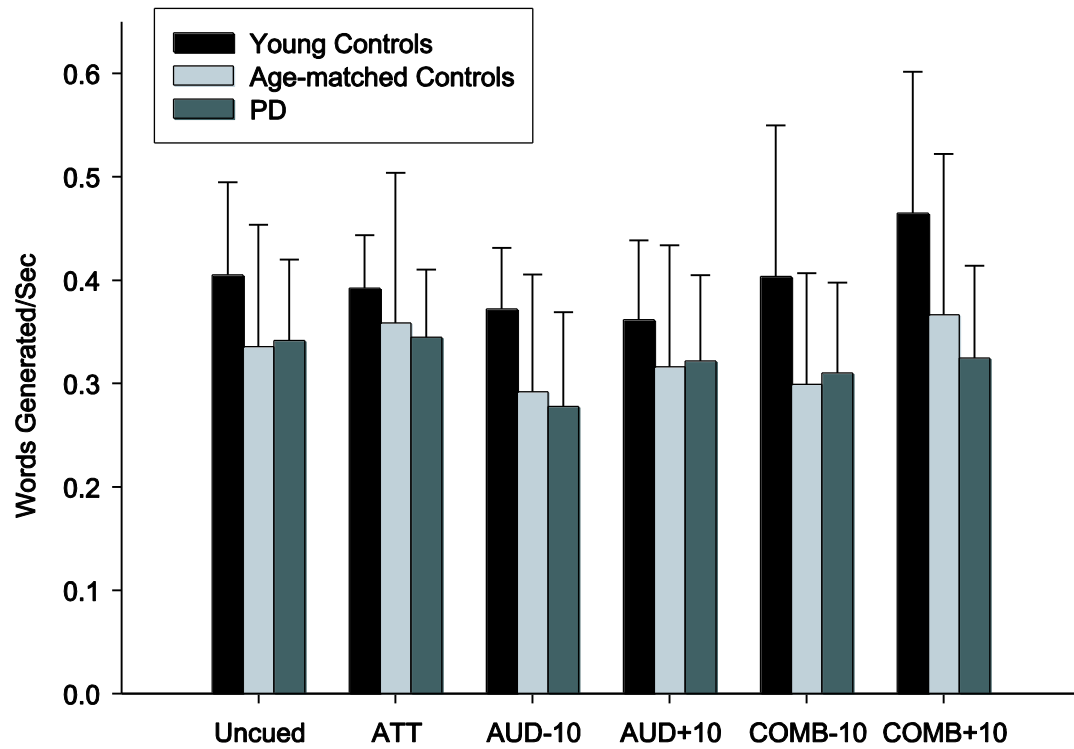
428 **Figures**



429

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

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



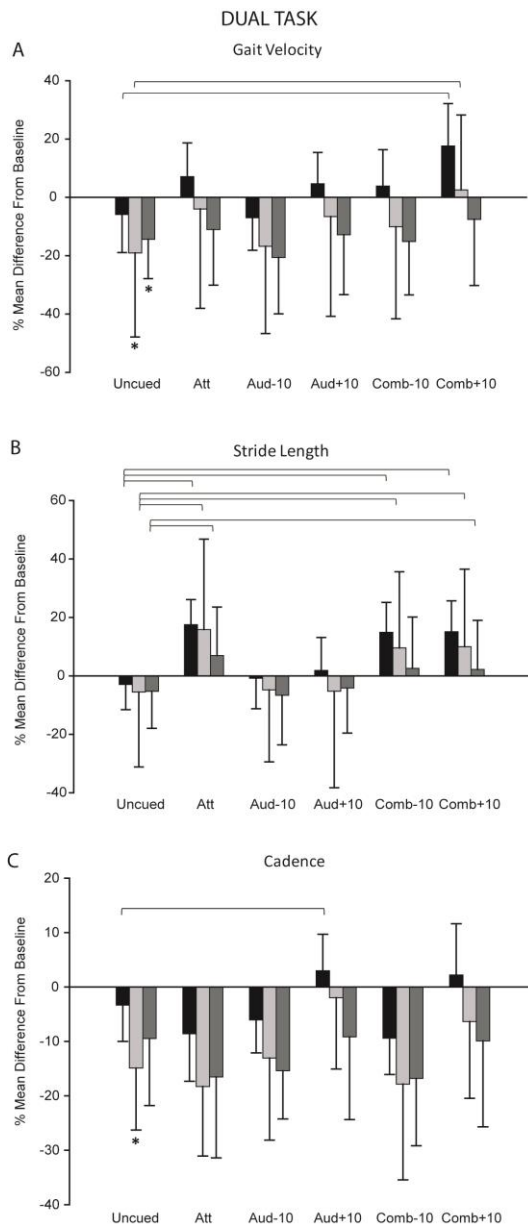
437

438 Figure 2. Graph representing cognitive performance during the dual task walking conditions.

439 Black bars indicate young healthy controls, light grey bars indicate age-matched controls, and

440 dark grey bars indicate PD. The number of correct words generated in each trial was normalized

441 to the length of the trial (ambulation time) Data are represented as mean \pm SD.



442

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

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

450 **Table 1. Subject Demographics**

451		PD	Controls	Young
452				
453				
454	Age (years)	70.27 ± 6.80	70.82 ± 10.44	24.09 ± 0.83
455	Male/Female	4/7	4/7	4/7
456	Averaged Leg Length	87.64 ± 6.21	83.68 ± 8.14	80.36 ± 6.07
457				
458	<u>PD Characteristics</u>			
459	Disease Duration	9.09 ± 5.39		
460	Hoehn & Yahr Stage (# in each stage)	2 = 7		
461		2.5 = 3		
462		3 = 1		
463				
464	Freezing of Gait Score	6.91 ± 5.54		
465	UPDRS Motor Score	21.55 ± 6.71		
466	ABC-16	65.17 ± 23.48		

467 Values are means ± standard deviations.

468

469

470

471

472

473

474

475

476

477

478

479

480

481

482

483

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		