Original Research Article

Dementia and Geriatric Cognitive Disorders

Dement Geriatr Cogn Disord 2008;26:364–369
DOI: 10.1159/000162358

Accepted: July 25, 2008
Published online: October 14, 2008

Impact of Impaired Executive Function on Gait Stability

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Key Words
Dementia · Gait disorder · Executive function · Attention

Abstract
Background: Executive dysfunction contributes to gait changes, but the precise mechanisms are still poorly understood. Dual-task-related gait changes depend in part on the capacity to appropriately allocate attention between tasks performed simultaneously and are mainly related to executive deficits. This study aimed to describe the impact of dysexecutive function on gait stability in subjects with dementia using dual tasking. ***Methods:*** Mean values and coefficients of variation of stride time while only walking and while walking and backward counting (dual tasking) were measured using the GAITRite® System in 18 subjects with dementia and impaired executive function (IEF), in 16 subjects with dementia and intact executive function, and in 22 nondemented subjects as controls. ***Results:*** Stride time, and particularly its variability, significantly increased while performing dual tasking ($p < 0.05$). IEF was related to both stride time and stride time variability during walking only and to even more gait changes, while dual tasking compared to nondemented subjects and demented subjects without IEF. ***Conclusions:*** These findings confirm the role of executive function in dual tasking, but also strongly suggest their importance for gait stability.

Gait instability is common among subjects with cognitive impairment [1, 2] and influenced by abnormal cortical level gait control related to impaired executive function (IEF) [3, 4]. Dual-task paradigms are used by clinicians to evaluate cortical involvement in gait control in subjects with cognitive decline [5]. Changes in gait while performing an attention-demanding task mainly result from interference caused by competing demands for attention resources [6]. Dual-task-related gait changes depend in part on the capacity to appropriately allocate attention between two tasks performed simultaneously and, therefore, are related to executive functions [7, 8].

Previous reports have shown that subjects with Alzheimer's disease (AD) have greater dual-task-related gait changes compared to normal age-matched controls [9, 10]. Some studies have shown that the control of the walk-

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ing-related rhythmic stepping mechanism is reflected by the stride time variability [11]. An increase in stride time variability under the dual-task condition has been associated with IEF in patients with moderate AD [12]. In addition, counting backwards provoked a higher increase in stride time variability than counting forwards among demented subjects with IEF, and the effect of dual tasking only affected the motor element in that the cognitive task of counting remained unchanged [13].

Whilst many studies [11–14] analyzed the influence of executive function on gait, none of these reports compared specifically the gait performance of demented subjects with and without dysexecutive syndrome. Acquiring more information about dual-task interferences in demented subjects with and without IEF could add to our understanding of IEF-related gait instability. The objective of this study was to quantify and compare mean values and coefficients of variation (CV) of stride time under single- and dual-task conditions in demented subjects with and without IEF, and in nondemented subjects as controls.

Methods

Participants and Clinical Assessment

Thirty-four demented subjects with moderate AD, vascular dementia (VaD) or mixed AD/VaD according to the criteria of the Diagnostic and Statistical Manual of Mental Disorders, 4th edition, and 22 nondemented subjects were included after giving informed consent. Dementia severity was measured with the Mini-Mental State Examination (MMSE) [15] and the Mattis Dementia Rating Scale (DRS) in the demented subjects [16]. Demented subjects were separated into 2 groups (i.e. with and without IEF) according to the Frontal Assessment Battery (FAB) [17] and the Behavioral Scale of Frontal Lobe Dysfunction [18], which are two validated short bedside questionnaires related to executive function. A FAB score of 18 indicates normal executive functions. The Behavioral Scale of Frontal Lobe Dysfunction is a 4-point questionnaire based on the caregiver's observation where a score of 4 reflects the highest frontal impairment. Exclusion criteria included extrapyramidal rigidity of the upper limbs with a score above 2, based on item 22 of the Unified Parkinson's Disease Rating Scale motor score [19]; acute medical illness in the past month; neurological and psychiatric diseases except dementia; severe orthopedic or rheumatologic condition affecting normal walking, as well as use of walking aids. Before the gait assessment, all participants received a full medical and neurological examination by a physician that included questions about the use of psychoactive drugs (particularly benzodiazepines, antidepressants and neuroleptics), and the number of drugs taken per day. The local ethics committee approved the project.

Gait Analysis

The participants were asked to perform, in randomized order, the following tasks to the best of their capacity: straight walking at their usual self-selected walking speed as a single task, and then while counting backward aloud (i.e. count down) starting from 50, and backward counting while sitting. Participants were not specifically instructed to prioritize either one of both tasks, but were asked to combine both tasks at their best capacity. Before the test was carried out, a trained evaluator gave standardized verbal instructions regarding the test procedure, along with a visual demonstration of the walking test. Each subject completed one trial for the testing conditions. The subjects wore their own footwear. To ensure safety, a belt was placed around each subject's waist for easy grasp by a research assistant who walked behind the subjects during the walking trial. Gait measurements were made according to the guidelines for clinical applications of spatio-temporal gait analysis in older adults [20]. Mean values and CV [CV = (standard deviation/mean) × 100] of stride time for both walking conditions were determined during steady-state walking on a 10-meter walkway using the GAITRite® System [21].

Statistics

Outcome measures included median and interquartile range of baseline characteristics, mean values and CV of stride time under single- and dual-task conditions. Comparisons between both groups were performed using Fischer's exact test, Kruskal-Wallis ANOVA with adjustment for multiple comparisons or Wilcoxon matched pairs signed ranks test, as appropriate. Univariate linear regression analysis was performed to specify the relationships between CV of stride time and FAB score among demented subjects. $p < 0.05$ was considered statistically significant. Statistics were performed using the STATA Statistical Software, release 9.2.

Results

Participant Characteristics

As shown in table 1, there were no significant differences between groups for age, sex ratio, use of psychoactive drugs, and number of chronic diseases. Subjects with dementia had a lower MMSE score compared to normal controls ($p < 0.001$), but no significant difference was shown between both groups of demented subjects ($p = 0.240$). The demented subjects with IEF had lower FAB scores ($p < 0.001$) and higher Behavioral Scale of Frontal Lobe Dysfunction scores compared to the demented subjects without IEF ($p < 0.001$), but there was no difference for the Mattis DRS ($p = 0.476$). Etiologies of dementia significantly differed between groups ($p < 0.001$). In the demented subjects without IEF, probable AD was the only diagnosis, whereas mixed AD/VaD was the main diagnosis in the demented subjects with IEF. On average, the Unified Parkinson's Disease Rating Scale scores of the two groups of demented subjects were significantly higher than those of the control group ($p = 0.021$), but there was no difference between the demented subjects with IEF and the demented subjects without IEF ($p = 0.506$).

Table 1. Baseline characteristics of subjects (n = 56)

	Demented subjects		Non-demented subjects (n = 22)	p value[a]
	without impaired executive function (n = 16)	with impaired executive function (n = 18)		
Age, years[b]	78.5 (8)	79.5 (5)	79.5 (8)	0.725
Females	11 (68.7%)	15 (83.3%)	20 (90.9%)	0.204
Height, cm[b]	157.5 (14)	160.5 (12)	161.5 (8)	0.596
Number of chronic diseases[b]	3.5 (2)	3.0 (1)	3.0 (1)	0.999
Psychoactive drugs[c]	7 (43.7%)	11 (61.1%)	9 (45.0%)	0.588
Extrapyramidal rigidity[d]	43.8 (7%)	66.7 (12%)	22.7 (5%)	0.021
MMSE (/30)[b]	22.0 (4)[e]	20.5 (6)[e]	30.0 (1)	<0.001
FAB (/18)[b]	14.0 (3)	8.0 (3)	–	<0.001
Behavioral scale of frontal dysfunction (/4)[b]	1.0 (1)	4.0 (0)	–	<0.001
Mattis Dementia Rating Scale (/144)[b]	117.5 (16.5)	115.0 (15)	–	0.476
Etiology of dementia				
AD	16 (100%)	5 (23.8%)	–	<0.001
VaD	0 (0%)	4 (22.2%)	–	<0.001
Mixed AD/VaD	0 (0%)	9 (50.0%)	–	<0.001

IQR = Interquartile range.
[a] Comparison among three groups based on Fisher's exact test or Kruskal-Wallis ANOVA as appropriate.
[b] Median (IQR).
[c] Use of benzodiazepines, or antidepressants or neuroleptics.
[d] All scores <2 based on item 22 of the Unified Parkinson's Disease Rating Scale motor score.
[e] Based on Kruskal-Wallis ANOVA and compared with nondemented adults with p significant < 0.05.

Gait Parameters

Mean value of stride time while walking only was higher in the demented subjects with IEF compared to the demented subjects without IEF (p = 0.007) and the nondemented subjects (p = 0.001), whereas the CV of stride time was higher compared to the nondemented subjects (p = 0.003), but not to demented subjects without IEF (p = 0.012; significant p value threshold adjusted for the multiple comparisons among groups fixed at 0.008). Mean value of stride time during the dual task was higher in demented subjects compared to the nondemented subjects ($p < 0.001$ for demented subjects with IEF and p = 0.003 for demented subjects without IEF), and there was no significant difference between the two subgroups of demented subjects (p = 0.128). Furthermore, CV of stride time was only higher in the demented subjects with IEF when compared to the nondemented subjects ($p < 0.001$), but not when compared to the demented subjects without IEF (p = 0.009; significant p value threshold adjusted for the multiple comparisons among groups fixed at 0.008). Mean value of stride time increased significantly for demented subjects when performing dual tasking as opposed to walking only (p = 0.003 for demented subjects with IEF and p = 0.005 for demented subjects without IEF). In contrast, the mean value of stride time did not increase when the nondemented subjects performed dual tasking (p = 0.638). In addition, CV of stride time increased significantly from single to dual task in all groups (p = 0.002 for demented subjects with IEF; p = 0.006 for demented subjects without IEF; p = 0.049 for the nondemented subjects).

Univariate linear regression showed a significant association between a low FAB score and a high stride time variability while walking only (p = 0.005), but not while performing the dual-task condition (p = 0.083).

Discussion

Our results clearly demonstrate the influence of executive functions on gait parameters in subjects with dementia. IEF significantly modified stride time parameters while walking only as well as while performing dual tasking. The mean value of stride time was an effective parameter to distinguish between demented subjects and healthy controls. Moreover, there was a significant nega-

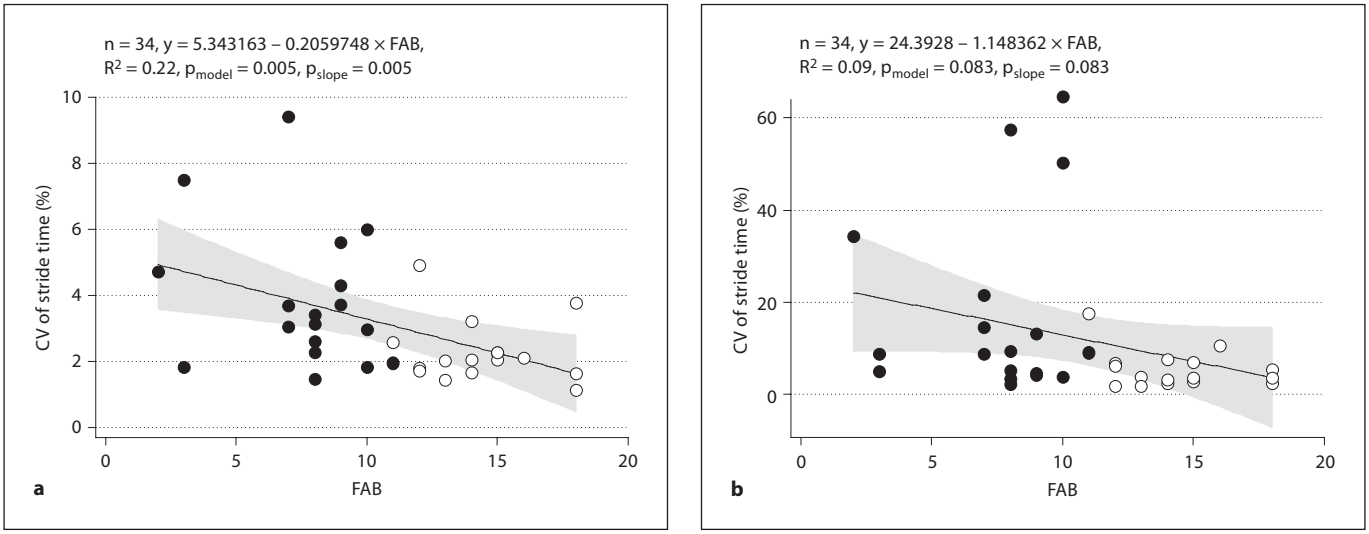

Fig. 1. Univariate linear regression looking for association between CV of stride time and score in FAB among demented subjects (n = 34). **a** Walking only. **b** Walking with backward counting. ○ = Demented subjects without IEF; ● = Demented subjects with IEF.

Table 2. Stride time parameters (median and interquartile range)

	Demented subjects		Nondemented subjects (n = 22)	p value[a]
	without impaired executive function (n = 16)	with impaired executive function (n = 18)		
Walking only				
Mean value, ms	1,137.4 (151.3)	1,199.9 (168.6)[b, c]	1,092.6 (123.6)	0.003
CV, %	2.1 (0.7)	3.3 (2.5)[b]	1.6 (1.4)	0.003
Walking with backward counting				
Mean value, ms	1,315.3 (409.5)[b, d]	1,463.9 (506.3)[b, d]	1,075.4 (208.3)	<0.001
CV, %	3.7 (4.3)[d]	9.0 (17.0)[b, d]	2.9 (1.8)[d]	0.003

CV = [(standard deviation/mean) × 100].

[a] Comparison among three groups based on Kruskal-Wallis ANOVA with significant difference at $p < 0.05$.

[b] Based on Kruskal-Wallis test and compared with nondemented subjects with significant difference at $p < 0.05$.

[c] Based on Kruskal-Wallis test and compared with demented subjects without impaired executive function with significant difference at $p < 0.05$.

[d] Compared between walking conditions within each group of subjects based on Wilcoxon matched pairs signed ranks test with significant difference at $p < 0.05$.

tive association between stride time variability and FAB score in subjects with dementia during single task. In addition, all gait changes under dual task compared to single task were significant. Both stride parameters increased in demented subjects, whereas in the healthy counterparts, the mean value tended to decrease and the CV to significantly increase.

First, our findings corroborate other data which found that subjects with dementia experienced greater gait impairment than normal subjects [6, 22, 23]. We also confirmed that there is a relationship between CV of stride time and the efficiency of executive functions [11–14], suggesting that this gait parameter was a good marker of cortical involvement in gait control, and thus could be a

specific index of gait instability associated with IEF. This relationship is particularly obvious in figure 1, where a significant linear relationship is shown between stride time variability and FAB during single task. However, the mean value of stride time while walking only was the only parameter that distinguished demented subjects with IEF from demented subjects without IEF. This lack of discrimination of CV between the two groups could be caused by a low sensitivity of the FAB in estimating the level of dysexecutive function in demented subjects without IEF. Interestingly, the two groups of demented subjects had statistically insignificant differences in performance on the Mattis DRS, a global test of dementia severity that is also used to evaluate executive function [16]. The fact that the CV did not discriminate between the two groups of demented subjects, whereas the mean value did, could be explained by the nuances of the groups' definition of cognitive decline.

Secondly, in this study, changes in stride parameters between single and dual task were significant for every subject except for the mean value of the control group. The capacity interference caused by a central overload seems to be responsible for these gait changes [24, 25]. Accordingly, in the dual-task model we used, both cognitive and motor tasks utilize different central information processing pathways which interact and compete with each other. Consequently, backward counting while walking is related to the capacity to properly allocate attention between two tasks [7] and, like in divided-attention paradigms [24], relies on efficient executive function. In contrast to demented subjects, the mean value of stride time in nondemented subjects tended to decrease while performing dual tasking when compared to the single task. One simple explanation might be that backward counting in healthy subjects is a relatively easy task that does not require major attention or executive function. Furthermore, Li et al. [26] showed that healthy older adults in a dual-task paradigm using also a cognitive task prioritize walking over the cognitive task. Another explanation might be that the rhythmic aspect of this attention-demanding task improves gait performance or that there is a facilitating effect of backward counting on stride time [27, 28]. Therefore, the decrease of stride time mean value among nondemented subjects may be explained by structural interference and, more specifically, by cross-talk models [7, 24]. This theoretical approach assumes that a similarity in tasks reduces interference and leads to better performance.

Gait variability is an index of gait stability and the general assumption is that enhanced variability is a reflection of reduced dynamic stability. Thus, increases in CV of stride time are an index of gait instability which has been related to lesions in the basal ganglia and impaired central processing of sensorimotor information [29]. While comparing Parkinson's disease patients with control subjects, Yogev et al. [29] found similar results to those in our study, but interestingly Parkinson's disease patients had less IEF than our demented patients. This last point questions the origin of gait stability in subjects with low extrapyramidal rigidity which might be more related to IEF than to the basal ganglia. The clinical relevance of this aspect of gait disorders in Parkinson's disease has been recently highlighted in the implantation of human pedunculopontine nucleus to treat gait and balance disorders in patients with Parkinson's disease [30].

Our study has limitations. First, our small sample size necessitates caution. Second, our subjects are relatively old; age may be a potential confounder while exploring cortical involvement in gait control as reported in previous studies [6, 9] and a negative correlation between the FAB score and increased age has also been reported [31]. Therefore, the increased age of our population might have reduced the effect magnitude of IEF. Third, the neuropsychological profile of our 2 demented groups was close. Actually, the main neuropsychological differences were related to the FAB and the Behavioral Scale of Frontal Lobe Dysfunction, but not to the Mattis DRS. This point could underestimate the gait differences related to executive function. Third, there was no anatomical correlation. The demented subjects with IEF mainly included subjects with mixed AD/VaD and VaD, where an alteration of cortical and subcorticofrontal networks could induce a dysexecutive syndrome. Otherwise, there were no differences for the extrapyramidal rigidity between the two demented groups. So the difference of gait parameters between the two demented groups cannot be attributed to the motor rigidity. Thus, while this study shows the importance of executive function in gait stability, it does not suggest that gait stability depends specifically on cortical function. Finally, the group of demented older subjects without impairment of executive functions is represented by all subjects with AD pathology which is different from VaD or mixed AD/VaD in the group of older subjects with impairment of executive functions. However, we chose two groups matched for comorbidities, extrapyramidal syndrome and other noncognitive clinical parameters. To our knowledge, there are no published data showing differences regarding stride time variability in two different etiologies of dementia (i.e. AD

vs. VaD) that would have to be matched on executive function, global cognitive function and extrapyramidal rigidity. As we mentioned in the previous point, the demented subjects with IEF could have a more subcortical deficit than the other demented group.

In conclusion, IEF has been implicated in gait changes during walking only and dual-task conditions. This finding confirms that executive functions are essential to gait control and may partially explain gait instability observed in demented subjects. In a practical context, these findings strongly indicate that stride time variability may be considered as a good parameter to evaluate executive control of gait in patients with dementia.

Acknowledgements

We would like to thank Celine Goetz for help in the preparation of the manuscript. Gilles Allali was supported by a grant from the Swiss National Science Foundation.

References

1 Hollman JH, Kovash FM, Kubik JJ, et al: Age-related differences in spatiotemporal markers of gait stability during dual task walking. Gait Posture 2007;26:113–119.
2 Camicioli R, Howieson D, Oken B, et al: Motor slowing precedes cognitive impairment in the oldest old. Neurology 1998;50:1496–1498.
3 Springer S, Giladi N, Peretz C, et al: Dual-tasking effects on gait variability: the role of aging, falls, and executive function. Mov Disord 2006;21:950–957.
4 Coppin AK, Shumway-Cook A, Saczynski JS, et al: Association of executive function and performance of dual-task physical tests among older adults: analyses from the InChianti study. Age Ageing 2006;35:619–624.
5 Lundin-Olsson L, Nyberg L, Gustafson Y: 'Stops walking when talking' as a predictor of falls in elderly people. Lancet 1997;349:617.
6 Beauchet O, Kressig RW, Najafi B, et al: Age-related decline of gait control under a dual-task condition. J Am Geriatr Soc 2003;51:1187–1188.
7 Pashler H: Dual-task interference in simple tasks: data and theory. Psychol Bull 1994;116:220–244.
8 Adcock RA, Constable RT, Gore JC, et al: Functional neuroanatomy of executive processes involved in dual-task performance. Proc Natl Acad Sci USA 2000;97:3567–3572.
9 Woollacott M, Shumway-Cook A: Attention and the control of posture and gait: a review of an emerging area of research. Gait Posture 2002;16:1–14.
10 Camicioli R, Howieson D, Lehman S, et al: Talking while walking: the effect of a dual task in aging and Alzheimer's disease. Neurology 1997;48:955–958.
11 Hausdorff JM: Gait variability: methods, modeling and meaning. J Neuroengineering Rehabil 2005;20:2–19.
12 Sheridan PL, Solomont J, Kowall N, et al: Influence of executive function on locomotor function: divided attention increases gait variability in Alzheimer's disease. J Am Geriatr Soc 2003;51:1633–1637.
13 Allali G, Kressig RW, Assal F, et al: Changes in gait while backward counting in demented older adults with frontal lobe dysfunction. Gait Posture 2007;26:572–576.
14 Yogev-Seligmann G, Hausdorff JM, Giladi N: The role of executive function and attention in gait. Mov Disord 2008;15:329–342.
15 Folstein MF, Folstein SE, McHugh PR: 'Mini-Mental State'. A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res 1975;12:189–198.
16 Mattis S: Dementia Rating Scale. Odessa, Psychological Assessment Resources, 1988.
17 Dubois B, Slachevsky A, Litvan I, et al: The FAB: a Frontal Assessment Battery at bedside. Neurology 2000;55:1621–1626.
18 Lebert F, Pasquier F, Souliez L, et al: Frontotemporal behavioral scale. Alzheimer Dis Assoc Disord 1998;12:335–339.
19 Ebersbach G, Baas H, Csoti I, et al: Scales in Parkinson's disease. J Neurol 2006;253:iv32–iv35.
20 Kressig RW, Beauchet O: Guidelines for clinical applications of spatio-temporal gait analysis in older adults. Aging Clin Exp Res 2006;18:174–176.
21 Bilney B, Morris M, Webster K: Concurrent related validity of the GAITRite walkway system for quantification of the spatial and temporal parameters of gait. Gait Posture 2003;17:68–74.
22 Verghese J, Lipton RB, Hall CB, et al: Abnormality of gait as a predictor of non-Alzheimer's dementia. N Engl J Med 2002;347:1761–1767.
23 Waite LM, Grayson DA, Piguet O, et al: Gait slowing as a predictor of incident dementia: 6-year longitudinal data from the Sydney Older Persons Study. J Neurol Sci 2005;229–230:89–93.
24 Abernethy B: Dual-task methodology and motor skills research: some applications and methodologies constraints. J Hum Mov Studies 1988;14:101–132.
25 Perry RJ, Hodges JR: Attention and executive deficits in Alzheimer's disease. A critical review. Brain 1999;122:383–404.
26 Li KZ, Lindenberger U, Freund AM, et al: Walking while memorizing: age-related differences in compensatory behavior. Psychol Sci 2001;12:230–237.
27 Ebersbach G, Dimitrijevic MR, Poewe W: Influence of concurrent tasks on gait: a dual-task approach. Percept Mot Skills 1995;81:107–113.
28 Baltadjieva R, Giladi N, Gruendlinger L, et al: Marked alterations in the gait timing and rhythmicity of patients with de novo Parkinson's disease. Eur J Neurosci 2006;24:1815–1820.
29 Yogev G, Giladi N, Peretz C, et al: Dual tasking, gait rhythmicity, and Parkinson's disease: which aspects of gait are attention demanding? Eur J Neurosci 2005;22:1248–1256.
30 Mazzone P, Lozano A, Stanzione P, et al: Implantation of human pedunculopontine nucleus: a safe and clinically relevant target in Parkinson's disease. Neuroreport 2005;16:1877–1881.
31 Appollonio I, Leone M, Isella V, et al: The Frontal Assessment Battery (FAB): normative values in an Italian population sample. Neurol Sci 2005;26:108–116.