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Gait and risk of falls associated with frontal cognitive functions at different stages of Alzheimer’s disease

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ABSTRACT

The decline in frontal cognitive functions contributes to alterations of gait and increases the risk of falls in patients with dementia, a category which included Alzheimer’s disease (AD). The objective of the present study was to compare the gait parameters and the risk of falls among patients at different stages of AD, and to relate these variables with cognitive functions. This is a cross-sectional study with 23 patients with mild and moderate AD. The Clinical Dementia Rating was used to classify the dementia severity. The kinematic parameters of gait (cadence, stride length, and stride speed) were analyzed under two conditions: (a) single task (free gait) and (b) dual task (walking and counting down). The risk of falls was evaluated using the Timed Up-and-Go test. The frontal cognitive functions were evaluated using the Frontal Assessment Battery (FAB), the Clock Drawing Test (CDT) and the Symbol Search Subtest. The patients who were at the moderate stage suffered reduced performance in their stride length and stride speed in the single task and had made more counting errors in the dual task and still had a higher fall risk. Both the mild and the moderate patients exhibited significant decreases in stride length, stride speed and cadence in the dual task. Was detected a
significant correlation between CDT, FAB, and stride speed in the dual task condition. We also found a significant correlation between subtest Similarities, FAB and cadence in the dual task condition. The dual task produced changes in the kinematic parameters of gait for the mild and moderate AD patients and the gait alterations are related to frontal cognitive functions, particularly executive functions.

**Keywords:** Walking; Dual task; Falls; Frontal cognitive functions; Dementia Alzheimer type.

Gait has recently become associated with cognitive functioning in the elderly (Duff, Mold, & Roberts, 2007), particularly those suffering from dementia (Holtzer, Verghese, Xue, & Lipton, 2006; Van Iersel et al., 2004; Wang, Larson, Bowen, & Belle, 2006). The cognitive impairments that are present in Alzheimer’s disease (AD), such as those related to the frontal cognitive functions, contribute to disorders in the kinematic parameters of gait (Kluger et al., 1997; Rossor et al., 1999; Sheridan & Hausdorff, 2007). Alterations in the kinematic parameters of gait are associated with an increased risk of falls in individuals with AD, and such individuals are three times more likely to fall in comparison with elderly individuals who do not suffer from dementia (Imamura, 2000). AD patients are therefore more susceptible to the consequences of falls, have an increased risk of fractures, decreased mobility, loss of independence, early institutionalization, and increased cardiovascular morbidity and mortality (Bloem et al., 2000; Wilson, Schneider, Beckett, Evans, & Bennett, 2002).

The variability in the rhythmic patterns of gait was significantly higher in patients with AD due to the decline in executive functions that are necessary for the control of motor behavior (Sheridan & Hausdorff, 2007; Sheridan, Mat, Kowall, & Hausdorff, 2003) and due to attention deficits, primarily in the form of divided attention, which is a skill that allows individuals to focus their behavior on two simultaneous tasks (dual task) (Allali et al., 2007).

The dual task refers to the involvement of the frontal cortex in the control of gait (Sheridan et al., 2003). Changes in gait are related to the dual task, and results from interference caused by the demands of attention for the control of gait and another task that is being performed simultaneously (Beauchet et al., 2008). Studies that examined the dual task in healthy elderly patients and patients with dementia have reported alterations in the kinematic parameters of gait, such as an increase in the duration of stride and a reduction in the length of stride, with the result being a decrease in gait speed (Allali et al., 2007; Beauchet, Dubost, Aminian, Gonthier, & Kressig, 2005).

Previous studies that have examined alterations in gait in AD patients did not consider the effect of the different degrees of severity of the disease (Cocchini et al., 2004; Maquet et al., 2010; Pettersson, Olsson, & Wahlund, 2010; Van Iersel et al., 2004).
GAIT AND FALLS ASSOCIATED WITH FRONTAL COGNITIVE FUNCTIONS

2005; Sheridan et al., 2003). One study did examine this effect (Allan, Ballard, Burn, & Kenny, 2005). That study analyzed gait during different AD stages and did not find locomotor disorders in patients during the mild stage of the disease. In contrast, several studies have suggested that changes in gait might precede dementia (Maquet et al., 2010; Verghese, Wang, Lipton, Holtzer, & Xue, 2007; Waite et al., 2005).

Further studies that have examined the alterations of motor function that are associated with frontal cognitive functions might aid in the identification of gait patterns and fall risks in AD patients during different severity stages of the disease. Our hypothesis is that there are differences in gait and risk of falls among the distinct stages of dementia and that these changes are related to frontal cognitive functions. Therefore, the objectives of this study were: (a) to analyze and compare the kinematic parameters of gait during the performance of a single task (motor activity) and a dual task (motor and cognitive activities simultaneously) and the fall risk of patients with mild and moderate AD and (b) to relate the kinematic parameters of gait and the risk of falls to frontal cognitive functions.

METHODS

Sample

This is a cross-sectional study that initially included 43 patients. All were community-dwelling citizens in Rio Claro, SP, Brazil and had a diagnosis of AD according to the international criteria (DSM-IV-TR, APA, 2000). All of the patients underwent a clinical and a neuropsychological evaluation performed by a trained team. The Clinical Dementia Rating (CDR; Morris, 1993) was used to classify dementia severity. We also used the Mini-Mental State Examination (MMSE; Folstein, Folstein, & McHugh, 1975), which is scored using a scale that ranges from 0 to 30 points.

Of the 43 patients who were initially evaluated, 19 were excluded due to visual or auditory impairments or the presence of vertigo syndrome, extrapyramidal symptoms, or other limitations that made gait difficult. Patients with severe dementia (CDR 3) or with other neuropsychiatric conditions were also excluded from the investigation.

The result was that 23 patients with mild (CDR 1) or moderate (CDR 2) AD who were capable of independent ambulation were included in the study. The mean age of the patients in CDR 1 \((n = 12)\) was 75.7 ± 6.8 years, education was 5.5 ± 3.0 years and their score on the MMSE was 22.0 ± 2.2 points. As regards the patients in CDR 2 \((n = 11)\), their mean age was 80.1 ± 7.5 years, education was 3.5 ± 1.1 and their mean score on the MMSE was 16.2 ± 2.2 points.
MEASURES

Frontal Cognitive Evaluation

Frontal Assessment Battery (FAB; Beato, Nitrini, Formigoni, & Caramelli, 2007; Dubois, Slachevsky, Litvan, & Pillon, 2000). This battery was used to assess specific executive functions in patients with neurodegenerative diseases and has been applied in patients with AD, frontotemporal dementia and Parkinson’s disease. The battery consists of six subtests that assess specific areas of frontal cognitive functions. The Brazilian version of FAB was readily comprehended by cognitively healthy elderly and is a viable tool for the brief assessment of executive functions.

Clock Drawing Test (CDT; Sunderland et al., 1989). This test evaluates executive functions, such as planning, abstract thinking, logical sequencing and monitoring of executive processing.

Symbol Search – Subtest of the WAIS-III (Wechsler Adult Intelligence Scale – III) (Symbol) (Wechsler, 2004). This subtest evaluates focused attention.

Kinematic Parameters of Gait

Data collection was performed at the Laboratory for the Study of Posture and Locomotion, which has a runway that is 8 m long and 1.40 m wide. We used a digital camera (JVC, model GR-DVL 9800) with an acquisition frequency of 60 Hz to film the gait of the patients. We recorded the kinetic data by attaching a passive marker to the fifth right metatarsus of each patient. The camera was placed in a position that was orthogonal to the runway in order to visualize the marker on the sagittal plane of the patients and capture full strides. Each stride started when the right heel touched the ground and ended when the right heel touched the ground again.

The kinematic procedures were performed using the Digital Video for Windows software (Dvideow – version 6.3). The data was filtered using a second-order digital Butterworth filter with a cutoff frequency of 4 Hz that used Matlab software (the Matworks Inc., 2004 – version 7.0) A routine written in Matlab language was developed for the analysis of kinematic variables of gait.

The gait variables, stride length, stride speed, and cadence, were analyzed under two sets of conditions: (a) free gait (single task) and (b) gait with a frontal cognitive task (walking and counting down from 20, dual task). The counting errors were recorded during the performance of the dual task.

As regards walking speed during gait analysis (in both tasks), the participants were instructed to walk as they did in their daily activities and to finish 8 m (distance of walking). The instructions given to the participants during the dual task were to walk normally and engage in counting down and in cases of error counts, to keep walking.
No instructions were given regarding focusing on the task (motor or cognitive). Each subject performed five trials of each task, with the aim of adjusting the spatial and temporal parameters.

**Fall Risk**

We applied the Timed Up-and-Go (TUG) test in order to evaluate basic functional mobility. We analyzed the time (TUGt) the patients took to stand up from sitting in an armchair, walk 3 m and return to the chair. We also measured the number of steps (TUGs) required to perform the activity. The higher time values and the number of steps taken represent an increased risk of falls (Podsiadlo & Richardson, 1991). We also distributed a questionnaire in order to obtain data regarding the number of falls during the last 4 months.

**Ethical Aspects**

The Committee of Ethics in Research of the Institute of Biosciences of UNESP – Universidade Estadual Paulista, Rio Claro Campus – approved this research.

**Data Analysis**

Statistical analyzes of the data were performed using Statistica 6.0. The Z-score calculation was performed in order to standardize the frontal-cognitive measures. We applied the one-way ANOVA in order to compare their ages, level of education, frontal-cognitive measures, variables of gait and fall risk corresponding to the CDR 1 and CDR 2 patients. Two-way ANOVA (repeated measures) was used to facilitate comparisons of gait under the two sets of conditions, single task and dual task, in patients classified as CDR 1 and CDR 2. The Pearson correlation coefficient was used to analyze correlations between the variables of gait, fall risk, and cognitive variables. The level of significance was set at 5% ($p < .05$) for all of the analyzes.

**RESULTS**

No differences were found between groups with respect to the control variables – age, $F(1, 21) = 2.70; p = .11$, MSE $= 134.9$, and education, $F(1, 21) = 3.8, p = 0.07$ – the analysis indicated that the groups were comparable.

**Variables of Gait During the Performance of a Single Task, a Dual Task, and Errors in the Counting Down of Patients Classified as CDR 1 and CDR 2**

The one-way ANOVA analysis showed the patients who were in the mild stage of AD (CDR 1) exhibited longer stride lengths, $F(1, 21) = 4.17$,
TABLE 1. Means, standard deviations and significance of the comparison of the variables of gait in the CDR 1 and CDR 2 patients during the performance of a single and a dual task

<table>
<thead>
<tr>
<th>Variables of gait</th>
<th>CDR 1</th>
<th>CDR 2</th>
<th>p</th>
<th>F</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stride length – single task (m)</td>
<td>0.94 ± 0.11</td>
<td>0.82 ± 0.19</td>
<td>.05</td>
<td>4.1</td>
<td>0.36</td>
</tr>
<tr>
<td>Stride speed – single task (m/s)</td>
<td>0.78 ± 0.14</td>
<td>0.67 ± 0.17</td>
<td>.05</td>
<td>4.0</td>
<td>0.33</td>
</tr>
<tr>
<td>Cadence – single task (p/s)</td>
<td>0.84 ± 0.09</td>
<td>0.82 ± 0.09</td>
<td>.49</td>
<td>0.4</td>
<td>0.11</td>
</tr>
<tr>
<td>Stride length – dual task (m)</td>
<td>0.86 ± 0.12</td>
<td>0.77 ± 0.18</td>
<td>.19</td>
<td>1.8</td>
<td>0.28</td>
</tr>
<tr>
<td>Stride speed – dual task (m/s)</td>
<td>0.56 ± 0.14</td>
<td>0.43 ± 0.16</td>
<td>.06</td>
<td>3.8</td>
<td>0.39</td>
</tr>
<tr>
<td>Cadence – dual task (p/s)</td>
<td>0.64 ± 0.10</td>
<td>0.56 ± 0.17</td>
<td>.17</td>
<td>1.9</td>
<td>0.27</td>
</tr>
<tr>
<td>Errors in counting</td>
<td>1.69 ± 1.65</td>
<td>4.70 ± 3.37</td>
<td>.05</td>
<td>4.0</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Note: m, meters; m/s, meters/second; p/s, strides/second.

$p = .05$, MSE = 893.4, and higher stride speeds, $F(1, 21) = 4.01$, $p = .05$, MSE = 889.1, in the single task in comparison with patients in the moderate AD stage (Table 1). However, we did not detect a significant difference between groups with respect to the variables of gait in the dual task. Results showed a significant difference, $F(1, 21) = 4.0$, $p = .05$, between groups with respect to the counting down errors during the performance of the dual task (Table 1).

The two-way ANOVA analysis showed an effect of task, $F(1, 21) = 19.0$, $p < .001$, i.e., both the mild and the moderate patients showed a significant decrease in cadence, $F(1, 21) = 80.5$, $p < .001$, MSE = 5373.34, stride speed $F(1, 21) = 78.8$, $p < .001$, MSE = 5863.81, and stride length, $F(1, 21) = 19.7$, $p < .001$, MSE = 481.00, during the performance of the dual task (Figure 1).

Timed Up-and-Go Test and the Number of Falls of CDR 1 and CDR 2 Patients

The patients who were in the mild stage of AD (CDR 1) performed better the variable time $F(1, 21) = 4.65$, $p = .04$, MSE = 78.0, and steps $F(1, 21) = 4.06$, $p = .05$, MSE = 91.6, of the TUG test in comparison with patients who were in the moderate stage of AD (CDR 2) (Table 2). As regards the number of falls during the last 4 months, two out of 12 patients in the CDR 1 group (16.6%) had falls, whereas the CDR 2 patients exhibited a higher frequency of falls: four out of 11 patients (36.3%).

Comparison of the Cognitive Variables Between CDR 1 and CDR 2

As regards analysis of the data, the scores on the FAB were examined based on their global scores and specific domains. The CDR 1 patients exhibited significantly better performance than did the CDR 2 patients.
for all the cognitive variables, except for the subtest of FAB Conflicting instructions/Go–No Go (Table 3).

**Correlation Between the Variables Gait and Fall Risk and Cognitive Variables**

A significant positive correlation was found to exist between the gait variables and cognitive tests. We detected a significant correlation, $r = .47$, $p = .02$, between planning (assessed by the Clock Drawing Test – CDT) and stride speed in the dual task condition and significant correlation, $r = .45$, $p = .02$, between executive functions (FAB) and stride speed in the dual task condition. We also found a significant correlation, $r = .60$, $p = .04$, between abstraction (assessed by subtests of the FAB: Similarities) and cadence in the dual task condition and significant correlation, $r = .42$, $p = .04$, between FAB and cadence in the dual task condition (Figure 2).

We did not detect any significant correlations between the fall risk and the cognitive tests among the CDR 1 and CDR 2 patients.

---

**Table 2.** The means and standard deviations of the variables of time and number of steps in the Timed Up-and-Go test of the in the CDR 1 and CDR 2 patients

<table>
<thead>
<tr>
<th>Variables (fall risk)</th>
<th>CDR 1</th>
<th>CDR 2</th>
<th>$p$</th>
<th>$F$</th>
<th>$d$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TUGt</td>
<td>9.2 ± 1.9</td>
<td>13.0 ± 5.5</td>
<td>.04</td>
<td>4.6</td>
<td>0.41</td>
</tr>
<tr>
<td>TUGs</td>
<td>5.5 ± 2.5</td>
<td>9.6 ± 6.4</td>
<td>.05</td>
<td>4.0</td>
<td>0.38</td>
</tr>
</tbody>
</table>

*Note:* TUGt, Time up-and-Go expressed in time; TUGs, Time up-and-Go expressed as steps.
**TABLE 3.** Results expressed as mean ± standard deviations of the CDR 1 and CDR 2 patients in the FAB and subtests; in the CDT and the Symbol Search subtest (Symbols)

<table>
<thead>
<tr>
<th>Cognitive variables</th>
<th>CDR 1</th>
<th>CDR 2</th>
<th>p</th>
<th>F</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FAB – Subtests</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Similarities</td>
<td>2.1 ± 0.8</td>
<td>1.2 ± 0.9</td>
<td>.005</td>
<td>9.9</td>
<td>0.46</td>
</tr>
<tr>
<td>Lexical Fluency</td>
<td>1.7 ± 1.0</td>
<td>0.8 ± 0.8</td>
<td>.025</td>
<td>5.8</td>
<td>0.44</td>
</tr>
<tr>
<td>Motor Series</td>
<td>1.7 ± 0.7</td>
<td>0.7 ± 0.5</td>
<td>.001</td>
<td>4.9</td>
<td>0.63</td>
</tr>
<tr>
<td>Conflicting instructions/Go–No Go</td>
<td>2.8 ± 2.0</td>
<td>1.3 ± 1.8</td>
<td>.08</td>
<td>6.3</td>
<td>0.36</td>
</tr>
<tr>
<td>Prehension behavior</td>
<td>3.0 ± 0</td>
<td>3.0 ± 0</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total FAB</td>
<td>1.5 ± 3.1</td>
<td>7.0 ± 2.5</td>
<td>.001</td>
<td>3.3</td>
<td>0.66</td>
</tr>
<tr>
<td>CDT</td>
<td>8.0 ± 2.1</td>
<td>3.9 ± 1.5</td>
<td>.000</td>
<td>6.2</td>
<td>0.68</td>
</tr>
<tr>
<td>Symbols</td>
<td>7.9 ± 1.8</td>
<td>4.4 ± 2.1</td>
<td>.008</td>
<td>8.6</td>
<td>0.66</td>
</tr>
</tbody>
</table>

**FIGURE 2.** Significant correlation between cognitive function and gait variables in patients.

**DISCUSSION**

We initially found differences in the kinematic parameters of gait between patients who were in the mild and moderate stages of AD. A significant difference was observed for stride length and stride speed in the performance of
GAIT AND FALLS ASSOCIATED WITH FRONTAL COGNITIVE FUNCTIONS

the single task: patients who were in the moderate stage of AD had shorter stride lengths and walked more slowly than did patients who were in the mild stage.

Several studies have identified a reduction in stride speed and length and an increase in the variability of stride during the performance of gait in AD patients (Allali et al., 2007; Maquet et al., 2010; Sheridan et al., 2003), but they did not examine these factors in conjunction with the different severity stages of the disease. The present study focused on gait characteristics that are associated with increasing levels of dementia severity. A study by Allan et al. (2005) that examined gait during different AD stages did not detect gait disorders in AD patients who were in the mild stage. However, those authors used the Tinetti scale to evaluate gait, which only classifies gait performance as normal, mild, moderate, or severe. In contrast, the present study evaluated the spatial and temporal parameters of gait using a kinematic instrument that is commonly used with dementia patients (Wittwer, Webster, Andrews, & Menz, 2008).

Patients in both stages, mild and moderate, showed a decrease in cadence, speed and length of stride during the performance of the dual task. These alterations are associated with a deficit in the executive functions both in the mild and moderate AD patients and in the demand for attentional activity during the performance of the dual tasks. Our results were consistent with other studies that revealed a reduction in the performance of gait parameters during the performance of a dual task by elderly persons who were cognitively preserved and by those with dementia (Allali et al., 2007; Beauchet et al., 2005; Hausdorff, Schweiger, Herman, Yoge-Seligmann, & Giladi, 2008). As noted, when comparing the two groups we detected different gait performances in single task only but not in that of dual task performances. One explanation for this finding is that the single task does not require a higher level of cognitive functioning as required by the dual task. Patients in both AD stages have decline in frontal cognitive functions that contribute to the greater the difficulty subjects have in sharing their attentional resources between two tasks (i.e., walking and counting down). In addition, patients in the mild stage had better motor performance, as demonstrated by the TUG test, which contributed to a better gait performance in single task.

Patients in the moderate stage exhibited a higher number of errors in number counting during the performance of the dual task. The patients in this AD stage were more sensitive to the impact of cognitive load while walking, which may be a result of the decline of the central executive system. These results corroborate the significant decline of the frontal cognitive functions of patients in the moderate stage in our study.

Another finding of this study was better performance on the TUG test of the patients in the mild stage. Patients in the mild stage required less time and a smaller number of steps to perform the test in comparison with
patients in the moderate stage. It is significant that these results are consistent with previous studies that showed that higher values of time and number of steps are correlated with a greater risk of falls (Shumway-Cook, Brauer, & Woollacott, 2000; Podsiadlo & Richardson, 1991). The increase in this risk that was suggested by Podsiadlo and Richardson (1991) was confirmed in our study because patients in the moderate stage of the disease experienced a greater number of falls.

In addition, we also found significant associations between the variables of gait and the frontal cognitive functions in patients in the mild and moderate stage of AD. This association demonstrates that the performance of the dual task requires greater involvement of frontal cognitive functions. The stride speed in the condition dual task was positively correlated with executive functions, specifically, planning. The planning of executive processing is important for maintaining the rhythmic pattern of gait and gait speed (Yoge, Hausdorff, & Giladi, 2008).

Cadence in the condition dual task was positively associated with executive functions specifically, abstraction. In this respect, the study of Maquet et al. (2010) found a positive correlation between executive functions and cadence in patients with mild cognitive impairment. According to those authors, this finding seems to suggest that the better the intention and initiation of an action (process that is related to executive functions), the higher the cadence. Yoge et al. (2008) stated the decline in intentional behavior might cause slowing of gait, and therefore an increase in the frequency of stride, due to a reduced motivation to move. Furthermore, the abstraction is important when individuals walk in complex environments because they allow themselves to ignore irrelevant stimuli, detect errors, and therefore focus their attention on gait (Yoge et al., 2008).

As noted there is evidence suggesting that a decline in executive functions ability may contribute to alterations in gait abilities, however, cause and effect has not been definitively demonstrated. Although associations were observed, the inclusion of a greater number of measures may explain of the relation between gait and executive functions and may help to define if and how specific executive functions affect patterns of walking.

This study has the following conclusions: (a) patients in the moderate stage exhibited a reduced performance in stride length and stride speed in the single task; (b) the dual task produced changes in the kinematic parameters of gait for both the mild and moderate AD patients; (c) gait variables in the dual task condition, were related to the frontal cognitive functions, particularly the executive functions; and (d) moderate stage Alzheimer’s patients had more difficulty performing the cognitive task (number countdown) and still exhibited a greater risk of falls. Finally, the elaboration of intervention programs that could simultaneously provide motor and frontal cognitive stimulation in AD patients interventions that target cognitive functions a potential strategy
for reducing cognitive decline, preserving and/or improving motor function and reducing the number of falls among the AD population.

**Study Limitations**

One important limitation of this study was the small sample size. It should be noted that many patients were not included in this study due to various exclusionary criteria. Another limitation is the absence of a group of elderly who were cognitively preserved (controls) in this study, which meant that we were unable to compare their gaits with the gaits of patients in the mild stage of AD. It is suggested that future studies compare the spatial and temporal variables of gait among patients in the mild stage with a control group in order to help identify the gait pattern for different cognitive profiles which may assist in the early diagnosis of Alzheimer’s disease, since changes in gait might appear in pre-stage of dementia.

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