Simultaneously measuring gait and cognitive performance in cognitively healthy and cognitively impaired older adults: the basel motor-cognition dual-task paradigm

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Abstract

OBJECTIVES: To investigate dual-task performance of gait and cognition in cognitively healthy and cognitively impaired older adults using a motor-cognition dual-task paradigm.

DESIGN: Cross-sectional retrospective study.

SETTING: The Basel Memory Clinic and the Basel Study on the Elderly (Project BASEL).

PARTICIPANTS: Seven hundred eleven older adults (mean age 77.2 ± 6.2, 350 (49.2%) female and 361 (50.8%) male).

MEASUREMENTS: Gait velocity and cognitive task performance using a working memory (counting backward from 50 by 2s) and a semantic memory (enumerating animal names) task were measured during single- and dual-task conditions. Gait was assessed using the GAITRite electronic walkway system. Cognitive impairment was defined as a score less than 25 on the Mini-Mental State Examination.

RESULTS: During dual tasks, participants reduced gait velocity (P<.001) and calculated fewer numbers (P=.03) but did not enumerate fewer animals and did not make more errors or repetitions (P>.10). Cognitively impaired individuals had lower baseline gait velocity and a greater reduction in gait velocity but not cognitive performance during dual tasks than cognitively healthy participants (P<.01).

CONCLUSION: Gait velocity was lower during both dual tasks, whereas decrease in cognitive performance depended on the cognitive ability needed in the dual-task condition. Cognitively impaired individuals generally have poorer baseline performance and greater dual task-related gait velocity reduction than those who are cognitively healthy. Future research should include different conditions for gait to determine adaptive potentials of older adults.
Simultaneously measuring gait and cognitive performance in cognitively healthy vs. cognitively impaired older adults: The Basel Motor-Cognition Dual-Task Paradigm

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Abstract

OBJECTIVES: To investigate dual-task performance of gait and cognition in cognitively healthy and cognitively impaired older adults using a motor-cognition dual task paradigm.

DESIGN: Cross-sectional retrospective study.

SETTING: Outpatients from the Basel Memory Clinic and participants of the Basel Study on the Elderly (Project BASEL).

PARTICIPANTS: Seven hundred eleven older adults (mean age 77.22 ± 6.24, 350 (49.2%) female and 361 (50.8%) male.

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Key words: aging, cognitive impairment, motor-cognition dual-task performance
Introduction

Many tasks of daily life require the simultaneous performance of multiple tasks, which often require both motor activity and memory. With advancing age, the ability to divide attention and to perform multiple tasks simultaneously seems to be impaired.1, 2 Particularly, when individuals have motor or cognitive impairments, it is more difficult for them to perform concurrent motor and cognitive tasks. Performance in one or both tasks may have to be adapted to execute both tasks simultaneously. Therefore, it is of great interest and importance to investigate motor activities such as gait in the presence of additional attention-demanding cognitive tasks. Gait is a process that requires attention, planning and memory,3-5 and hence attention-demanding tasks can affect it. According to previous research,1 older adults require more attention to maintain stable gait. Usually, when older individuals are asked to walk and simultaneously perform another task, they walk more slowly.6-15 Moreover, gait disturbances are especially common in individuals with cognitive impairment.10, 16-18 These findings are of particular importance given that abnormal gait is a strong predictor of future falls, institutionalization, and even death.4, 11, 19-21

The current study investigated the interaction of gait and cognition in older individuals with and without cognitive impairment using a dual task paradigm consisting of a working and a semantic memory task. Both tasks have already been used to demonstrate dual task-related gait impairment in older adults with and without cognitive impairment,6-15, 22 but only few studies have investigated gait under dual task conditions comparing older adults depending on their state of cognitive impairment.10, 17, 18 Cognitively impaired older adults seem to have a lower gait velocity than those who are cognitively less impaired or healthy.10, 17, 18
Most previous studies on motor-cognition dual task performance investigated only gait parameters such as velocity. The current study additionally analyzed changes in cognitive performance between single and dual task conditions, which to the knowledge of the authors has not been done before. By investigating both motor and cognitive performance, it is possible to evaluate whether and to what extent the individuals are able to walk and simultaneously perform an additional cognitive task, as well as which performance is more impaired in general and with increasing cognitive impairment. For example, some may adapt to the task and the single ability decrements by reducing gait velocity, some by reducing gait regularity, some by producing more cognitive errors, and some with a combination of the adaptive adjustments. With a working and a semantic memory task we used two different types of cognitive tasks to examine whether there are task-specific dual task effects on gait and on cognitive performance. According to the literature, there seems to be no task-specific gait changes during dual-task walking, at least with regard to gait velocity, but little is known as to whether there are task-specific effects on cognitive performance during dual tasks.

It was hypothesized that the participants would not only reduce their gait velocity, but also perform worse in both memory tasks during dual-task conditions and that such dual-task interference would be greater in those with cognitive impairments. Additionally, whether the performance changes during the dual-task condition were greater in gait or in cognitive performance and whether there were performance differences between the different memory tasks or between cognitively healthy and cognitively impaired older individuals were investigated.
Methods

Participants

Of the 894 older adults tested, 711 (mean age 77.22 ± 6.24, age range 65-97, 49.2% female) were included in this analysis. The sample consisted of 419 outpatients from the Basel Memory Clinic and 292 participants from the Basel Study on the Elderly (Project BASEL). The local Ethics Committee approved the project. Participants were excluded if they had severe medical, psychiatric or neurological conditions that could impair their cognitive ability or gait such as Parkinson's disease or major depression, or if they suffered from severe dementia (Mini-Mental State Examination (MMSE) score < 16\(^24\)). Participants with walking aids were excluded unless they were able to accomplish the task without using their walking aid. Furthermore, only participants were included whose answers were explicit without any interpretational bias such as translation problems or ambiguous corrections during the working memory task. Cognitive impairment was defined as a score of less than 25 points on the MMSE.\(^24\) Of the sample, 548 (77.1%) participants had an MMSE score greater than 24 and were categorized as cognitively healthy, 163 (22.9%) participants had an MMSE score between 16 and 24, and were categorized as cognitively impaired. Mean MMSE score was 26.7 ± 3.1 (range 16 to 30). All group characteristics are listed in Table 1.

Instruments For Gait

Gait analyses were performed according to the European guidelines for clinical applications of spatiotemporal gait analysis in older adults\(^25\) using the GAITRite\(^\text{®}\) system (GAITRite\(^\text{®}\) Gold, CIR Systems, Easton, PA). This system consists of a 972cm-long electronic walkway with integrated pressure sensors placed every
1.27 cm over an active electronic surface area of 792 x 610 cm, giving a total of 29,952 sensors. The scanning frequency was 60 Hz. Onboard processors collect data from the mechanically activated sensors and then transferred through a cable and serial port to a computer and analyzed with the GAITRite® software version 3.8; 1.25 m-long electronically inactive walkway sections flank the walkway at the beginning and the end. Acceleration and deceleration phases of gait occur on these electronically inactive sections, ensuring measurement of gait parameters under steady-state conditions.

**Testing Procedure**

Before each gait analysis, participants were asked about their medical conditions; medications; fall history; and the current use of walking, vision, or hearing aids. They were then verbally instructed regarding the gait analysis test procedure. A demonstration followed if the verbal instructions were not understood. No practice walks were performed before testing. Participants wore their normal shoes and a safety belt, and were accompanied by the test administrator for each walk.

Participants were instructed to complete one trial each of the following consecutive walking trials: self-selected speed (“normal walking”), self-selected speed while performing the working memory dual task (counting backward out loud from 50 by 2s) and self-selected speed while performing the semantic memory dual task (enumerating animals out loud). Previous studies have typically used rather demanding working memory tasks, but with increasing difficulty, even healthy older adults tend to either neglect the additional tasks or prioritize the walking task, so a simple working memory task (serial subtraction by 2s) was used in the current
study, which should allow even cognitively impaired individuals to divide their attention successfully to complete both tasks simultaneously.

For the dual tasks, participants were instructed to perform both tasks simultaneously; no task priorities were given. The order of the dual tasks was counterbalanced to avoid practice effects. Time needed for the dual tasks was measured in seconds. This time was used for the same cognitive task performed while seated (cognitive single task). All participants of the current sample were able to perform the working memory as well as semantic memory dual task independent of their cognitive status.

**Analysis Procedures**

Gait velocity was normalized with height (cm/sec divided by height in meters) because of the potential height-dependent differences. For the working memory task the correct calculations counting backward, as well as the number of calculation errors and repetitions were counted. For the semantic memory task, the total number of animals named, errors, and repetitions were counted, wit errors defined as any word that was not an animal. Because of the greater chance to produce more correct calculations, animal names, or errors and repetitions with more time, scores from the working and semantic memory tasks were normalized with the time required to complete the tasks (number of calculation, animal names and error/repetitions divided by time). Relative changes of the normalized scores represented decrements of performance from single to dual task.
**Statistical Analysis**

Distribution assumption of the data was verified looking at distribution histograms and values of skewness or kurtosis. In cases in which approximate normal distribution was violated, nonparametric tests were used. The data from gait analysis as well as the performance of the working and semantic memory tasks underwent analysis of variance (ANOVA) or to analysis of covariance (ANCOVA) for repeated measures with the single- and dual-task performance as within-subject factors, the group variable as between-subject factor, and possible confounders as covariates. In cases in which normal distribution of data was violated, Mann Whitney U and Friedman test were used. MMSE scores, age, and number of psychoactive drugs per day were considered as confounding variables when analyzing gait velocity. Years of education were also considered when investigating the cognitive performance of the memory tasks, allowing better comparability between the cognitively healthy and the cognitively impaired individuals, because there was a significant difference between these two groups on these variables (Table 1). Significance values reported were based on effects before and after controlling for confounders, to allow an estimation of their influence on the findings.

For the comparison of the number of individuals reducing gait velocity or cognitive performance during dual task between the cognitively impaired and the cognitively healthy group, participants were split into groups of those who decreased and those who increased their gait velocity or cognitive performance, which were then analyzed using chi square test.

To compare decrements of gait velocity and cognitive performance, relative performance changes in percentage from single to dual task were calculated and subjected to ANOVA and ANCOVA for repeated measures, using the confounding
variables mentioned above as covariates. The two-tailed level of significance was set at $p < .05$. All statistics were calculated using SPSS 18 for Macintosh (SPSS, Inc., Chicago, IL).
Results

Dual-Task Gait Velocity

Gait velocity was significantly lower under the working memory ($F(1,704) = 725.75, p < .001, \eta^2 = .508$) and the semantic memory dual-task conditions ($F(1,704) = 1080.13, p < .001, \eta^2 = .605$) than under the normal walking single condition (Table 2), although 12.6% of the participants increased their gait velocity during the working memory dual-task condition and 6.2% during the semantic memory dual-task condition (defined as difference in velocity between dual and single task of < 0). Additionally, gait velocity during the semantic memory task was significantly lower than during the working memory task ($F(1,704) = 162.47, p < .001, \eta^2 = .188$). The latter result was, however, no longer significant after adjustment for confounders.

Dual-Task Cognitive Performance of Working and Semantic Memory Tasks

Participants made fewer correct calculations counting backward during the working memory dual-task than under the single-task condition ($F(1,691) = 518.10, p < .001, \eta^2 = .428$). Overall, 76.4% of them made fewer correct calculations, 10.6% improved their performance and 13% of participants had no differences on their single- and dual-task performance. The effect was still significant after controlling for confounders ($p = .03$). During the semantic memory dual-task, the participants enumerated significantly fewer animal names ($F(1,689) = 6.40, p = .01, \eta^2 = .009$), but this effect disappeared after controlling for confounders. These results were reflected in 44.1% of the participants doing poorer in naming animals, whereas 34.4% doing better, and 21.5% being unchanged. The dual-task condition had no effect on error or repetition rate in both cognitive tasks ($p > .10$). Values of cognitive performance are displayed in Table 3.
Comparison of Cognitively Healthy and Cognitively Impaired Individuals

Gait velocity of the cognitively impaired individuals was lower under the single walking condition and under both dual-task conditions ($p < .001$) than of cognitively healthy individuals (Figure 1). During the working memory task, significantly more cognitively impaired individuals (93.6%) reduced their gait velocity than those who were cognitively healthy ($\chi^2 (1) = 7.47, p = .006$), of whom 85.5% walked slower. Furthermore, there was a significantly greater reduction of gait velocity during the working memory dual-task in cognitively impaired individuals ($F (1,703) = 32.04, p < .001, \eta^2 = .044$) with a main effect for dual-task condition ($F (1,703) = 682.01, p < .001, \eta^2 = .492$) and for group ($F (1,703) = 83.90, p < .001, \eta^2 = .107$). These effects remained significant after adjustment for the confounding variables mentioned above ($p < .01$). During the semantic memory dual task, there was no difference between the two groups in the number of participants who walked slower or faster ($p = .47$), but the cognitively impaired individuals reduced their velocity more than cognitively healthy individuals ($F (1,703) = 9.83, p = .002, \eta^2 = .014$). Additionally, there was a main effect for the dual-task condition ($F (1,703) = 862.24, p < .001, \eta^2 = .551$) and for group ($F (1,703) = 65.81, p < .001, \eta^2 = .086$). Again, the results remained significant after controlling for confounders ($p < .01$).

Cognitively impaired individuals generally made fewer correct calculations and committed more errors and repetitions during both working memory single and dual-tasks than cognitively healthy individuals ($p < .001$). They also produced fewer animal names during the semantic memory single as well as dual-task ($p < .001$) and committed more errors and repetitions under both conditions ($p < .05$).

As indicated in Figure 2, only the number of correct calculations counting backward significantly changed from single- to dual-task condition, at least when
controlling for confounders. Cognitively healthy individuals showed a greater decrease in their cognitive performance in the form of calculation backward than cognitively impaired individuals ($F (1,690) = 20.84, p < .001, \eta^2 = .029$), which was still significant after adjustment for confounders ($p < .001$). Only 66.2% of the cognitively impaired individuals decreased their cognitive performance during the working memory dual-task, compared with 79.3% of the cognitively healthy individuals. Moreover, 20.3% of the cognitively impaired individuals even increased their performance, compared with 7.9% of the cognitively healthy individuals, which represents a significant difference ($\chi^2 (1) = 19.31, p < .001$). There was no difference in improvement or decline between the two groups during the semantic memory task ($p = .61$) and no difference in reduction of number of animals named between the two groups ($p = .84$).

**Gait Velocity and Memory Task Performance**

Generally, 66.5% of the participants walked slower and performed worse cognitively during the working memory dual-task, whereas only 0.9% increased their gait velocity and their cognitive performance. During the semantic memory dual-task, only 41.8% showed had worse gait and cognitive performance; 2.8% had better. One-third of the participants had worse gait velocity or cognitive performance while increasing the other performance at the same time, but there was no difference between those walking slower or faster and their direction of performance change during dual-task, independent of their cognitive status ($p > .10$).
Comparison Between Cognitive Performance on Working and Semantic Memory Task and Gait Velocity

Because there was no change in the number of errors and repetitions made during single versus dual-tasks, only decrements in gait velocity and cognitive performance in the form of correct calculations and number of animals named were compared. During the working memory dual-task, the relative reduction of gait velocity and the number of correct calculations counting backward did not differ \( (p = .93) \), but during the semantic memory dual-task, participants reduced their gait velocity more than their cognitive performance \( (F(1,673) = 357.75, p < .001, \eta^2 = .347) \). The reduction in gait velocity was greater during the semantic memory than the working memory dual task \( (F(1,704) = 164.27, p < .001, \eta^2 = .189) \), whereas the decrease in cognitive performance was greater for the working memory than the semantic memory dual task \( (F(1,635) = 165.32, p < .001, \eta^2 = .207) \). Only the reduction in gait velocity remained significant after adjustment for confounders \( (p = .03) \).

There was a significant interaction between performance change and group during the working memory dual task \( (F(1,660) = 19.15, p < .001, \eta^2 = .028) \), with only a small main effect for the type of task performance \( (F(1,660) = 6.17, p = .013, \eta^2 = .009) \) and a main effect for group \( (F(1,660) = 16.32, p < .001, \eta^2 = .024) \). Cognitively healthy individuals therefore decreased their cognitive performance more than their gait velocity, whereas cognitively impaired individuals decreased their gait velocity more than their cognitive performance. The interaction was still significant after adjustment for confounding variables \( (p < .001) \). During the semantic memory dual-task, both groups showed a greater decline in gait velocity than in cognitive performance \( (F(1,672) = 312.68, p < .001, \eta^2 = .318) \).
Discussion

The goal of our study was to investigate motor-cognitive dual-task performance of older adults with and without cognitive impairment with regard to gait velocity as well as to task-specific cognitive performance.

During both dual-task conditions, participants reduced their gait velocity compared to their gait speed while walking alone under the single-task condition. These findings were consistent with results reported from previous studies investigating dual-task gait performance in older adults with and without cognitive impairment.6-15 The reduction of gait velocity from single- to dual-task was greater during the semantic memory task than the working memory task, although previous studies did not find any difference in gait velocity or velocity change from single- to dual-task condition between different types of dual tasks.6, 14, 23

The current study also investigated change in cognitive performance under dual-task condition. Whereas participants performed worse in the working memory task under dual-task condition, their performance in the semantic memory task remained stable regardless of single- or dual-task condition. One reason is that there were more individual differences during the semantic memory task with fewer than the half of the participants performing worse and at least one-third performing better during the dual compared to the single task. By way of comparison, only one in 10 performed better during working memory dual-task. Participants did not make more errors or repetitions under either of the cognitive dual-task conditions, indicating a negative impact of dual tasking on productivity but not on error rate. The more demanding of executive functions the cognitive task was, the greater the productivity suffered.
 Individuals with greater cognitive impairments had lower gait velocity and performed worse during the memory tasks, which is consistent with previous findings.\textsuperscript{10, 17, 18} Additionally, cognitively impaired individuals decreased their gait velocity more from single- to dual-task than cognitively healthy, which has not been reported before. The reduction in cognitive performance during the memory dual-tasks was equal to or even lower than that of the healthy group. Moreover, during the working memory dual-task, cognitively impaired individuals decreased their gait velocity more than their cognitive performance, which was contrary to cognitively healthy individuals, who decreased cognitive performance more than gait velocity. In both groups, there were no significant differences in semantic memory task performance between the single- and dual-task, and they both decreased their gait velocity more than their cognitive performance during semantic memory dual-task. One reason for the greater reduction of working memory performance in cognitively healthy older individuals could be their higher baseline performance, which could be more susceptible to an additional motor task than the already lower single-task baseline performance of cognitively impaired individuals. Additionally, the heterogeneity of working memory task performance seems to be greater in cognitively impaired individuals. Fewer individuals performed worse and almost three times as many performed even better during working memory dual task compared to the cognitively healthy group, although some researchers have found that individuals with a better counting performance while walking than while sitting also have lower MMSE scores.\textsuperscript{22}

 Under both dual-task conditions, cognitively impaired individuals reduced their gait velocity more than their cognitive performance and, at least during the semantic memory task, cognitively healthy individuals also reduced gait velocity more than cognitive performance. Nevertheless, the difficulty of the memory tasks was low, and
only with increasing difficulty of the additional tasks, a prioritization of the walking task, or even neglect of the memory task performance would have been expected.\textsuperscript{26,27} Especially in cognitively impaired individuals, a reduction in gait velocity may allow them to maintain gait safety in the presence of an additional attention-demanding task and to have enough attentional resources to manage both tasks without having to neglect one of the tasks.

Finally, some cognitively healthy and cognitively impaired individuals showed improvement of gait velocity or cognitive performance or both from single- to dual-task during both memory tasks. Fewer than two-thirds of participants decreased velocity and cognitive performance during the working memory dual-task and fewer than half during the semantic memory dual-task. Some individuals predominantly reduced motor performance, whereas others tended to reduce cognitive performance suggesting that the same person could potentially be stimulated to use either one of these strategies. Rather than assume that as individuals get older they increasingly and in a stable way tend to prioritize fall prevention over cognitive performance, the degree to which an individual may be able to do both, and to prioritize one or the other depending on the situation, needs to be determined. For example, this can be done by variation of cognitive task difficulty or by including obstacles such as steps into the motor task. This way, the approach to determine adaptive potentials in cognitively impaired individuals could be taken a step further, which could lead to a better understanding of adaptation processes to different tasks in everyday life including the consideration of potential dangerous situations.

There are some limitations of the current study. First, individuals with a score of less than 16 in the MMSE were not included, so the current findings cannot be generalized to patients with severe cognitive impairment. Additionally, the MMSE is
only a screening questionnaire and has limitations detecting executive cognitive dys-
function. The study did not specifically investigate dual-task performance depend-
ing on executive function, which indeed could be of particular interest with regard to
the working memory task, which requires executive functions.

Because of the large sample size, with its wide range of age and different
states of cognitive impairment, the findings of the current study provide good repre-
sentation of dual-task performance within the population of older adults. The study is
therefore best qualified to characterize motor-cognition dual-task performance in
cognitively healthy and cognitively impaired older individuals with regard to individual
differences in gait and cognitive performance change depending on different dual-
task conditions. Future research could investigate dual-task performance in clinical
populations or in populations with different age ranges. It would be of particular in-
terest to investigate cognitively healthy centenarians and their performance under
dual-task condition. Because they are known to have fewer cognitive and physical
resources, they might approach a dual-task situation differently than younger geriat-
ric individuals.
Acknowledgments

Conflict of Interest

There are no conflicts of interest for any of the authors (see the attached file “Acknowledgment COI table”).

Author’s Contributions

Nathan Theill: Analysis and interpretation of data, drafting of manuscript, revising the article, final approval of the version to be published

Mike Martin: Interpretation of data, drafting parts of the Introduction, revising the article, final approval of the version to be published

Vera Schumacher: Interpretation of data, revising the article, final approval of the version to be published

Stephanie A. Bridenbaugh: Acquisition of data, drafting parts of the methods and revising the article, final approval of the version to be published

Reto W. Kressig: study conception and design, revising the article, final approval of the version to be published

Sponsor’s Role

There was no influence of any sponsor on the design, methods, subject recruitment, data collections, analysis and preparation of paper.
References


Table 1

**Participant Characteristics of the Cognitively Healthy and Cognitively Impaired Groups**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>All (n = 711)</th>
<th>Cognitively healthy (n = 548)</th>
<th>Cognitively impaired (n = 163)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender, n (%), n (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>361 (50.8)</td>
<td>290 (52.9)</td>
<td>71 (43.6)</td>
<td>.04</td>
</tr>
<tr>
<td>Female</td>
<td>350 (49.2)</td>
<td>258 (47.1)</td>
<td>92 (56.4)</td>
<td></td>
</tr>
<tr>
<td>Age, mean ± SD</td>
<td>77.22 ± 6.24</td>
<td>76.56 ± 6.27</td>
<td>79.43 ± 5.58</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>MMSE, mean ± SD</td>
<td>26.66 ± 3.13</td>
<td>28.10 ± 1.63</td>
<td>21.84 ± 1.86</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Number of drugs per day, mean ± SD</td>
<td>3.55 ± 2.45</td>
<td>3.54 ± 2.40</td>
<td>3.60 ± 2.56</td>
<td>.80</td>
</tr>
<tr>
<td>Number of psychoactive drugs per day</td>
<td>0.29 ± 0.62</td>
<td>0.23 ± 0.59</td>
<td>0.47 ± 0.80</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Education (years), mean ± SD</td>
<td>12.04 ± 2.82</td>
<td>12.30 ± 2.83</td>
<td>11.28 ± 2.70</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Previous falls, n (%), n (%)</td>
<td></td>
<td></td>
<td></td>
<td>.71</td>
</tr>
<tr>
<td>Yes</td>
<td>288 (41.4)</td>
<td>219 (41)</td>
<td>69 (42.9)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>407 (58.6)</td>
<td>315 (59)</td>
<td>92 (57.1)</td>
<td></td>
</tr>
<tr>
<td>Walking aid, n (%), n (%)</td>
<td></td>
<td></td>
<td></td>
<td>.07</td>
</tr>
<tr>
<td>Yes</td>
<td>46 (6.5)</td>
<td>30 (5.5)</td>
<td>16 (9.8)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>665 (93.5)</td>
<td>518 (94.5)</td>
<td>147 (91.2)</td>
<td></td>
</tr>
</tbody>
</table>

SD = Standard deviation; MMSE = Mini Mental State Examination
Table 2

Mean Values (± SD) Relative Gait Velocity during Single Task (ST) and Dual Task (DT)

<table>
<thead>
<tr>
<th>Group</th>
<th>Single task (ST)</th>
<th>Working memory (WM-DT)</th>
<th>p (ST vs. WM-DT)†</th>
<th>Semantic memory (SM-DT)</th>
<th>p (ST vs. SM-DT)†</th>
</tr>
</thead>
<tbody>
<tr>
<td>All (n = 711)</td>
<td>68.4 (± 13.1)</td>
<td>55.5 (± 16.5)</td>
<td>&lt; .001</td>
<td>50.6 (± 17.1)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Cognitively healthy (n = 548)</td>
<td>70.0 (± 12.6)</td>
<td>58.6 (± 15.6)</td>
<td>&lt; .001</td>
<td>53.2 (± 16.2)</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Cognitively impaired (n = 163)</td>
<td>62.6 (± 13.3)</td>
<td>44.9 (± 15.4)</td>
<td>&lt; .001</td>
<td>41.7 (± 17.0)</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

* normalized with height (m)
† based on ANOVA for repeated measures

SD = Standard deviation
Table 3

Mean Values (± SD) of Cognitive Performance During Working and Semantic Memory Single- and Dual-Task, Normalized Using Time Spent for Dual Task

<table>
<thead>
<tr>
<th>Cognitive Performance</th>
<th>Single task</th>
<th>Dual task</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Working memory task</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of correct calculations per second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All (n = 711)</td>
<td>0.76 (± 0.28)</td>
<td>0.63 (± 0.24)</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td>Cognitively healthy (n = 548)</td>
<td>0.83 (± 0.24)</td>
<td>0.67 (± 0.22)</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td>Cognitively impaired (n = 163)</td>
<td>0.53 (± 0.26)</td>
<td>0.44 (± 0.23)</td>
<td>&lt; .001*</td>
</tr>
<tr>
<td><strong>Working memory task</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of errors and repetitions per second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All (n = 711)</td>
<td>0.026 (± 0.070)</td>
<td>0.029 (± 0.090)</td>
<td>.69†</td>
</tr>
<tr>
<td>Cognitively healthy (n = 548)</td>
<td>0.018 (± 0.058)</td>
<td>0.024 (± 0.088)</td>
<td>.92†</td>
</tr>
<tr>
<td>Cognitively impaired (n = 163)</td>
<td>0.052 (± 0.098)</td>
<td>0.046 (± 0.093)</td>
<td>.62†</td>
</tr>
<tr>
<td><strong>Semantic memory task</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of animal names per second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All (n = 711)</td>
<td>0.53 (± 0.22)</td>
<td>0.52 (± 0.22)</td>
<td>.01†</td>
</tr>
<tr>
<td>Cognitively healthy (n = 548)</td>
<td>0.58 (± 0.20)</td>
<td>0.57 (± 0.20)</td>
<td>.03†</td>
</tr>
<tr>
<td>Cognitively impaired (n = 163)</td>
<td>0.35 (± 0.18)</td>
<td>0.34 (± 0.17)</td>
<td>.21†</td>
</tr>
<tr>
<td><strong>Semantic memory task</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of errors and repetitions per second</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All (n = 711)</td>
<td>0.010 (± 0.027)</td>
<td>0.011 (± 0.035)</td>
<td>.11†</td>
</tr>
<tr>
<td>Cognitively healthy (n = 548)</td>
<td>0.007 (± 0.024)</td>
<td>0.011 (± 0.035)</td>
<td>.02†</td>
</tr>
<tr>
<td>Cognitively impaired (n= 163)</td>
<td>0.016 (± 0.033)</td>
<td>0.014 (± 0.030)</td>
<td>.67†</td>
</tr>
</tbody>
</table>

* based on ANOVA for repeated measures
† based on Friedman Test

SD = Standard deviation
Figure Captions

Figure 1. Mean gait velocity (normalized with height) of cognitively healthy (n= 548) and cognitively impaired individuals (n = 163) during single- and dual-tasks. Both groups decreased their gait velocity during the working and the semantic memory task ($p < .001$). Velocity of cognitively impaired individuals was lower under all the three conditions ($p < .001$). Cognitively impaired individuals decreased their velocity during both working and semantic memory tasks more than cognitively healthy individuals ($p < .01$). Error bars represent standard deviation.

Figure 2. Single- and dual-task performance of cognitively healthy (n = 548) and cognitively impaired individuals (n = 163). Both groups produced significantly fewer correct calculations under dual- than single-task conditions ($p < .001$) but did not produce more animal names and did not make more errors or repetitions during both dual tasks, at least when controlling for confounders ($p > .01$). Cognitively impaired individuals produced fewer correct calculations and animal names and made more errors and repetitions than cognitively healthy individuals ($p < .05$). Whereas the decrease in cognitive performance from semantic memory single- to dual-task did not differ between the two groups ($p = .84$), cognitively healthy individuals showed a greater decrease in cognitive performance on the working memory dual-task ($p < .001$). Error bars represent standard deviation.
Figure 1

![Graph showing mean gait velocity (cm/sec) for single task walking alone, working memory dual task, and semantic memory dual task for cognitively healthy and impaired individuals.](image)

* normalized with height (m)
Figure 2

![Graph showing relative cognitive performance for different tasks and conditions.](image-url)