Dual-Task Performance in Alzheimer’s Disease, Mild Cognitive Impairment, and Normal Ageing

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Abstract

Although several studies have shown that dual-tasking ability is impaired in Alzheimer’s disease (AD), the stage at which this deficit manifests remains unclear. This study investigated if a new paper-and-pencil assessment of dual-tasking ability could distinguish between AD, mild cognitive impairment (MCI) and normal ageing in a sample of 50 people with AD, 49 people with MCI, and 50 healthy age-matched controls. The AD group demonstrated a significant impairment in dual-task ability. There was no effect of either MCI or healthy ageing on dual-task performance, indicating that the dual-task impairment is specific to AD.

Keywords: Alzheimer’s disease; Attention; Elderly/geriatrics/aging; Mild cognitive impairment

Introduction

Dual tasking is the ability to do two things at once. It is thought to tax a coordination function, which is one of the executive resources within working memory (Baddeley, 2007; Logie, Cocchini, Della Sala, & Baddeley, 2004). Several studies have shown that, when two distinct task components are performed concurrently and performance on each individual task component is equated across participants, dual-task performance in healthy older and younger people does not significantly differ (Baddeley, Logie, Bressi, Della Sala, & Spinnler, 1986; Belleville, Rouleau, & Caza, 1998; Inasaridze, Della Sala, & Logie, 2007; Logie et al., 2004; MacPherson, Della Sala, Logie, & Wilcock, 2007; Salthouse, Fristoe, Lineweaver, & Coon, 1995).

In contrast, for people with Alzheimer’s disease (AD), the early symptom of episodic memory impairment has been shown in several studies to be coupled with a striking impairment in dual-tasking ability when compared with healthy age-matched controls (Baddeley, Logie, Della Sala, & Spinnler, 1991; Baddeley et al., 1986; Della Sala, Baddeley, Papagno, & Spinnler, 1995; Hultzer, Burright, & Donovick, 2004; Logie et al., 2004; MacPherson, Della Sala, & Logie, 2004; MacPherson et al., 2007; Morris, 1986; Morris & Baddeley, 1988; Sebastian, Menor, & Eloisa, 2006). This dual-task deficit becomes more pronounced with increasing severity of the disease (Baddeley et al., 1991; Baddeley, Baddeley, Bucks, & Wilcock, 2001).

In the original Baddeley and colleagues (1986) study, 28 people with AD, 28 healthy age-matched controls, and 19 healthy young controls were compared on their ability to perform a tracking task with a concurrent task of digit recall. In the tracking task, participants were asked to use a light-sensitive pen to follow a moving square on a computer screen. Individual tracking span was considered to be the highest speed at which the participant could reliably maintain 40%–60% time on target. In the digit-span task, participants were asked to listen to and repeat back sequences of numbers, read at a rate of one number per second. Three trials for each sequence length were read. Individual digit span was considered to be the longest sequence.
length at which the participant could recall two of three sequences accurately. Ability to perform the tracking task and digit span was assessed, and then the demand level of each task was adjusted to the assessed individual ability level for each participant. This then equated single-task performance across the three groups when these tasks were performed alone. This procedure of adjusting or titrating single-task demand ensured that any dual-task decrements could not be attributed to differences between groups in single-task performance. When the tracking task was paired with immediate recall of digit sequences, AD patients demonstrated marked dual-task impairment relative to their own single-task performance. The size of this dual-task impairment was substantially larger than the very small dual-task impairment relative to titrated single task found for healthy age-matched or younger controls, who did not differ from each other.

This specific dual-task impairment in AD contrasted with a lack of a dual-task effect in healthy ageing has been replicated in multiple subsequent studies (e.g., Baddeley, Della Sala, Gray, Papagno, & Spinnler, 1997; Della Sala et al., 1995; Greene, Hodges, & Baddeley, 1995; Kaschel, Logie, Kazén, & Della Sala, 2009; Logie et al., 2004; MacPherson et al., 2007; Sebastian et al., 2006). In each of these previous reports, it has been noted that a dual-task impairment linked with healthy ageing tends to appear in studies in which single-task performance is not equated between the younger and older groups tested, tasks involve time pressure for response, or the two tasks chosen involve cognitive conflicts such as if both tasks involve verbal processing (e.g., Logie, Della Sala, MacPherson, & Cooper, 2007; Naveh-Benjamin, Craik, Guez, & Kreuger, 2005; Salthouse et al., 1995; Salthouse, Rogan, & Prill, 1984).

Baddeley and colleagues (1997) assessed dual-task performance using digit recall and a test of tracking, the latter of which required participants to use a pen to cross out a series of boxes arranged in a path around a large sheet of paper. Digit recall demand was titrated for the individual level of ability, by determining the maximum sequence length at which the participant could repeat three lists without error. Digit recall was assessed by calculating the percentage of correct digit sequences repeated in dual-task versus single-task conditions. Tracking was assessed by calculating the total number of boxes crossed out in dual-task conditions as a percentage of the total crossed out in single-task conditions. Ability to perform digit span and tracking, in single- and dual-task conditions, was assessed in 108 healthy adults aged 20–99, replicating earlier findings that dual-task performance was not affected by age.

It could be argued that the differential dual-task decrement observed in AD patients reflects an interaction between task demand and the need to divide attention, rather than a specific problem with dual-task coordination. In order to test this hypothesis, Logie and colleagues (2004) examined dual-task performance in several conditions, with varying levels of task demand. The AD group always displayed dual-task impairment, even when the two tasks were set at very low levels of demand, but they did not display differential sensitivity to increased demands within a single task. Moreover, the AD-specific dual-task impairment is robust over practice (Baddeley, Cocchini, Della Sala, Logie, & Spinnler, 1999) and with task combinations that avoid response times and cognitive conflicts, including memory and motor tasks (Baddeley et al., 1986), visual and verbal memory tasks (MacPherson et al., 2007), and more everyday task combinations, like walking and talking (Cocchini et al., 2004).

The stage of disease at which this dual-task deficit manifests, however, remains unclear. Although studies repeatedly show that people with moderate AD demonstrate an impairment in dual-task performance, some studies (e.g., Calderon et al., 2001; Greene et al., 1995; Perry et al., 2000) have not found any dual-task impairment in mild or minimal AD, a condition the definition of which overlaps with that of mild cognitive impairment (MCI; Petersen et al., 1999).

Accurate diagnosis of MCI remains a challenging process, with an unclear relationship between the diagnosis and conversion to AD or brain pathology (Belanger, 2007). Currently, MCI diagnosis contains both true positives (individuals who will progress to dementia) and false positives (individuals whose deficits/weaknesses remain stable, or even improve), making it difficult to determine individual prognosis (Brooks, Iverson, Holdnack, & Feldman, 2008).

However, the accurate diagnosis of MCI is essential for identifying the therapeutic window in which the management of risk factors and medical therapies may be used to reduce the likelihood of conversion to AD. Currently, accurate differential diagnosis of MCI and AD requires several hours of neuropsychological interview and assessment, investigating the multiple domains that may be affected by AD, and determining how any impairments impact upon everyday functioning. Thus, a measure that could reliably and quickly separate MCI from AD would be of significant clinical importance (DeKosky, 2003).

The evidence for dual-task deficits in MCI is equivocal. Some studies show significant dual-task decrement in comparison with healthy age-matched controls (Dannhauser et al., 2005; Holtzer et al., 2004; Ritchie, Artero, & Touchon, 2001). However, these studies did not titrate single-task difficulty across participants, and thus any group dual-task difference could be accounted for in terms of initial single-task differences (cf. Salthouse et al., 1984). Interestingly, the few studies that do titrate single-task difficulty across participants (Lopez et al., 2006; Nordlund et al., 2005; Pettersson, Olsson, & Wahlund, 2005) do not find any group difference.

The diagnostic specificity of the dual-task assessment first must be established before investigating any differences in the dual-task performance of MCI patients who later convert to AD and those who do not (cf. Robert et al., 2006). Therefore, the aim of this study is to determine how specific is the previously reported dual-task deficit to AD compared with MCI and healthy...
ageing using a modified version of Della Sala and colleagues’ (1995) dual-task paradigm. This will determine if this dual-task assessment can be used to support the accurate, brief, and reliable differential diagnosis of MCI and AD and enable future longitudinal studies to investigate the predictive power of dual-tasking ability in the conversion of MCI to AD.

Methods

Participants

A total of 50 patients with AD, 49 people with MCI, and 50 healthy older adults participated in this study.

The 50 AD patients (27 women and 23 men) had been diagnosed in accordance with National Institute of Neurologic, Communicative Disorders, and Stroke-AD and Related Disorders Association (NINCDS-ADRDA; McKhann et al., 1984) and DSM-IV (APA, 2000) criteria. All the AD patients scored ≤25 on the Mini-Mental State Examination (MMSE; range 10–25, mean = 19.32, SD = 4.14) and had a Clinical Dementia Rating (Berg, 1988) score of 1 or 2, indicating mild or moderate disease, respectively. The AD patients ranged in age between 57 and 86 (mean = 71.40, SD = 7.08) and in formal education from 4 to 17 years (mean = 9.72, SD = 4.16).

The 49 MCI patients (31 women and 18 men) were diagnosed with MCI in accordance with the criteria established by Petersen and colleagues (1999). These criteria include (a) the presence of subjective memory complaints and objective memory impairment, (b) the absence of impairment in other cognitive domains, and (c) the absence of impairments in activities of daily living. Objective memory impairment was confirmed by a test score at least 2 SDs below the cutoff for normal performance on the “Appointments” test of episodic long-term memory (Kaschel, 1994). The absence of impairment in other cognitive domains was assessed using the LPS-K (Sturm & Wilmes, 1983). All participants included performed in the average or low average on this battery of measures assessing reasoning, fluency, and visuo-spatial abilities. The absence of functional impairment was assessed by reviewing ability to perform various daily living activities. Moreover, none of these patients met the DSM-IV criteria for dementia and all scored above 24 on the MMSE. Their mean MMSE score was 27.04 (SD = 1.74), and their mean Clinical Dementia Rating score was 0.5, indicating questionable dementia. The MCI patients ranged in age between 57 and 86 (mean = 69.43, SD = 6.74) and in education from 3 to 18 years (mean = 8.90, SD = 3.15).

The 50 healthy older adults (28 women and 22 men) were matched as closely as possible to the AD and MCI groups for age, gender, and education. All healthy participants had no history of psychiatric, neurological, or degenerative disorder or brain injury. The healthy older adults had an age range of 56–86 years (mean = 72.56, SD = 7.85) and an education range of 3 to 18 years (mean = 8.76, SD = 4.65).

The research was completed in accordance with the Helsinki Declaration.

Procedure

Each participant completed the dual-task assessment, which consisted of performing digit recall and tracking tasks separately and then simultaneously. This dual-task assessment, and the full instructions for its administration and scoring, can be found at www.psy.ed.ac.uk/people/sdsala/tests/sdsdualtask/.

Before commencing the digit recall task, digit span for each individual was established. Participants heard a list of digits at a rate of one per second. Participants were then asked to repeat these digits back in the same order as they heard them. The initial sequence length was two digits long and participants were presented with six sequences at each sequence length. If five of the six sequences were recalled correctly, the digit sequence was lengthened by one digit. Once a participant could no longer recall five of the six digit sequences, digit span was taken as the maximum length at which the participant was able to recall five of six digit sequences correctly. After the participant’s span had been established, they heard sequences at their individual span length for immediate serial recall, and this was repeated for as many sequences as could be presented and recalled over a 90 s period. Therefore, the number of lists for each participant varied depending on the length of their digit span, and the performance measure was the proportion of digits accurately recalled in the correct serial-order position.

The tracking task consisted of using a pencil to draw a line through a series of circles arranged in a path around a sheet of A3 paper. Participants were given a shortened version for a practice trial, with only 17 circles, to ensure that they understood the task demands. After this, the participant was presented with the full version comprising 319 circles and asked to start at one end of the path and draw a line through each successive circle as quickly as they could for a period of 90 s. The performance measure was the number of circles crossed by the pencil.

In the dual-task condition, participants were asked to perform the tracking task at the same time as listening to and repeating back the digit sequences they heard, for a further 90 s. The performance measures were the proportion of digits accurately
recalled in the correct serial-order position and the number of circles crossed by the pencil. Proportional performance in digit recall ($p_m$) was calculated by measuring the change in digit recall between single ($m_{\text{single}}$) and dual-task ($m_{\text{dual}}$) conditions, where $m$ is the proportion of digits recalled accurately, and using:

$$p_m = 100 - \frac{(m_{\text{single}} - m_{\text{dual}}) \times 100}{m_{\text{single}}}$$

Proportional performance in tracking ($p_t$) was calculated by measuring the change in tracking between single ($t_{\text{single}}$) and dual-task ($t_{\text{dual}}$) conditions, where $t$ is the number of circles drawn through, and using:

$$p_t = 100 - \frac{(t_{\text{single}} - t_{\text{dual}}) \times 100}{t_{\text{single}}}$$

It is important to ensure that data from dual-task studies are examined for possible trade-off between tasks; that is, the possibility that participants preserve performance on one task at the expense of the other. Therefore, it is essential to consider dual-task effects on performance of both tasks. It is also useful for clinical purposes to generate a single score that can be used for assessment. Therefore, as in our previous dual-task studies, we generated a combined measure ($\mu$) of overall dual-task performance relative to single task for both tasks together. If this overall dual-task measure shows a decrement, then we can be confident that this is a genuine overall drop from single-task performance on both tasks and not a trade-off between tasks.

Proportional performance in both tasks overall ($\mu$) was calculated by using:

$$\mu = \frac{p_m + p_t}{2}$$

**Results**

**Analytical Strategy**

Mean and standard deviations were calculated for each of the variables. Normality of distribution was assessed using the Kolmogorov–Smirnov test and, if significant, by examining the $z$-scores for skewness and kurtosis. Homogeneity of variance was assessed using the Levene test. Unless otherwise stated, all data met the assumptions of normality and homogeneity of variance. Data were analyzed using SPSS for Windows (version 14).

**Participant Characteristics**

A one-way between-subjects analysis of variance showed that there were no group differences in age—$F(2, 148) = 2.36$, $p = .10$. A Kolmogorov–Smirnov test revealed that education was not normally distributed in two of the three participant groups—$D(148) = 0.20$, $p < .001$, with a positively skewed and leptokurtic distribution in the data of MCI patients ($z_{\text{skewness}} = 3.88$; $z_{\text{kurtosis}} = 4.05$) and a positively skewed distribution in the healthy controls ($z_{\text{skewness}} = 3.85$). A Kruskal–Wallis test was used, therefore, to assess for any differences in years of formal education between the three groups, and this revealed that there were none—$H(2) = 3.89$, $p = .15$.

A Levene test revealed that the three participant groups’ MMSE scores had significantly different variances—$F(2, 116) = 38.08$, $p < .001$. A Kruskal–Wallis test revealed significant group differences in MMSE scores—$H(2) = 86.08$, $p < .001$—and the post hoc Mann–Whitney tests revealed that there was a significant difference in average MMSE score between the AD and MCI ($U = 30.00$, $p < .001$, $r = -.84$), between the AD and healthy controls ($U = 0.00$, $p < .001$, $r = -.78$), and between the MCI and healthy controls ($U = 307.50$, $p < .016$, $r = -.30$), when using the Bonferroni correction.

**Dual-Task Performance**

Group means and standard deviations of proportional performance in digit recall ($p_m$), tracking ($p_t$), and both tasks overall ($\mu$) are presented in Table 1, and individual overall dual-task scores ($\mu$), in the three groups, are presented in a scatterplot in Fig. 1.
Scores of proportional performance of the digit recall task ($p_m$) were not normally distributed in the three participant groups—$D(142) = 0.13$, $p < .001$. There was a significantly negatively skewed and leptokurtic distribution in the AD group ($z_{skewness} = 2.97$, $z_{kurtosis} = 3.24$) and a positively skewed and leptokurtic distribution in the MCI group ($z_{skewness} = 11.35$, $z_{kurtosis} = 28.39$). In addition, a Levene test revealed that the three participant group scores had significantly different variances—$F(2, 139) = 7.81$, $p = .001$. A Kruskal–Wallis test revealed significant group differences in proportional performance of the digit recall task—$H(2) = 6.88$, $p < .05$, with the post hoc Mann–Whitney tests revealing that the AD group performed significantly lower than the healthy control group ($U = 528.00$, $p = .001$, $r = .25$), but not the MCI group ($U = 1,015.00$, ns, $r = -.15$), and with no difference between the MCI and healthy control groups ($U = 866.00$, ns, $r = -.25$), using the Bonferroni correction.

A Levene test revealed that the three participant groups’ proportional performance scores on the tracking task ($p_t$) had significantly different variances—$F(2, 139) = 7.81$, $p = .001$. A Kruskal–Wallis test revealed significant group differences in proportional performance of both tasks overall—$H(2) = 17.39$, $p < .001$, with the post hoc Mann–Whitney tests revealing that the AD group performed significantly lower than the MCI group ($U = 768.00$, $p < .016$, $r = -.32$) and the healthy control group ($U = 640.00$, $p < .001$, $r = -.39$), but with no difference between the MCI and healthy control groups ($U = 1,033.50$, ns, $r = -.34$), using the Bonferroni correction.

Scores of proportional performance of both tasks overall ($\mu$) were not normally distributed in the three participant groups—$D(142) = 0.13$, $p < .001$, with a significantly positively skewed and leptokurtic distribution in the MCI group ($z_{skewness} = 3.80$, $z_{kurtosis} = 8.63$). In addition, a Levene test revealed that the three participant group scores had significantly different variances—$F(2, 139) = 7.81$, $p = .001$. A Kruskal–Wallis test revealed significant group differences in proportional performance of both tasks overall—$H(2) = 26.94$, $p < .001$, with the post hoc Mann–Whitney tests revealing that the AD group performed...
significantly lower than the MCI group ($U = 750.00, p < .001, r = -.33$) and the healthy control group ($U = 528.00, p < .001, r = -.50$), but with no difference between the MCI and healthy control groups ($U = 925.00, ns, r = -.50$), using the Bonferroni correction.

There were two outliers within the MCI group data for overall dual-task performance; with one data point more than 2 $SD$s above the mean and one data point more than 2 $SD$s below the mean. When these two outliers were removed from the MCI data, and the analysis repeated, the results remained the same, with the AD group still performing significantly lower than the MCI group in proportional performance of the tracking task ($U = 710.00, p < .001, r = -.34$) and overall ($U = 707.00, p < .001, r = -.34$), but not in proportional performance of the digit recall task ($U = 974.00, ns, r = -.15$), when using the Bonferroni correction. Similarly, the AD group still performed significantly lower than the healthy controls in proportional performance of the digit recall task ($U = 755.00, p < .016, r = -.25$), tracking task ($U = 640.00, p < .001, r = -.39$), and overall ($U = 528.00, p < .001, r = -.50$). There remained no significant differences between the MCI and healthy control groups in proportional performance of the digit recall task ($U = 875.00, ns, r = -.22$), tracking task ($U = 1020.50, ns, r = -.06$), and overall ($U = 823.00, ns, r = -.15$), using the Bonferroni correction.

Figure 2a–c shows receiver operating characteristic (ROC) curves, depicting the relative sensitivity and specificity of the overall dual-task measure for each of the three participant groups. The thin diagonal line in each of the three figures indicates the expected finding should the dual-task measure provides zero discrimination, yielding an area under the curve of 50%. Figure 2a illustrates that the measure is both sensitive (64.00%) and specific (88.00%) in discriminating between the AD group and healthy older adults, using the cutoff criterion of 87.51%. The area under the curve is 0.79 (SE = 0.05), which is significant ($p < .001$). Confidence intervals are 0.70 (lower bound) and 0.87 (upper bound). Figure 2b illustrates that the dual-task measure is also sensitive (62.00%) and specific (69.39%) in discriminating between the AD and MCI patients, using the cutoff criterion of 87.18%. The area under the curve is 0.69 (SE = 0.05), which is significant ($p < .001$). Confidence intervals are 0.59 (lower bound) to 0.78 (upper bound). Figure 2c illustrates that the dual-task measure discriminates between MCI and healthy ageing, with low sensitivity (44.90%) and high specificity (82.0%), when using a cutoff criterion of 89.63%. The area under the curve is 0.62 (SE = 0.06), which is significant ($p < .05$), although its confidence intervals are 0.52 (lower bound) to 0.72 (upper bound), which approach chance (zero discrimination), making it clinically irrelevant. This poor discrimination is further confirmed by the lack of statistical difference in the post hoc Mann–Whitney test.

### Discussion

Several studies have consistently shown that people with AD demonstrate dual-task impairment in comparison with healthy controls (Baddeley et al., 1986, 1991; Della Sala et al., 1995; Holtzer et al., 2004; Logie et al., 2004; MacPherson et al., 2004, 2007; Morris, 1986; Morris & Baddeley, 1988; Sebastian et al., 2006) and depressed older people (Kaschel et al., 2009). A dual-task impairment in AD compared with healthy ageing also was observed in the current study.

The major goal for the present study was to identify whether or not dual-task assessment also could distinguish between AD and MCI. The AD group demonstrated a significantly larger dual-task decrement than the MCI group, with no significant differences between the MCI and healthy control groups. It is clear that once care is taken to titrate individual performance on the component single tasks, the dual-task measure is a sensitive and specific discriminator between AD and MCI (and healthy ageing).

Dual-task performance was not found to be statistically significantly different between the MCI and healthy older adult groups. However, dual-task performance in the MCI group was characterized by a large variability. It may be that the individuals in the MCI group who perform well on the dual-task measure will have stable deficits longitudinally, whereas the individuals who perform poorly on the dual-task measure will be more likely to convert to AD, as found by Robert and colleagues (2006). Of course, this hypothesis can only be tested using a longitudinal design, but before launching such study it was imperative to show that our dual-task measure could reliably separate out normal ageing and average MCI from AD.

The specificity of dual-task impairments in AD cannot be attributed to general cognitive load on a damaged brain (Logie et al., 2004). This is of theoretical interest as it suggests that some form of cognitive function is available to the healthy brain for a successful coordination of the concurrent performance of two distinct tasks. This dual-task coordination function appears to be impaired in the brain of patients with AD. This in turn raises questions about the possible underpinnings of dual-task performance at the neurobiological level, possibly pointing to a break down in connectivity within the brain (e.g., Rose et al., 2000) or progression of the disease through the prefrontal cortex (Foster et al., 2008).

More important for the current paper are the clinical implications of our results. Both MCI and AD are usually diagnosed on the basis of a primary impairment in memory (Petersen et al., 1999), which therefore is a very sensitive measure but is not
Fig. 2. (a) ROC curve depicting sensitivity and specificity of the overall dual-task measure. This curve compares the AD group using the healthy older adults as a reference group (higher sensitivity scores indicate higher performance). (b) ROC curve depicting sensitivity and specificity of the overall dual-task measure. This curve compares the AD group using the MCI patients as a reference group (higher sensitivity scores indicate higher performance). (c) ROC curve depicting sensitivity and specificity of the overall dual-task measure. This curve compares the MCI patients using the healthy older adults as a reference group (higher sensitivity scores indicate higher performance).
specific to the disease. Dual task appears to be specific for AD, relative to MCI and normal ageing. Thus, although people with MCI and those with AD may both demonstrate significant impairment on measures of episodic memory, only individuals with AD will demonstrate impaired performance on the dual-task measure. Therefore, the dual-task impairment is specific to AD, and the dual-task assessment can be used to support the accurate and reliable differential diagnosis of MCI and AD.

Moreover, episodic memory performance tends to deteriorate rapidly as the disease progresses, soon reaching floor levels of performance (Greene et al., 1995). This makes it less suitable for tracking the progression of cognitive impairments with the progression of the disease. In contrast, a dual-task procedure, in which demands of the single tasks are titrated for the ability of each individual participant, avoids floor effects and shows progressive impairment as the disease progresses (Baddeley et al., 1991). Because the measure is not affected by practice with repeated testing on the same individuals, it may also detect genuine improvements for evaluation of the effectiveness of new therapies that might become available. In addition, this paper and pencil version of tracking together with simple audio presentation and oral recall of digit sequences makes the procedure inexpensive, easily transportable and usable by primary health care staff with a minimal amount of training.

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Conflict of Interest

None declared.

References


