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Dynamic working memory performance in individuals with single-domain amnestic mild cognitive impairment

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Previous studies have observed poorer working memory performance in individuals with amnestic mild cognitive impairment than in healthy older adults. It is unclear, however, whether these difficulties are true only of the multiple-domain clinical subtype in whom poorer executive functioning is common. The current study examined working memory, as measured by the self-ordered pointing task (SOPT) and an n-back task, in healthy older adults and adults with single-domain amnestic mild cognitive impairment (aMCI). Individuals with single-domain aMCI committed more errors and required longer to develop an organizational strategy on the SOPT. The single-domain aMCI group did not differ from healthy older adults on the 1-back or 2-back, but had poorer discrimination on the 3-back task. This is, to our knowledge, the first characterization of dynamic working memory performance in a single-domain aMCI group. These results lend support for the idea that clinical amnestic MCI subtypes may reflect different stages on a continuum of progression to dementia and question whether standardized measures of working memory (span tasks) are sensitive enough to capture subtle changes in performance.

Keywords: Mild cognitive impairment; Working memory; Dynamic working memory; Memory span; Cognition.

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Mild cognitive impairment (MCI) is a syndrome that characterizes individuals who demonstrate cognitive decline beyond what is expected for their age, education, and intelligence, but who have a preserved ability to function independently (Albert et al., 2011). The etiologies underlying MCI can vary, and the clinical syndrome itself presents as heterogeneous. Approximately a decade ago, researchers suggested that there are four clinical MCI subtypes defined on the basis of whether memory is affected or not, and whether a single or multiple cognitive domain(s) are affected (Petersen, 2004; Petersen et al., 2001). The hallmark of the two amnestic MCI (aMCI) subtypes —single-domain and multiple-domain—is a significant decline in long-term memory relative to the individual's estimated baseline functioning (Albert et al., 2011; Petersen et al., 1997). In the case of multiple-domain aMCI, the individual presents with a significant decline in one (or more) cognitive

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domain(s) in addition to deficits in long-term memory. The most common additional cognitive domain is executive functioning (Duchek et al., 2009; Hutchison, Balota, Duchek, & Ducheck, 2010; Johns et al., 2012), which includes poor working memory (Gagnon & Belleville, 2011).

One motivation for characterizing clinical subtypes of MCI was to improve prognostication of the underlying dementia type that individuals were likely experiencing. It was suggested that both amnestic subtypes reflect prodromal Alzheimer's disease most typically, while multiple-domain amnestic MCI also commonly reflects prodromal vascular dementia (Petersen, 2004). However, the notion of MCI subtypes is not advocated in the recently published MCI diagnostic criteria (Albert et al., 2011), and indeed it has been suggested that multiple-domain aMCI may instead reflect a more progressed stage with overall poorer cognitive functioning (Alexopoulos, Grimmer, Perneczky, Domes, & Kurz, 2006; Brambati et al., 2009; Brandt, Spencer, & Folstein, 1988; Tabert et al., 2006; but also see Yaffe, Petersen, Lindquist, Kramer, & Miller, 2006). If so, it should be possible to detect impairments in nonepisodic memory cognitive domains in individuals with the single-domain aMCI subtype, with sensitive cognitive measures. However, many standardized neuropsychological tests are not sensitive to subtle impairments. Tests of working memory are a case in point. The most common operationalization of working memory in neuropsychological batteries and in aMCI research is with a backwards digit span task (Johns et al., 2012). This is a task composed of relatively short trials of material that is easily rehearsed (Wechsler, 1997). Recent work suggests that performance on span tasks may be bolstered when the material is highly familiar and verbalizable, affording articulatory rehearsal (Rose, Olsen, Craik, & Rosenbaum, 2012). Span tasks typically utilize highly familiar and verbalizable material along with mental transformation as the controlled processing requirement, in addition to short-term storage (Conway et al., 2005). This may place minimal requirements on frontally mediated cognitive control. Indeed, some studies have found that in a factor analysis, backwards span clusters with short-term memory tasks, suggesting that mental transformation may not be sufficiently demanding compared to other types of working memory manipulations (Bryan & Luszcz, 2001; Engle, Tuholski, Laughlin, & Conway, 1999). Thus, the commonly used neuropsychological measures of working memory span may be overlooking important working memory constructs.

One limitation of the prior work examining working memory in individuals with aMCI is that the vast majority of studies examined performance in a mix of participants with single-domain aMCI or multiple-domain aMCI. If poorer working memory performance is observed in a single-domain aMCI group than in healthy older adults it would lend support for the view that single-domain and multiple-domain clinical presentations may fall on a common continuum of neurodegenerative progression. An important question then becomes what working memory measures would be most sensitive to subtle changes in working memory that may be occurring in a single-domain aMCI group. For the reasons described below, we selected two tasks that require continuous monitoring of stimuli in addition to short-term storage. Tasks like these have been previously referred to as "dynamic" working memory tasks as they place greater demands on monitoring than do working memory tasks made up of short, discrete trials (Conway et al., 2005).

As a way of measuring concurrent processing and storage, continuously over multiple trials, a self-ordered pointing task (SOPT; Jennings, Webster, Kleykamp, & Dagenbach, 2005; Petrides & Milner, 1982) was selected. This task required dynamic, continuous monitoring of abstract designs across 16 trials. The SOPT was originally developed in a clinical context to examine the ability of patients with frontal and temporal lobe excisions to initiate, organize, and monitor a sequence of responses (Petrides & Milner, 1982). It has been used extensively since, including in studies of older adults (Daigneault & Braun, 1993; West, Ergis, Winocur, & Saint-Cyr, 1998), but not, to our knowledge, examined in individuals with aMCI.

Another dynamic working memory task that has been adopted widely in experimental research (Kane & Engle, 2002; Owen, McMillan, Laird, & Bullmore, 2005) is the n-back task. This is a demanding task that requires processing of potentially interfering intervening stimuli in addition to short-term storage, often for an unknown length of time. One previous investigation has shown that dynamic working memory performance as measured by the n-back task (1-back and 2-back conditions) is indeed diminished in a general aMCI group (Borkowska, Drozdz, Jurkowski, & Rybakowski, 2009); however, this study did not examine single- and multiple-domain groups separately. One advantage of using an n-back task (Dobbs & Rule, 1989) to examine dynamic working memory performance is the flexibility to systematically increase the retention interval (e.g., one intervening item, two intervening items, and three intervening items), which

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also systematically increases the amount of interfering information and in turn may uncover more subtle working memory deficits.

Below we present our results comparing dynamic working memory performance among individuals with single-domain aMCI and healthy older adults. Exploration of working memory performance on tasks other than standardized span tasks is important for identifying potentially overlooked weaknesses in working memory in this population. Evidence of poorer working memory performance in single-domain aMCI would have implications for the conceptualization of single-domain aMCI as an earlier, less progressed stage of decline relative to the multiple-domain aMCI profile.

METHOD

Participant selection

Forty-eight healthy older adults (22 males; age M = 70.65 years, SD = 4.47, range 64–87) and 14 older adults with single-domain aMCI (2 males; age M = 73.07, SD = 6.44, range 65–83) were recruited from the Baycrest participant database and from community talks and advertisements as part of a larger ongoing cognitive training study. The two groups did not differ in terms of age, $t(60) = 1.61$, $p = .11$. There was a marginal difference in years of formal education (healthy older M = 15.88 years, SD = 2.47, range 12–21 years; MCI M = 14.57, SD = 1.83, range 12–18 years), $t(60) = 1.83$, $p = .07$, which was examined as a covariate. All participants were native English speakers or learned English before the age of 5, had no prior history of neurological disorder, head injury, dementia, stroke, heart attack, diabetes, anxiety, or psychiatric disorder requiring hospitalization, and were normotensive with normal or controlled cholesterol and thyroid function. No current psychiatric issues were reported by participants upon recruitment. In addition, participants were excluded if a medical or psychiatric condition (other than possible incipient Alzheimer's disease) identified by an experienced psychiatrist (L.M.) or an incidental finding on magnetic resonance imaging (MRI) T1 scans reviewed by an experienced neurologist (J.W.) could account for the memory impairment. Patients were free from any major lesions (ischemic, mass) as detected by MRI. Data from two additional participants with aMCI who met criteria for major depressive disorder were excluded. Participants received monetary compensation for participation, and all procedures were approved by Baycrest's Research Ethics Board.

Neuropsychological battery

All participants completed a neuropsychological test battery (Table 1). For a clinical diagnosis of single-domain aMCI, we required a subjective memory complaint, intact activities of daily living (Lawton & Brody, 1969), and scores on at least two memory tests being 1.5 standard deviations or more lower than expected for the individual's age, education, and verbal IQ as estimated by vocabulary performance (Shipley Institute of Living Scale; Zachary, 1986) and visuospatial reasoning (Wechsler Abbreviated Scale of Intelligence, WASI, Matrix Reasoning; Wechsler, 1999), with intact performance in all other cognitive domains (Petersen et al., 1997). Healthy older adults and participants with single-domain aMCI did not differ in their cognitive abilities, including digit span, except in the memory domain (Table 1).

Behavioral testing

Participants completed a set of experimental tasks conducted in a session separate from neuropsychological testing. For this investigation we examined performance on the self-ordered pointing task and an n-back task.

Self-ordered pointing task

The version used in the current study involved 16 abstract designs that are easily distinguishable from each other and that minimize the use of a verbal coding strategy and articulatory rehearsal (Jennings et al., 2005). Designs were a selection of 16 six-point shapes from Vanderplas and Garvin (1959). Participants completed the task three times, which we referred to as three separate trials. Each trial consisted of 16 pages. Each page contained a 4 by 4 array of 16 abstract designs arranged in a distinct random order. The participant's task was to point to a different design on every page, avoiding repetition errors (i.e., pointing to the same design more than once). Two measures of successful performance were obtained. One was the total number of repetition errors analyzed separately for each trial. The degree to which participants commit repetition errors is theorized to index the degree to which participants can successfully monitor previously selected stimuli. Our second measure was an estimate of strategy use termed "subjective organization." Similar to how individuals can use serial or semantic clustering strategies on word list learning tasks, we measured the extent to which participants selected abstract designs in the same order

TABLE 1
Neuropsychological test results

Test name	*Healthy older Mean (SD)*	*Single-domain aMCI Mean (SD)*
Mini-Mental Status Exam raw score	28.88 (1.36)	28.14 (1.46)
Wechsler Abbreviated Scale of Intelligence		
Block Design raw score	39.33 (13.08)	32.21 (12.84)
Matrix Reasoning raw score	23.54 (5.54)	22.00 (6.11)
Phonemic Fluency total correct[a]	45.31 (12.03)	45.31 (12.95)
Category Fluency total correct[a]	18.88 (5.72)	18.15 (3.48)
Boston Naming Test raw score[a]	14.35 (1.04)	13.85 (1.21)
Shipley Vocabulary Test total	35.85 (2.72)	36.29 (1.44)
Trail Making Test A (time in s)	32.33 (10.12)	33.50 (11.79)
Trial Making Test B (time in s)	72.65 (22.35)	79.79 (32.67)
Wechsler Adult Intelligence Scale–III		
Digit Symbol total correct	66.25 (11.82)	64.00 (14.06)
Digit Span total	18.15 (4.18)	17.14 (3.28)
Longest Digit Forward	6.65 (1.30)	6.79 (1.31)
Longest Digit Backward	5.44 (1.43)	5.21 (1.12)
Wechsler Memory Scale–Revised		
Mental Control raw total	28.13 (5.91)	29.29 (4.62)
Arithmetic raw total	13.21 (3.31)	12.50 (3.70)
Logical Memory I total	25.52 (5.78)	21.36 (6.30)*
Logical Memory II total	26.15 (7.04)	18.71 (8.41)**
Visual Paired Associates I total	12.06 (3.94)	10.21 (3.73)
Visual Paired Associates II total	5.25 (1.08)	4.43 (1.65)*
Verbal Paired Associates I total	18.25 (2.86)	12.79 (2.42)***
Verbal Paired Associates II total	7.15 (1.32)	5.36 (0.93)***
Wechsler Memory Scale–III		
Faces total	35.13 (4.04)	31.00 (4.30)**
Modified Wisconsin Card Sorting Test		
Number of Categories Completed	5.00 (1.46)	5.14 (1.46)
Failure to Maintain Set	0.81 (1.33)	1.43 (1.45)
California Verbal Learning Test–II		
List A total correct (Trials 1–5)	47.65 (7.92)	37.50 (8.95)***
List A Long Delay Free Recall total	10.56 (2.39)	6.00 (2.45)***
List A Long Delay Cued Recall total	11.50 (2.33)	6.86 (2.21)***

Notes. aMCI = amnestic mild cognitive impairment.
[a]One MCI participant missing data.
*Significantly different at $p < .05$. **$p < .01$. ***$p < .001$.

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across subsequent trials. Such a pattern is inferred to be indicative of application of a self-initiated organizational strategy (Daigneault, Braun, & Whitaker, 1992; Sternberg & Tulving, 1977). More specifically, we calculated subjective organization as the number of pairs of successive designs selected regardless of the order in which they were selected (not including repetition errors). This is termed bidirectional pair frequency. Higher values indicated a greater degree of subjective organization. For example, suppose a participant selected the designs in this order on Trial 1: GCAIEHJKBLNOFDPP. On Trial 2, he would obtain a subjective organization score of 2 based on his selecting the designs in the following order (the second selection of each pair contributing to subjective organization in bold): C**GC**P**IE**J**EF**K**N**B**OLDO**. Bidirectional pair frequency was then adjusted for chance using the calculation PFobs – $2c(c - 1)/hk$, where PFobs is the observed pair frequency, c is the number of selections common to trial n and trial $n + 1$, h is the number correct on trial n, and k is the number correct on trial $n + 1$. Using these corrected values, 0 represents chance.

The n-back task

The n-back task is used extensively in experimental studies of working memory (Owen et al., 2005) and is believed to specifically tap dynamic working memory abilities (Conway et al., 2005). It is commonly grouped with other continuous monitoring tasks such as running span (Pollack, Johnson, & Knaff, 1959) and keeping-track tasks (Yntema & Mueser, 1962). These tasks require a person to constantly change their mental representation (i.e., which letter is the target) while also continually monitoring a stream of information, often for an

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unknown length of time (Conway et al., 2005). On our n-back task, a single letter of the alphabet in either upper or lower case was presented one at a time. The participants' objective was to indicate when the same letter, regardless of case, was presented "n" positions previously. The 1-back task required participants to indicate when the letter on the current trial was the same as that on the previous trial, the 2-back task required participants to indicate when the current letter was the same as the letter two trials ago, and the 3-back task required participants to indicate when the current letter matched the letter three trials previously. Consecutive blocks of 1-back, 2-back, and 3-back were presented. Each block (referred to as separate tasks) consisted of 48 trials, including 15 targets. Measures analyzed were hit rate, false-alarm rate, and discrimination. Hit rate was calculated as the proportion of target items correctly endorsed out of the total number of possible target items (expressed as a percentage). False-alarm rate was calculated as the proportion of nontarget items incorrectly endorsed as targets out of the total number of nontarget items (expressed as a percentage). Discrimination was calculated as hit rate minus the false-alarm rate, which is a more accurate reflection of how the participant performed than simple hit rate. For example, a participant who endorses every single item in the task would be 100% correct by hit rate alone, but would have a discrimination of 0.0 when false alarms are subtracted.

RESULTS AND DISCUSSION

Repetition errors on the SOPT

A Group (2; healthy older, single-domain aMCI) × Trial (3; SOPT Trial 1, Trial 2, and Trial 3) mixed analysis of variance (ANOVA) on repetition errors revealed a main effect of group, $F(1, 60) = 4.84$, $MSE = 3.28$, $p < .05$, $\eta_p^2 = .08$, a main effect of trial, $F(2, 120) = 3.99$, $MSE = 1.30$, $p < .05$, $\eta_p^2 = .06$, and a significant group by trial interaction, $F(2, 120) = 3.46$, $MSE = 1.30$, $p < .05$, $\eta_p^2 = .06$. Significant within-subjects linear contrasts were observed for both the main effect of trial, $F(1, 60) = 5.73$, $MSE = 1.10$, $p < .5$, $\eta_p^2 = .09$, and the group by trial interaction,[1] $F(1, 60) = 7.13$, $MSE = 1.10$, $p < .01$, $\eta_p^2 = .11$, demonstrating that participants with single-domain aMCI committed more errors than healthy older adults but this difference between groups became smaller across subsequent trials (Figure 1A). The pattern of results remained the same when education was examined as a covariate, and, although the main effects and interaction became marginally significant (see the Appendix), the within-subjects linear contrast for the group by trial interaction remained significant, $F(1, 59) = 5.60$, $MSE = 1.10$, $p < .05$, $\eta_p^2 = .09$. This indicates that the difference in errors between groups still showed a linear decrease across trials even after accounting for education.

Organization on the SOPT

As previously mentioned, one way to minimize errors on the SOPT is through employing an organizational strategy. Therefore, we computed chance-adjusted bidirectional pair frequency as a measure of subjective organization (Sternberg & Tulving, 1977), which assesses the extent to which participants selected the same two designs back-to-back, in either order on one trial and the next. These were analyzed in a Group (2; healthy older, single-domain aMCI) × Trial pair (2; SOPT Trials 1–2 and SOPT Trials 2–3) mixed ANOVA. This analysis revealed that subjective organization increased from Trials 1–2 to Trials 2–3, $F(1, 60) = 5.01$, $MSE = 1.06$, $p < .05$, $\eta_p^2 = .08$. There was no main effect of group, $F < 1$; however, there was a significant group by trial pair interaction, $F(1, 60) = 7.42$, $MSE = 1.06$, $p < .01$, $\eta_p^2 = .11$ (Figure 1B), such that participants with single-domain aMCI used less subjective organization than healthy older adults on Trials 1–2, but from Trials 2–3 the two groups used similar levels of subjective organization.[2] This pattern suggests that the single-domain aMCI group required longer to develop an organizational strategy than did healthy older adults, yet were able to do so eventually with practice. When education was included as a covariate in the analysis of subjective organization, the significant group by trial pair interaction remained, $F(1, 59) = 5.35$, $MSE = 1.03$, $p < .05$, $\eta_p^2 = .08$, while the main effect of trial pair became marginally significant, $F(1, 59) = 4.01$, $MSE = 1.03$, $p = .05$, $\eta_p^2 = .06$. There was still no main effect of group, $F < 1$.

The observation of diminished strategy use, initially, within the single-domain aMCI group aligns

[1]The significant linear within-subjects contrast observed for the trial by group interaction remained when gender and age were each analyzed as a covariate.

[2]The significant group by trail pair interaction remained when gender and age were each analyzed as a covariate.

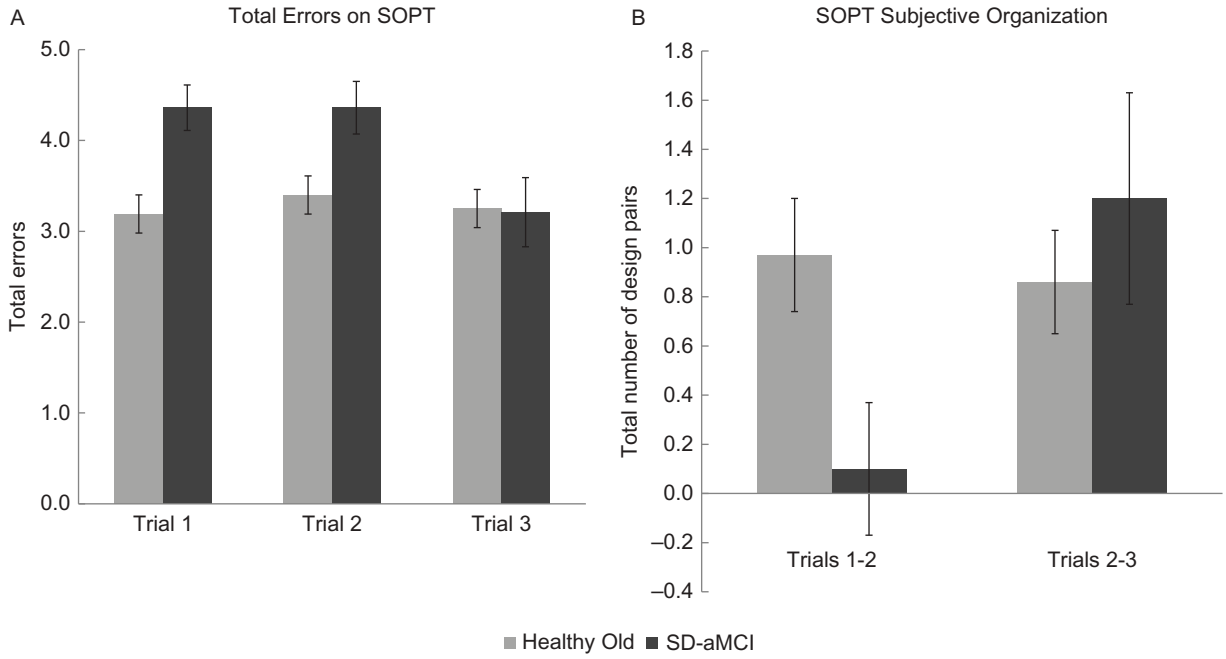

Figure 1. (A) Total repetition errors on the self-ordered pointing task (SOPT) as a function of group and trial. (B) Subjective organization on the SOPT as a function of group and trial pair. aMCI = amnestic mild cognitive impairment. Error bars represent standard errors.

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with previous studies that have examined a mixture of single-domain and multiple-domain aMCI participants and found decreased strategy use in the form of reduced semantic clustering on verbal list learning tasks (Bröder, Herwig, Teipel, & Fast, 2008; Perri, Carlesimo, Serra, Caltagirone, & The Early Diagnosis Group of the Italian Interdisciplinary Network on Alzheimer's Disease, 2005; Ribeiro, Guerreiro, & De Mendonça, 2007). Our results demonstrate that this reduced self-initiated strategy use may not simply be owed to inclusion of the multiple-domain aMCI individuals who often have greater executive impairment, but emerges in a single-domain aMCI group as well. However, our results also indicate that the single-domain aMCI participants were able to increase their strategy use with practice (over repeated trials). An interesting question that remains is why the healthy older adult group did not also show an increase in subjective organization across the three trials like the single-domain aMCI group. This pattern may relate to group differences in neurocognitive plasticity. It has been proposed that in the prodromal stages of dementia—before hypoactivation in neurocognitive networks occurs—there is a period of increased plasticity thought to reflect attempts at compensation (indicated by hyperactivation; Dickerson et al., 2005; Dickerson & Sperling, 2008). The observed improvement in SOPT subjective organization among our single-domain aMCI group, but not in the healthy control group, is in keeping with this prior work.

N-back discrimination

Discrimination (calculated as hits minus false alarms) was analyzed in a Group (2; healthy older, single-domain aMCI) × Task (3; 1-back, 2-back, 3-back) mixed ANOVA (Figure 2). We did not analyze *d*-prime values because false-alarm rates were .00 for many participants in the 1-back condition.

Discrimination was higher in the healthy group than in the single-domain aMCI group, $F(1, 60) = 4.10$, $MSE = .04$, $p < .05$, $\eta_p^2 = .06$, and performance decreased from 1-back to 3-back, $F(2, 120) = 121.08$, $MSE = .02$, $p < .001$, $\eta_p^2 = .67$. This decrease across n-back tasks had a significant linear component, $F(1, 60) = 224.46$, $MSE = .02$, $p < .001$, $\eta_p^2 = .79$, and a significant quadratic component, $F(1, 60) = 15.81$, $MSE = .02$, $p < .001$, $\eta_p^2 = .21$, such that there was a general decrease in discrimination from 1-back to 3-back, which levelled off from 2-back to 3-back (Figure 2). The main effects of group and task also interacted, $F(2, 120) = 4.01$, $MSE = .02$, $p < .05$, $\eta_p^2 = .06$, with group differences showing in the degree of linear trend across n-back tasks, $F(1, 60) = 5.60$, $MSE = .02$, $p < .05$, $\eta_p^2 = .09$, such that the greatest difference between groups was observed on the more

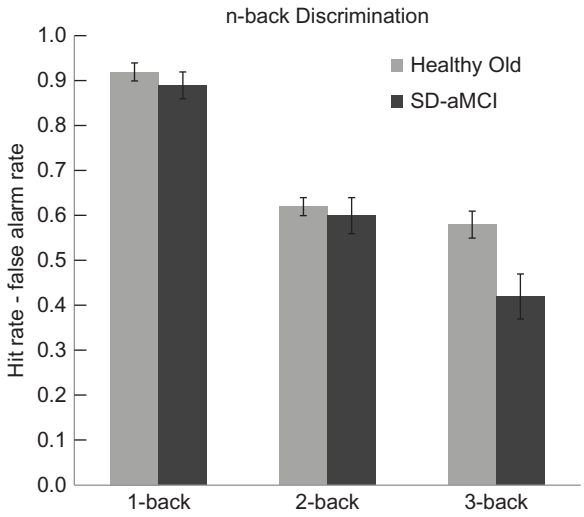

Figure 2. N-back discrimination as a function of group and task. aMCI = amnestic mild cognitive impairment. Error bars represent standard errors.

challenging 3-back task.[3] When education was included as a covariate, the main effect of n-back task, $F(2, 118) = 10.97$, $MSE = .02$, $p < .001$, $\eta_p^2 = .16$, and the interaction, $F(2, 118) = 3.58$, $MSE = .02$, $p < .05$, $\eta_p^2 = .06$, were maintained.

We also analyzed hit rates and false-alarm rates separately to determine the source of the reduced discrimination in the single-domain aMCI group during the 3-back task. Analysis of n-back hit rates in a Group (2; healthy older, single-domain aMCI) × Task (3; 1-back, 2-back, 3-back) mixed ANOVA did not reveal a main effect of group, $F < 1$, but did reveal a significant main effect of task, $F(2, 120) = 95.57$, $MSE = .01$, $p < .001$, $\eta_p^2 = .61$, and an interaction, $F(2, 124) = 8.52$, $MSE = .01$, $p < .001$, $\eta_p^2 = .12$, such that the groups did not differ in number of hits on the 1-back and 2-back, but did differ on the more challenging 3-back. When education was included as a covariate in these analyses, the main effect of task, $F(2, 118) = 8.36$, $MSE = .01$, $p < .001$, $\eta_p^2 = .12$, and the interaction, $F(2, 118) = 6.74$, $MSE = .01$, $p < .01$, $\eta_p^2 = .10$, remained.

Analysis of false-alarm rates revealed a marginally significant main effect of group, $F(1, 60) = 3.90$, $MSE = .02$, $p = .05$, $\eta_p^2 = .06$ (which became nonsignificant when education was included as a covariate, $F(1, 59) = 2.15$, $MSE = .01$, $p = .15$, $\eta_p^2 = .04$), and a significant main effect of task, $F(2, 120) = 33.85$, $MSE = .01$, $p < .001$, $\eta_p^2 = .36$ (which remained with education as a covariate, $F(2, 118) = 3.09$, $MSE = .01$, $p < .05$, $\eta_p^2 = .05$). There was no interaction. $F(2, 120) = 1.12$, $MSE = .01$, $p = .33$, $\eta_p^2 = .02$ (nor with the education covariate, $F < 1$, *ns*).

The significant interaction between group and n-back task for hit rate but not for false alarms suggests that participants with single-domain aMCI may have had particular difficulty with the monitoring aspect of the task in the 3-back condition, as evidenced by their inability to correctly endorse target items (Stuss & Alexander, 2007).

GENERAL DISCUSSION

In this study, we built upon prior research that has observed working memory difficulties in the aMCI cognitive profile by looking specifically at the single-domain amnestic clinical subtype (Petersen, 2004). This is an important next step in understanding the aMCI syndrome, as it has been unclear in the previous literature whether poorer working memory is owing to inclusion of people with the multiple-domain amnestic subtype where executive function deficits are common (Gagnon & Belleville, 2011; Johns et al., 2012). While our study is limited by a small sample size, we nonetheless found significant differences demonstrating that participants with single-domain aMCI show poorer performance on the first two trials of the SOPT and the 3-back task than did healthy controls. Analysis of strategy use (subjective organization) on the SOPT suggested that participants with single-domain aMCI required longer to implement an effective organizational strategy, although could do so given repeated trials, bolstering their ability to meet working memory demands. Our results demonstrate that poorer working memory performance is not restricted to the multiple-domain aMCI subtype but exists in the single-domain amnestic subtype relative to healthy older adults. These findings favor the viewpoint that single-domain aMCI may reflect an earlier stage of neurodegenerative progression where executive function inefficiencies are less pronounced, but detectible with sensitive measures, relative to a multiple-domain aMCI profile (Alexopoulos et al., 2006; Brambati et al., 2009; Tabert et al., 2006). Dynamic working memory measures appear to heavily tax executively mediated controlled processing, requiring the continuous processing of stimuli in addition to short-term storage. These types of working memory tasks may capture differences in performance that are overlooked by standardized span tasks typically used in neuropsychological batteries.

In addition to subtle changes in executive functioning, difficulty on these dynamic working memory tasks among individuals with single-domain aMCI

[3]The significant linear within-subjects contrast observed for the task by group interaction remained when gender and age were each analyzed as a covariate.

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could also, in part, relate to declines specifically in the basic process of forming and maintaining a mental representation. Emerging evidence suggests that medial temporal lobe structures—known to support long-term memory—may be critical for maintenance of novel, relational information that is not readily rehearsed, even if only for very brief intervals (Jonides et al., 2008; Rose et al., 2012). The use of novel, abstract designs on the SOPT is a good example of this. On the basis of theories that see mental representation and memory processes as continuous rather than segregated processes (Graham, Barense, & Lee, 2010; Lee, Yeung, & Barense, 2012), it is possible that deficits in long-term memory in the single-domain aMCI group may also be contributing to poor performance, particularly on the SOPT. Future studies are needed to further explore the role of mental representation in dynamic working memory performance.

In sum, the current investigation demonstrates that individuals with single-domain aMCI showed poorer performance on dynamic working memory tasks—the SOPT and n-back task—than do healthy older adults. These are weaknesses not captured by commonly used standardized neuropsychological measures—namely, backwards span tasks. Our findings suggest that dynamic working memory tasks requiring continuous processing and storage over numerous trials may be most sensitive to the subtle cognitive changes occurring in single-domain aMCI. These types of tasks may be ideal candidates for further development and standardization for the purpose of earlier identification of individuals likely to progress to dementia.

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APPENDIX

Analysis of covariance for repetition errors on the SOPT

Source	*df*	*Mean square*	*F*	*Significance*
	Between subjects			
Education	1	2.66	0.811	.371
Group	1	12.26	3.73	.058
Error	59	3.29		
	Within subjects			
SOPT trial	2	3.07	2.38	.097
SOPT Trial × Education	2	1.92	1.49	.231
SOPT Trial × Group	2	3.30	2.56	.082
Error	118	1.29		

Note. SOPT = self-ordered pointing task.

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