Original Research Article

Higher Working Memory Predicts Slower Functional Decline in Autopsy-Confirmed Alzheimer's Disease

Jagan A. Pillai^{a, b} Aaron Bonner-Jackson^b Esteban Walker^c
Lyla Mourany^b Jeffrey L. Cummings^{a, d}

^aDepartment of Neurology, ^bLou Ruvo Center for Brain Health, and ^cQuantitative Health Sciences, Cleveland Clinic, Cleveland, Ohio, and ^dLou Ruvo Center for Brain Health, Cleveland Clinic, Las Vegas, Nev., USA

Key Words

Alzheimer's disease · Dementia · Cognitive decline · Neuropsychology in dementia · Working memory · Rate of decline

Abstract

Background: There is heterogeneity in the pattern of early cognitive deficits in Alzheimer's disease (AD). However, whether the severity of initial cognitive deficits relates to different clinical trajectories of AD progression is unclear. **Objective:** To determine if deficits in specific cognitive domains at the initial visit relate to the rate of progression in clinical trajectories of AD dementia. **Methods:** 68 subjects from the National Alzheimer's Coordinating Center database who had autopsy-confirmed AD as the primary diagnosis and at least 3 serial assessments a year apart, with a Mini-Mental State Examination (MMSE) score >15 and a Clinical Dementia Rating Scale-Global (CDR-G) score ≤1 at the initial visit were included. A mixed regression model was used to examine the association between initial neuropsychological performance and rate of change on the MMSE and CDR Sum of Boxes. **Results:** Preservation of working memory, but not episodic memory, in the mild cognitive impairment and early dementia stages of AD relates to slower rate of functional decline. **Discussion:** These findings are relevant for estimating the rate of decline in AD clinical trials and in counseling patients and families. Improving working memory performance as a possible avenue to decrease the rate of functional decline in AD dementia warrants closer investigation.

© 2014 S. Karger AG, Basel

Jagan A. Pillai, MBBS, PhD
Lou Ruvo Center for Brain Health
Cleveland Clinic Lerner College of Medicine, Case Western Reserve University
9500 Euclid Ave/U10, Cleveland, OH 44195 (USA)
E-Mail pillaij@ccf.org

Introduction

There is significant variability in the rate of progression of clinical symptoms in Alzheimer's disease (AD) [1]. The progression of AD from diagnosis to death is approximately 10 years in most cases, although rapid progression is observed in others [2]. It is often difficult on an individual basis to predict which patients with mild cognitive impairment (MCI) or early dementia will decline faster, needing early additional supportive care. Identifying variables at the initial visit of a patient with MCI or early dementia that could be related to faster or slower clinical trajectories would be valuable for patient and family counseling and planning. This information could assist in exploring underlying biological factors relating to varying clinical trajectories and would help us develop therapies tailored for individual patients.

It is increasingly recognized that there is substantial heterogeneity among AD patients, with differences in age of onset, clinical and behavioral symptoms, principal brain regions of neuropathologic burden, and speed of clinical progression [3]. Some have noted that clinical features, such as age of onset, sex, duration of illness, and the presence or absence of extrapyramidal features, are associated with the time to progression as assessed by time to nursing home placement, decline in Mini-Mental State Examination (MMSE) score or death [3]. Others have noted that the initial stage of disease at the beginning of the observation period ('how far') is an important predictor of subsequent decline ('how fast') [3, 4]. Some staging measures fail to document linear decline over the course of AD, and both 'bilinear' and 'trilinear' models of decline have been proposed [5]. Predictive models of progression have been developed and validated for AD [6]. A large literature on AD also documents predictors of conversion from normal cognition to amnesic MCI and to AD dementia [7–11].

Multiple models [5, 6, 12, 13] and a meta-analysis of AD progression models [14] document clinical predictors of rates of decline. One longitudinal study of neuropsychological predictors of decline has noted that short-term memory deficits, temporospatial disorientation, and constructive apraxia predict more rapid dependency in AD patients [15]. Lower memory scores and executive dysfunction at baseline have been shown to predict greater likelihood of future decline [16, 17]. However, previous studies have a few limitations. Most studies predicting the rate of decline in AD do not have conclusive biomarkers or autopsy-confirmed diagnosis of AD pathology. This is a significant drawback, as the sensitivity and specificity of a probable and possible AD diagnosis without the aid of biomarkers was only between 70.9 and 87.3% for sensitivity and between 44.3 and 70.8% for specificity in one large analysis [18]. Further, when non-AD dementia was diagnosed, 39% of these individuals were found to have AD pathology at autopsy [18]. This adds significant error to previous analyses of rates of decline of AD without autopsy confirmation.

There is significant variability in initial symptoms among clinical variants of AD, and patients do not have the same degree of cognitive impairments across cognitive domains. The rate of clinical progression in terms of MMSE scores has been noted to be different between neuropathological subtypes of AD, with the fastest rate in hippocampal sparing AD and the slowest rate in limbic-predominant AD [19]. However, the highly verbal nature of the MMSE could overestimate AD severity in patients with predominant language deficits [20]. Performance in each of the cognitive domains is not independent and there is significant interaction among cognitive domains. For example, executive functioning is a mediator between other cognitive domains and daily functioning and may contribute to the rate of decline [21]. We therefore undertook an analysis of autopsy-confirmed AD dementia subjects in a large national database to investigate how clinical and neuropsychological markers at the initial visit in the MCI and early dementia stage of AD relate to the rate of cognitive and functional decline.

Table 1. Demographic characteristics

Variable	Patients, n	Mean	SD	Range
Age, years	67	73.8	9.6	47–94
Education, years	68	15.7	2.7	9–23
Female	42 (62%)			
MMSE score				
Initial	68	22.7	3.5	16–30
Final	56	11.6	5.6	0–22
CDR-G score				
Initial	68	0.8	0.2	5–1
Final	68	2.3	0.5	2–3
CDR-SB score				
Initial	68	4.7	2.3	5–9
Final	68	13.6	2.7	10–18
Follow-up, years	68	3.9	0.89	3–6
Braak stage	68			
3	1 (1%)			
4	7 (10%)			
5	32 (47%)			
6	28 (41%)			
APOE 4, n	68			
No APOE 4 allele	39 (57%)			
1 APOE 4 allele	22 (32%)			
2 APOE 4 alleles	7 (10%)			

Materials and Methods

The National Alzheimer's Coordinating Center (NACC) maintains a database of participant information collected from 34 past and present Alzheimer's Disease Centers funded by the National Institute on Aging. Data from the uniform data set maintained by the NACC between September 2005 and May 2012 were used for the present analysis. Details on data collection and curation are well documented [22]. The Clinical Dementia Rating Scale-Global (CDR-G) assesses the participant's current cognitive and functional status. The level of impairment in the domains or 'boxes' of memory, orientation, judgment and problem solving, community affairs, home and hobbies, and personal care are rated. The CDR-G ratings are calculated using a complex algorithm and range from 0 (no dementia) to 3 (severe dementia) [23]. All subjects included in the analysis had an initial CDR-G score of 0.5 or 1 and a final CDR-G score >1 meeting clinical criteria for a diagnosis of dementia. The primary diagnosis of AD dementia was confirmed by neuropathology analysis. The CDR Sum of Boxes (CDR-SB) is an operationalized measure of cognitive and functional ability. CDR-SB scores are calculated by simply adding the 'box scores', and range from 0 to 18 (higher scores indicate more impairment). The CDR-SB mean scores decline nearly linearly across different severities of AD in the 2-year Alzheimer's Disease Neuroimaging Initiative study [24]. CDR-SB provides a global assessment of cognitive and functional ability and is significantly associated with the severity of amyloid burden [25] and metabolic deficits in patients with AD [26]. All subjects also had a minimum score >15 on the MMSE [27] at the initial visit. The mean time from the last visit to death was 0.43 years (range 1–2 years). The subjects included in the analysis had a minimum of 3 longitudinal visits separated by 1 year. The presence of any behavioral symptom at the initial visit (delusions, hallucinations, agitation, depression or dysphoria, anxiety, elation or euphoria, apathy, irritability or lability and disinhibition: yes or no) was evaluated for its predictive role in future cognitive decline, in addition to each subject's Hachinski ischemic scores. Patient characteristics are described in table 1.

Neuropsychological Measures

A core battery of neuropsychological measures was administered to all participants at each visit [28]. All four cognitive domains documented in the uniform data set were evaluated: attention, executive functioning, language, and memory. Attention was assessed using the digit span subtest (digits forward) from the

Table 2. Neuropsychological characteristics at the initial visit

Test	Patients, n	Mean	SD	Range
Logical memory	68	4.8	3.4	0–16
Digit span – forward	68	6.9	2.2	2–12
Digit span – forward length	68	5.8	1.3	3–8
Digit span – backward	68	4.5	1.6	0–10
Digit span – backward length	68	3.5	1.1	0–7
Semantic fluency (animals)	68	11.6	5.1	2–29
Semantic fluency (vegetables)	68	7.3	3.8	0–20
Trail-Making Test – part A	68	74.4	40.0	23–150
Trail-Making Test – part B	49	219.3	85.6	54–300
Digit symbol coding	51	24.4	12.0	0–55
BNT	66	21.0	5.5	4–29

Wechsler Adult Intelligence Scale [29] and the Trail-Making Test part A [30]. Executive functioning was quantified using the Wechsler Adult Intelligence Scale digit span (digits backward) [29], Trail-Making Test part B, and the digit symbol coding subtest from the Wechsler Adult Intelligence Scale [29, 30]. Digits backward length (i.e., number of digits correctly repeated in reverse order) was also included as a variable of interest. Object naming was assessed using the 30-item version of the Boston Naming Test (BNT) [31]. The evaluation of memory included measures of verbal episodic memory (Wechsler Memory Scale, logical memory subtest) [29, 32] and semantic memory (animal names generated in 60 s) [33]. Table 2 notes the detailed neuropsychological characteristics of the subjects at the initial visit.

Statistical Analysis

A total of 158 subjects had a primary diagnosis of AD dementia confirmed by neuropathology. The flow chart for subject selection is shown in figure 1. The rationale for subject inclusion/exclusion criteria was to reduce the potential effect of the large variability of initial cognitive deficits on the rate of decline analysis. A total of 68 subjects were used for further analysis. Given the ordinal nature of APOE and Braak stage, they were included in the models as continuous variables. All the analyses were done with JMP Pro 10.0 (SAS Institute) and SAS 9.2 (SAS Institute).

Mixed models for repeated measurements were used to determine which measures were associated with rate of change of MMSE and CDR-SB after adjustment for demographic covariates. In each model, age, sex, education, and APOE 4 status were included as covariates and all the initial performance measures were added as possible predictors. For the Braak stage, a multivariate regression model was built using a mixed strategy of backward elimination and forward selection. Only terms with p values ≤ 0.05 were included (except for the covariates). In the final models, interactions between initial neuropsychological measures were explored and were not significant.

The role of age at diagnosis, duration of clinical follow-up, presence of initial behavioral symptoms, and Hachinski score at the first visit on the rate of decline of MMSE and CDR-SB scores was explored. Moreover, the role of final neuropathology burden, noted by the Braak stage, as an independent predictor of the rate of decline of the MMSE and CDR-SB scores was analyzed in a secondary analysis.

Results

Rate of Change of MMSE

Age at diagnosis ($\beta = 0.14$, $p = 0.0006$), initial MMSE score ($\beta = 0.37$, $p = 0.001$), initial digit span backward trial correct scores ($\beta = 0.67$, $p = 0.004$), and initial BNT scores ($\beta = 0.23$, $p = 0.007$) were all associated with a lower rate of decline of MMSE scores (table 3).

Fig. 1. Flow chart for AD sample selection for the present analysis from the NACC database.

Table 3. Mixed models (repeated measures) to predict MMSE and CDR-SB decline and multiple regression model for Braak stage

Baseline variable	MMSE ^a	CDR-SB ^a	Braak stage ^a
Age at diagnosis	0.14 (0.0006)	–0.008 (0.70)	–0.02 (0.01)
Education	–0.17 (0.19)	0.22 (0.004)	–0.043 (0.22)
Male gender	0.29 (0.70)	–0.02 (0.97)	0.09 (0.31)
APOE	0.56 (0.27)	–0.29 (0.32)	
Initial MMSE	0.37 (0.001)		
Digit backward trials correct score	0.67 (0.004)	–0.29 (0.03)	
BNT	0.23 (0.007)		
Initial CDR-SB		0.80 (<0.0001)	
Digit backward length			–0.15 (0.05)
First behavioral symptom		0.76 (0.059)	

^a β value with p value in parentheses. Interactions were explored and were nonsignificant.

Rate of Change of CDR-SB

Higher education ($\beta = 0.22$, $p = 0.004$) and initial CDR-SB score ($\beta = 0.80$, $p < 0.0001$) were associated with an increase in the rate of decline of CDR-SB scores. A higher amount of digit span backward trial correct scores ($\beta = -0.29$, $p = 0.03$) was related to a slower rate of decline of CDR-SB scores. The presence of a behavioral symptom at the initial visit ($\beta = 0.79$, $p = 0.059$) reached close to significance cutoff and was related to an increase in the rate of decline of CDR-SB scores (table 3).

In our supplementary analysis, longer duration of clinical follow-up was not related to slower rates of decline on the MMSE and CDR-SB ($p = 0.63$ and $p = 0.90$, respectively). We further noted that the initial Hachinski score was not related to the rate of decline on the MMSE and CDR-SB ($p = 0.81$ and $p = 0.92$, respectively). The Braak stage was not associated with the slope of MMSE or CDR-SB in a univariate model. In a regression model, age at diagnosis ($\beta = -0.02$, $p = 0.05$) and initial digit backward length ($\beta = -0.19$, $p = 0.02$) were associated with lower final Braak stage but not logical memory scores.

Discussion

In the current study, we found that the rate of cognitive and functional decline could be predicted based on baseline performance on measures of working memory and naming, along with initial behavioral symptoms and demographic factors, among subjects with autopsy-confirmed AD dementia in a longitudinal cohort. Notably, performance on the episodic memory measure did not predict the rate of decline of either MMSE or CDR-SB scores. The Braak stage at autopsy did not explain the rate of decline in MMSE or CDR-SB after accounting for age, sex, and education, further supporting the notion that additional factors (apart from neuropathology) contribute to longitudinal changes in AD dementia. Higher education and high initial digit backward performance were related to lower Braak stage at autopsy.

Perhaps our most clinically significant finding relates to the association between initial neuropsychological performance and longitudinal changes in global functional status (CDR-SB). Better initial performance on the digit span backward task was related to a slower rate of functional decline over time. This measure taps overlapping but distinctive cognitive skills,

including working memory, complex attention, and speed of information processing, and can be categorized as a measure of attention and executive functioning.

A large body of empirical work has found relationships between executive functioning and performance of instrumental activities of daily living in healthy older adults [34], as well as among individuals with MCI and mild AD [10, 16, 17, 35]. A very recent study found that performance on tasks requiring working memory and complex attention were related to real-world task performance [36]. Executive functioning has also been noted as a mediator between other cognitive domains and daily functioning [21] and is associated with a higher number of falls and gait speed slowing [37]. Others have posited that executive functioning explains at least 3 times as much variance in instrumental activities of daily living performance as memory [38]. This is relevant concerning our results, as we found no association between memory performance and CDR-SB change over time. As such, those with more intact executive and attentional skills at baseline may be able to more effectively compensate for memory impairment, at least temporarily. Deficits in attentional control and working memory are also increasingly recognized as early cognitive changes in the AD prodrome [39]. Alternatively, better function in these measures may be a marker of more robust cognitive reserve [40].

We also note significant associations between the performance on two measures (i.e., BNT and digits backward) and longitudinal changes in the MMSE score. The highly verbal nature of the MMSE has been noted to overestimate dementia severity in patients with primary language disorders [20], and MMSE scores correlate with BNT scores and baseline higher intellectual performance. Our results support this close correspondence. These results are consistent with the CDR-SB results in supporting the role for relative preservation of working memory skills at baseline to help compensate for cognitive decline, although it should be noted that the MMSE does not thoroughly assess executive functions.

Taken together, these results suggest that slower rate of decline in MMSE and global functioning are both related to relatively preserved frontal lobe functions of attention and working memory. Episodic memory impairment, though a hallmark of AD phenomenology, does not appear to influence the rate of decline of these measures. There are several potential explanations for this observation. Episodic memory could be uniformly impaired across all subjects and would, therefore, not significantly contribute to the model (i.e., floor effect). This was supported in our post hoc analysis, in which we found that the variance in episodic memory scores was lower than in other cognitive domains.

Multiple studies have assessed CSF biomarkers ($A\beta/\tau$) and MRI measures of hippocampal atrophy in predicting AD progression. Our analysis suggests that variations in cognitive profiles of patients, in addition to subject demographics, duration of symptoms, and early progression rate, impact later clinical measures of progression in AD dementia. This could be related to differences in the regional neuropathology burden and/or differences in biological factors underlying disease progression or due to specific test features of MMSE and CDR-SB in capturing some cognitive domains better than others, and need to be considered as measures that reflect clinical disease progression in AD.

Among the covariates there was a consistent influence of education on rates of decline in MMSE and CDR-SB. Although highly educated subjects often have a slower rate of decline prior to dementia, faster cognitive decline has been well described in the same subjects following dementia onset [41, 42]. Our results are consistent with this and may be attributed to effects of cognitive reserve [40]. Age at diagnosis was noted to have a discrepant influence, with higher age at diagnosis related to slower rate of decline of MMSE but not CDR-SB scores. One possible reason could be that medical comorbidities, including physical disability from illness, interval surgical interventions or uncontrolled vascular risk factors (e.g. diabetes), may influence global ability (and CDR scores) but could not completely be accounted for in our analysis.

Our results have important implications. Currently, the drug-versus-placebo arm comparisons in clinical trials evaluate cognitive function from the start of the study using MMSE to establish initial disease severity. As pre-progression rates and differing neuropsychological profiles of subjects lead to differences in rates of progression, accurate evaluation of the drug-versus-placebo effect might best be captured by more careful matching of subjects across both executive function and episodic memory deficits than is currently practiced. Further, some studies support the effectiveness and durability of the cognitive training interventions in improving targeted cognitive abilities in the elderly [43], but reports of transfer of benefits to other cognitive domains following cognitive training in the older population are few [44, 45]. Our results suggest that targeting working memory performance could be a fruitful avenue to improve functional task performance and slow the rate of progression to AD dementia and warrants further investigation.

Study limitations include the nature of our convenience sample with a potential bias in participant recruitment and in their agreeing on final autopsy confirmation of diagnosis. Requiring autopsy confirmation led to a smaller number of subjects in our analysis compared to previously published AD progression studies, although it adds to the strength of this analysis in that all the subjects have a definitive AD dementia diagnosis. All subjects included in the analysis had a minimum of 3 visits. When we estimate that the AD pathology progresses over almost two decades in dominantly inherited AD, a 3-year analysis of the rate of progression is limiting. This study therefore best captures the rate of decline among AD subjects with early dementia or MCI at the initial visit. The number of cognitive measures included in the study was also less than would be found in most standard neuropsychological batteries used for clinical evaluation of dementia, which may have limited our ability to detect other early cognitive predictors of decline. A detailed analysis of neuropsychological measures predicting conversion from MCI to dementia could not be undertaken in the present data set due to the smaller number of subjects in the MCI range at the initial visit (39.7%).

Previous staging measures have proposed a nonlinear decline in cognition over the course of AD [5, 41], but decline is often modeled to occur at a constant linear rate after the onset of dementia [41, 42]. The CDR-SB mean scores have been noted to decline nearly linearly across different severities of AD in the 2-year Alzheimer's Disease Neuroimaging Initiative study [24]. Our analysis therefore tracks clinical progression of AD only in stages of dementia and assumes a linear rate of decline. Future studies on a larger sample with a longer longitudinal follow-up are needed to confirm the present results.

Our results are best used to understand predictors of clinical deterioration and neuropsychological variables of interest at the time of first clinical visit in individuals with MCI or early dementia. Most sporadic AD patients are expected to meet a health care provider at this stage and are often in need for counseling as to what to expect regarding the rate of symptom progression. These findings are relevant to developing better cognitive markers for estimating the rate of clinical progression in prospective AD clinical trials and in counseling patients and families. Improving working memory performance as a possible avenue to decrease the rate of functional decline in AD dementia warrants closer investigation.

Acknowledgement

We thank the NACC publication review committee for their suggestions and comments. The NACC database is funded by NIA Grant U01 AG016976.

Disclosure Statement

Drs. Pillai, Bonner-Jackson, Walker and Ms. Mourany have no disclosures. Dr. Cummings has the following disclosures: consultation for pharmaceutical companies (Acadia, ADAMAS, Anavex, Avanir, Baxter, Boehringer-Ingelheim, Bristol-Myers Squibb, Eisai, EnVivo, Genentech, GlaxoSmithKline, Lilly, Lundbeck, Merck, Novartis, Orion, Otsuka, Pfizer, Prana, QR Pharma, Resverlogix, Roche, Sonexa, Suven, Takeda, and Toyoma pharmaceutical companies); consultation for assessment companies (GE Healthcare and MedAvante); stock (ADAMAS, Prana, Sonexa, MedAvante, Neurotrax, and Neurokos); other (Dr. Cummings owns the copyright of the Neuropsychiatric Inventory). Expert witness/legal consultation: Dr. Cummings has provided expert witness consultation regarding olanzapine and ropinerol.

References

- Cummings JL: Cognitive and behavioral heterogeneity in Alzheimer's disease: seeking the neurobiological basis. *Neurobiol Aging* 2000;21:845–861.
- Schmidt C, Wolff M, Weitz M, Bartlau T, Korth C, Zerr I: Rapidly progressive Alzheimer disease. *Arch Neurol* 2011;68:1124–1130.
- Drachman DA, O'Donnell BF, Lew RA, Swearer JM: The prognosis in Alzheimer's disease. 'How far' rather than 'how fast' best predicts the course. *Arch Neurol* 1990;47:851–856.
- Kraemer HC, Tinklenberg J, Yesavage JA: 'How far' vs 'how fast' in Alzheimer's disease. The question revisited. *Arch Neurol* 1994;51:275–279.
- Doody RS, Massman P, Dunn JK: A method for estimating progression rates in Alzheimer disease. *Arch Neurol* 2001;58:449–454.
- Doody RS, Pavlik V, Massman P, Rountree S, Darby E, Chan W: Predicting progression of Alzheimer's disease. *Alzheimers Res Ther* 2010;2:2.
- Chen P, Ratcliff G, Belle SH, Cauley JA, DeKosky ST, Ganguli M: Patterns of cognitive decline in presymptomatic Alzheimer disease: a prospective community study. *Arch Gen Psychiatry* 2001;58:853–858.
- Tabert MH, Manly JJ, Liu X, Pelton GH, Rosenblum S, Jacobs M, Zamora D, Goodkind M, Bell K, Stern Y, Devanand DP: Neuropsychological prediction of conversion to Alzheimer disease in patients with mild cognitive impairment. *Arch Gen Psychiatry* 2006;63:916–924.
- Fleisher AS, Sowell BB, Taylor C, Gamst AC, Petersen RC, Thal LJ: Alzheimer's Disease Cooperative Study: Clinical predictors of progression to Alzheimer disease in amnesic mild cognitive impairment. *Neurology* 2007;68:1588–1595.
- Blacker D, Lee H, Muzikansky A, Martin EC, Tanzi R, McArdle JJ, Moss M, Albert M: Neuropsychological measures in normal individuals that predict subsequent cognitive decline. *Arch Neurol* 2007;64:862–871.
- Ahmed S, Mitchell J, Arnold R, Nestor PJ, Hodges JR: Predicting rapid clinical progression in amnesic mild cognitive impairment. *Dement Geriatr Cogn Disord* 2008;25:170–177.
- Stallard E, Kinosian B, Zbrozek AS, Yashin AI, Glick HA, Stern Y: Estimation and validation of a multiattribute model of Alzheimer disease progression. *Med Decis Making* 2010;30:625–638.
- Ito K, Corrigan B, Zhao Q, French J, Miller R, Soares H, Katz E, Nicholas T, Billing B, Anziano R, Fullerton T: Alzheimer's Disease Neuroimaging Initiative: Disease progression model for cognitive deterioration from Alzheimer's Disease Neuroimaging Initiative database. *Alzheimers Dement* 2011;7:151–160.
- Ito K, Ahadiel S, Corrigan B, French J, Fullerton T, Tensfeldt T: Alzheimer's Disease Working Group: Disease progression meta-analysis model in Alzheimer's disease. *Alzheimers Dement* 2010;6:39–53.
- Sarazin M, Stern Y, Berr C, Riba A, Albert M, Brandt J, Dubois B: Neuropsychological predictors of dependency in patients with Alzheimer disease. *Neurology* 2005;64:1027–1031.
- Albert MS, Moss MB, Tanzi R, Jones K: Preclinical prediction of AD using neuropsychological tests. *J Int Neuropsychol Soc* 2001;7:631–639.
- Dickerson BC, Sperling RA, Hyman BT, Albert MS, Blacker D: Clinical prediction of Alzheimer disease dementia across the spectrum of mild cognitive impairment. *Arch Gen Psychiatry* 2007;64:1443–1250.
- Beach TG, Monsell SE, Phillips LE, Kukull W: Accuracy of the clinical diagnosis of Alzheimer disease at National Institute on Aging Alzheimer Disease Centers, 2005–2010. *J Neuropathol Exp Neurol* 2012;71:266–273.
- Murray ME, Graff-Radford NR, Ross OA, Petersen RC, Duara R, Dickson DW: Neuropathologically defined subtypes of Alzheimer's disease with distinct clinical characteristics: a retrospective study. *Lancet Neurol* 2011;10:785–796.
- Osher J, Wicklund A, Rademaker A, Johnson N, Weintraub S: The Mini-Mental State Examination in behavioral variant frontotemporal dementia and primary progressive aphasia. *Am J Alzheimers Dis Other Dement* 2007;22:468–473.
- O'Bryant SE, Falkowski J, Hobson V, Johnson L, Hall J, Schrimsher GW, Win O, Ngo B, Dentino A: Executive functioning mediates the link between other neuropsychological domains and daily functioning: a Project FRONTIER study. *Int Psychogeriatr* 2011;23:107–113.

- 22 Beekly DL, Ramos EM, Lee WW, Deitrich WD, Jacka ME, Wu J, Hubbard JL, Koepsell TD, Morris JC, Kukull WA; NIA Alzheimer's Disease Centers: The National Alzheimer's Coordinating Center (NACC) database: the Uniform Data Set. *Alzheimer Dis Assoc Disord* 2007;21:249–258.
- 23 Morris JC: The Clinical Dementia Rating (CDR): current version and scoring rules. *Neurology* 1993;43:2412–2414.
- 24 Hernandez C, Cedarbaum JM, Jaros M, Hernandez C, Coley N, Andrieu S, Grundman M, Vellas B; Alzheimer's Disease Neuroimaging Initiative: Rationale for use of the Clinical Dementia Rating Sum of Boxes as a primary outcome measure for Alzheimer's disease clinical trials. *Alzheimers Dement* 2013;9:S45–S55.
- 25 Doraiswamy PM, Sperling RA, Coleman RE, Johnson KA, Reiman EM, Davis MD, Grundman M, Sabbagh MN, Sadowsky CH, Fleisher AS, Carpenter A, Clark CM, Joshi AD, Mintun MA, Skovronsky DM, Pontecorvo MJ; AV45-A11 Study Group: Amyloid- β assessed by florbetapir F 18 PET and 18-month cognitive decline: a multi-center study. *Neurology* 2012;79:1636–1644.
- 26 Pernecky R, Hartmann J, Grimmer T, Drzezga A, Kurz A: Cerebral metabolic correlates of the clinical dementia rating scale in mild cognitive impairment. *J Geriatr Psychiatry Neurol* 2007;20:84–88.
- 27 Folstein MF, Folstein SE, McHugh PR: 'Mini-mental state': a practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res* 1975;12:189–198.
- 28 Weintraub S, Salmon D, Mercaldo N, Ferris S, Graff-Radford NR, Chui H, Cummings J, DeCarli C, Foster NL, Galasko D, Peskind E, Dietrich W, Beekly DL, Kukull WA, Morris JC, et al: The Alzheimer's Disease Centers' Uniform Data Set (UDS): the neuropsychologic test battery. *Alzheimer Dis Assoc Disord* 2009;23:91–101.
- 29 Wechsler D: The Wechsler Adult Intelligence Scale – Revised. San Antonio, The Psychological Corporation, 1981.
- 30 Army Individual Test Battery. Department of Health and Human Services. Washington, War Department, Adjutant General's Office, 1944.
- 31 Kaplan E, Goodglass H, Weintraub S: Boston Naming Test. Philadelphia, Lea & Febiger, 1983.
- 32 Wechsler D: Wechsler Memory Scale – Revised. San Antonio, The Psychological Corporation, 1987.
- 33 Strauss E, Sherman EMS, Spreen O: A Compendium of Neuropsychological Tests: Administration, Norms, and Commentary, ed 3. New York, Oxford University Press, 2006.
- 34 Vaughan L, Giovanello K: Executive function in daily life: age-related influences of executive processes on instrumental activities of daily living. *Psychol Aging* 2010;25:343–355.
- 35 Marshall GA, Rentz DM, Frey MT, Locascio JJ, Johnson KA, Sperling RA; Alzheimer's Disease Neuroimaging Initiative: Executive function and instrumental activities of daily living in mild cognitive impairment and Alzheimer's disease. *Alzheimers Dement* 2011;7:300–308.
- 36 Miloyan BH, Razani J, Larco A, Avila J, Chung J: Aspects of attention predict real-world task performance in Alzheimer's disease. *Appl Neuropsychol Adult*, in press.
- 37 Kearney FC, Harwood RH, Gladman JR, Lincoln N, Masud T: The relationship between executive function and falls and gait abnormalities in older adults: a systematic review. *Dement Geriatr Cogn Disord* 2013;36:20–35.
- 38 Royall DR, Lauterbach EC, Kaufer D, Malloy P, Coburn KL, Black KJ; Committee on Research of the American Neuropsychiatric Association: The cognitive correlates of functional status: a review from the Committee on Research of the American Neuropsychiatric Association. *J Neuropsychiatry Clin Neurosci* 2007;19:249–265.
- 39 Summers MJ, Saunders NLJ: Neuropsychological measures predict decline to Alzheimer's dementia from mild cognitive impairment. *Neuropsychology* 2012;26:498–508.
- 40 Stern Y: Cognitive reserve. *Neuropsychologia* 2009;47:2015–2028.
- 41 Hall CB, Derby C, LeValley A, Katz MJ, Verghese J, Lipton RB: Education delays accelerated decline on a memory test in persons who develop dementia. *Neurology* 2007;69:1657–1664.
- 42 Pillai JA, Hall CB, Dickson DW, Buschke H, Lipton RB, Verghese J: Association of crossword puzzle participation with memory decline in persons who develop dementia. *J Int Neuropsychol Soc* 2011;17:1006–1013.
- 43 Ball K, Berch DB, Helmers KF, Jobe JB, Leveck MD, Marsiske M, Morris JN, Rebok GW, Smith DM, Tennstedt SL, Unverzagt FW, Willis SL; Advanced Cognitive Training for Independent and Vital Elderly Study Group: Effects of cognitive training interventions with older adults: a randomized controlled trial. *JAMA* 2002;288:2271–2281.
- 44 Zelinski EM: Far transfer in cognitive training of older adults. *Restor Neurol Neurosci* 2009;27:455–471.
- 45 Anguera JA, Boccanfuso J, Rintoul JL, Al-Hashimi O, Faraji F, Janowich J, Kong E, Larraburo Y, Rolle C, Johnston E, Gazzaley A: Video game training enhances cognitive control in older adults. *Nature* 2013;501:97–101