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Cognitive Decline and Oral Health in Middle-aged Adults in the ARIC Study

ABSTRACT

Even before dementia becomes apparent, cognitive decline may contribute to deterioration in oral health. This cohort study of middle-aged adults evaluated associations of six-year change in cognitive function with oral health behaviors and conditions in the Atherosclerosis Risk in Communities (ARIC) study. Cognitive function was measured at study visits in 1990-1992 and 1996-1998 with three tests: (a) Delayed Word Recall (DWR), (b) Digit Symbol Substitution (DSS), and (c) Word Fluency (WF). Cognitive decline scores were computed as 'studentized' residuals of 1996-1998 scores regressed against 1990-1992 scores. In 1996-1998, 10,050 participants answered dental screening questions, and 5,878 of 8,782 dentate participants received a comprehensive oral examination. Multiple regression models used cognitive change to predict oral health behaviors and conditions with adjustment for covariates. In the fully adjusted models, greater decline in all three measures of cognitive function was associated with increased odds of complete tooth loss. Greater decline in DSS and WF scores was associated with infrequent toothbrushing. Decline in WF scores was also associated with higher plaque levels. In these middle-aged adults, six-year cognitive decline was modestly associated with less frequent toothbrushing, plaque deposit, and greater odds of edentulism, but not with other oral behaviors or diseases.

KEY WORDS: oral hygiene, tooth loss, periodontitis, cognition, executive function, memory.

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INTRODUCTION

Cognition refers to mental processes, including attention, memory, producing and understanding language, solving problems, and decision-making. Cognitive ability decreases with age (Drag and Bieliauskas, 2010), while low cognitive ability, even within a normal range, is predictive of adverse health outcomes (St John *et al.*, 2002; Pavlik *et al.*, 2003). We posit that perceptions and behaviors regarding oral health can be adversely affected if cognitive ability is impaired, and may be accompanied by potential harm to oral health.

Various neuropsychological tests have been used to measure cognitive ability in studies of cognition and oral health. In studies of people who had already developed cognitive impairment or dementia (Chalmers *et al.*, 2003, 2005; Avlund *et al.*, 2004; Yu and Kuo, 2008; Ellefsen *et al.*, 2009; Syrjälä *et al.*, 2012), participants had more dental caries, fewer teeth, and poorer periodontal health than adults without dementia. Poor oral health may be attributable to functional decline, poor oral hygiene care, and less use of dental services (Avlund *et al.*, 2004; Wu *et al.*, 2007). Ideally, interventions to prevent oral disease would begin prior to manifestation of cognitive impairment, when change in cognitive function could be assessed. However, little is known about middle-aged adults when cognitive decline is at an early stage, or about the effects of cognitive change on dental behaviors and oral health. A clearer understanding of this relationship at different points in the life span could advance our knowledge of biological and environmental determinants of worsening oral health.

We used data from the Atherosclerosis Risk in Communities (ARIC) study, wherein cognitive function was measured at two visits separated by six years, and oral health was evaluated at the latter visit. The aim was to evaluate associations between a six-year change in cognitive function and a wide range of oral health measures and behaviors. We hypothesized that initial signs of cognitive decline would be associated with a greater likelihood of unfavorable dental health behaviors, plaque accumulation, and gingivitis, but not with indicators of chronic oral diseases, such as periodontitis and tooth loss.

METHODS

Data and Participants

This study included a secondary analysis of data from the ARIC study. Details regarding study design and participant eligibility requirements have been reported previously (The ARIC Investigators, 1989; Cerhan *et al*., 1998). In brief, ARIC is a prospective, community-based study of vascular disease in a biracial cohort of middle-aged adults (45-64 yrs of age at inception) followed since 1987-1989 (examination 1). Participants were residents of four U.S. study sites: (a) Forsyth County, NC; (b) Minneapolis, MN; (c) Washington County, MD; and (d) Jackson, MS. The Dental ARIC, an ancillary study of the ARIC, was conducted from 1996-1998 (examination 4), when 11,375 participants answered dental screening questions. Of the 9,726 dentate respondents, 6,676 attended their local ARIC study center for a comprehensive oral examination.

Cognitive Function

Cognitive function assessment in the ARIC consisted of the Delayed Word Recall (DWR) Test, the Word Fluency (WF) Test, and the Digit Symbol Substitution (DSS) Test. The DWR is a test of verbal learning and recent memory (Knopman and Ryberg, 1989). The DSS measures executive function and processing speed (Wechsler, 1981). The WF is a test of executive function and expressive language (Benton *et al*., 1981). Cognitive tests were administered by trained examiners using standard protocols (Cerhan *et al.*, 1998).

Oral Health Measures

Outcomes of interest included: (a) complete tooth loss, (b) number of teeth, (c) periodontitis, (d) plaque deposits, (e) gingival inflammation, (f) oral hygiene care, and (g) dental utilization. Self-reported data about complete tooth loss were available for all dentally screened study participants. If participants had dental prostheses, they were asked when the prostheses were first used. For dentally examined people with no contraindications to periodontal probing, examiners recorded the number of teeth present and measured probing pocket depth and gingival recession at 6 sites for all teeth present. For each tooth, the examiners also assessed the extent of gingivitis and plaque deposits. During data analysis, the severity of periodontitis was classified as none/mild, moderate, or severe based on CDC/AAP case definitions (Page and Eke, 2007). Variables reflecting oral hygiene care and dental utilization were from dental interview questions among dentate participants (Appendix 1). Edentulous individuals were excluded from the analysis of oral health behaviors, because their patterns of oral hygiene care and dental visits differed substantially from those of dentate individuals (Appendix Table 4).

Covariates

Potential confounding variables were ARIC study sites, demographic variables, socio-economic status, and health history. Health status measures were comprised of diabetes mellitus, hypertension, stroke, coronary heart disease (CHD), smoking, and alcohol consumption (Appendix 1).

Data Analyses

The summary scores for change in cognitive function were computed from race- and gender-specific linear regression models that regressed examination 4 scores against examination 2 scores. The residual was divided by its standard error, creating a 'studentized' residual (hereafter labeled 'cognitive decline score') that was the main predictor variable (Appendix Fig. 1).

Four multiple regression models were created to evaluate each oral health outcome: (a) model 1, adjusted for age, gender, and race-center; (b) model 2, adjusted for model 1 covariates and education; (c) model 3, adjusted for model 2 covariates, smoking, and alcohol use; and (d) model 4, adjusted for model 3 covariates and medical history. Income was not used as a covariate because it was correlated with education, producing variance inflation greater than 10. Appropriate regression methods were used according to the scale of the following dependent variables: (a) logistic regression for binary outcomes (*e.g.*, severe periodontitis *vs*. moderate/none); (b) multinomial logistic regression for categorical outcomes (*e.g.*, toothbrushing); and (c) linear regression for continuous outcomes (*e.g.*, number of teeth). The final sample included participants who completed cognitive function assessments during Examinations 2 and 4 as well as a dental screening (n = 10,050) or an additional periodontal examination (n = 5,878) (Appendix Fig. 2).

Review by the IRB determined that this study was limited to secondary data analysis of de-identified data. The manuscript was prepared in accordance with the STROBE statement.

RESULTS

At examination 2, about 90% of participants were aged 46-65 yrs, with 44.5% males and 81.5% whites. Overall, African Americans had poorer socio-economic status, general and oral health status, and worse dental behaviors when compared with whites. African American participants also had a higher prevalence of complete tooth loss (18.2% *vs*. 11.3%), fewer teeth, poorer oral hygiene care, and fewer dental visits. About one-third of African Americans, compared with 80% of whites, visited dentists on a regular basis (Table 1). Most participants with no teeth (98%) and approximately half (46%) of dentate participants had dentures (Appendix Table 5).

Change in cognitive function over the course of 6 yrs was small for all tests. In general, older participants with low education, low income, and more medical co-morbidities had greater cognitive decline (Appendix Tables 2, 3).

A one-unit increase in all three cognitive decline scores was associated with fewer teeth and greater odds of complete tooth loss. However, in the fully adjusted models, the association between cognitive decline and the number of teeth was not evident (Table 2). The greater decline in DSS was associated with not brushing the teeth and gingivitis, but only the association with not brushing teeth remained robust after adjustment for all covariates. The greater decline in the WF was associated with infrequent toothbrushing and higher plaque deposits in both the

Table 1. Race- and Gender-specific Characteristics of Study Participants at ARIC Examination 2

	African American		White		
Characteristics	Female n = 1,214	Male n = 647	Female n = 4,368	Male n = 3,821	All n = 10,050
Age at examination 2, mean ± SD	55.6 ± 5.6	55.7 ± 5.7	56.7 ± 5.6	57.5 ± 5.7	56.8 ± 5.7
Study sites,%					
Forsyth	12.4	12.1	28.8	28.7	25.7
Jackson	87.6	87.9	0	0	16.3
Minneapolis	0	0	36.7	37.4	30.1
Washington	0	0	34.5	33.9	27.9
Education,%					
Basic	30.6	30.0	13.2	14.5	16.9
Intermediate	32.0	29.7	51.5	39.7	43.2
Advanced	37.4	40.3	35.3	45.8	39.9
Income,%					
< $25,000	62.8	43.4	27.9	17.6	29.3
$25,000 < $50,000	23.6	27.8	37.5	38.0	35.4
$50,000 or more	11.3	25.0	32.5	42.3	33.2
Refused to provide	2.3	2.8	2.1	2.1	2.2
Cigarette use,%					
Current	18.5	29.1	18.4	18.3	19.1
Former	23.2	41.7	30.5	53.3	39.0
Never	58.3	29.2	51.1	28.3	41.9
Alcohol use,%					
Current	25.7	49.9	62.0	70.1	59.9
Former	27.5	34.2	13.2	19.6	18.7
Never	46.8	15.9	24.8	10.3	21.4
Diabetes mellitus,%	22.2	19.0	8.6	12.5	12.4
Hypertension,%	53.4	45.6	26.3	30.1	32.3
Coronary heart disease,%	2.5	4.9	1.7	8.4	4.6
Stroke,%	1.6	1.7	0.9	1.3	1.2
Oral health conditions and behaviors					
Edentulous,%	20.8	13.3	10.4	12.4	12.6
Number of teeth[1], mean ± SD	17.1 ± 7.5	18.1 ± 7.9	23.0 ± 6.4	22.7 ± 6.8	22.0 ± 7.1
Extent of plaque deposits[1,2], mean ± SD	66.6 ± 44.8	79.4 ± 36.9	28.0 ± 30.7	42.3 ± 34.2	41.1 ± 37.6
Extent of gingival inflammation[3], mean ± SD	79.6 ± 36.6	86.8 ± 30.4	17.3 ± 27.5	25.7 ± 33.1	32.2 ± 39.1
Severe periodontal disease[1],%	13.2	34.5	10.5	21.5	16.7
Brushing[4],%					
Not at all	1.5	2.7	0.4	2.7	1.6
Once a day	25.0	42.2	18.0	38.3	28.1
Twice a day or more	73.5	55.1	81.6	59.0	70.3
Flossing[4],%					
Not at all	44.2	61.8	21.9	44.2	35.4
Once a week	8.3	8.9	6.7	9.9	8.3
Twice a week or more	47.5	29.2	71.4	45.9	56.3
Last time visited a dentist[4],%					
> 36 mos	24.2	25.7	4.8	7.3	9.2
12-36 mos	26.3	24.6	8.5	11.7	12.7
< 12 mos	49.5	49.7	86.7	81.0	78.1
Reasons to visit a dentist [4],%					
Do not visit a dentist	3.8	3.9	0.6	0.5	1.1
When problems occur	59.7	64.7	13.5	22.4	25.2
A regular basis	36.5	31.4	85.9	77.1	73.7
Change in cognitive scores					
Delayed word recall, mean ± SD	–0.2 ± 1.7	–0.3 ± 1.7	–0.1 ± 1.5	–0.2 ± 1.5	–0.1 ± 1.5
Digit symbol substitution, mean ± SD	–2.3 ± 9.1	–1.4 ± 8.1	–2.8 ± 6.8	–2.7 ± 6.1	–2.6 ± 7.0
Word fluency, mean ± SD	–0.7 ± 8.3	–1.8 ± 8.5	–0.1 ± 7.8	–0.8 ± 7.9	–0.6 ± 8.0

n, total number in study group; SD, standard deviation.
[1]Of dentate participants, 5,878 completed periodontal examinations.
[2]Extent of plaque deposits was a percentage of buccal surfaces with visible plaque.
[3]Extent of gingival inflammation was available for 5,638 participants, calculated as a percentage of teeth with Löe & Silness Gingival Index (GI) score ≥ 1.
[4]Only dentate participants (n = 8,782).

Table 2. Association between a Six-year Cognitive Decline[1] and Oral Health Conditions

	β (upper, lower 95% CI)			OR (upper, lower 95% CI)	
Cognitive Function	Mean Number of Remaining Teeth n = 5,878	Extent of Dental Plaque[2] n = 5,878	Extent of Gingival Inflammation[3] n = 5,638	Severe Periodontitis[4] n = 5,878	Complete Tooth Loss[5] n = 10,050
Delayed word recall					
Model 1[6]	–0.20 (–0.37, –0.02)	0.97 (0.13, 1.81)	0.29 (–0.47, 1.06)	1.01 (0.94, 1.09)	1.19 (1.12, 1.26)
Model 2[7]	–0.12 (–0.29, 0.05)	0.71 (–0.13, 1.54)	0.12 (–0.63, 0.88)	1.00 (0.93, 1.08)	1.13 (1.07, 1.21)
Model 3[8]	–0.08 (–0.25, 0.09)	0.64 (–0.19, 1.47)	0.09 (–0.67, 0.85)	0.99 (0.92, 1.07)	1.12 (1.05, 1.19)
Model 4[9]	–0.07 (–0.24, 0.10)	0.54 (–0.28, 1.37)	0.03 (–0.73, 0.78)	0.99 (0.92, 1.06)	1.11 (1.04, 1.18)
Digit symbol substitution					
Model 1[6]	–0.35 (–0.53, –0.17)	1.50 (0.65, 2.35)	1.22 (0.45, 1.99)	1.08 (1.01, 1.17)	1.17 (1.11, 1.25)
Model 2[7]	–0.24 (–0.42, –0.07)	1.15 (0.30, 1.99)	1.01 (0.24, 1.78)	1.07 (0.99, 1.15)	1.12 (1.05, 1.19)
Model 3[8]	–0.18 (–0.35, –0.01)	0.96 (0.12, 1.79)	0.91 (0.14, 1.68)	1.06 (0.98, 1.14)	1.10 (1.03, 1.06)
Model 4[9]	–0.16 (–0.33, 0.01)	0.76 (–0.08, 1.59)	0.76 (–0.01, 1.53)	1.05 (0.97, 1.13)	1.08 (1.01, 1.15)
Word fluency					
Model 1[6]	–0.27 (–0.44, –0.10)	1.64 (0.82, 2.46)	0.66 (–0.09, 1.41)	1.00 (0.93, 1.07)	1.21 (1.13, 1.28)
Model 2[7]	–0.13 (–0.29, 0.04)	1.19 (0.37, 2.00)	0.37 (–0.38, 1.12)	0.98 (0.91, 1.05)	1.12 (1.05, 1.20)
Model 3[8]	–0.12 (–0.29, 0.04)	1.09 (0.28, 1.90)	0.32 (–0.42, 1.07)	0.98 (0.91, 1.05)	1.12 (1.05, 1.20)
Model 4[9]	–0.11 (–0.27, 0.05)	0.97 (0.16, 1.77)	0.24 (–0.51, 0.98)	0.98 (0.91, 1.05)	1.10 (1.03, 1.18)

OR, Odds ratios; CI, confidence interval; β, regression coefficient.
[1]A six-year change in cognitive scores was expressed as race- and gender-specific 'studentized' residuals.
[2]Extent of plaque deposits was a percentage of buccal surfaces with visible plaque.
[3]Extent of gingival inflammation was a percentage of teeth with Löe & Silness Gingival Index (GI) score ≥ 1.
[4]OR and 95% CI from binary logistic regression models estimated the associations between cognitive decline, and odds of severe periodontitis *vs.* none/mild/moderate periodontitis [The Centers for Disease Control and Prevention/The American Academy of Periodontology (CDC/AAP) classification].
[5]OR and 95% CI from binary logistic regression models estimated the associations between cognitive decline, and odds of complete tooth loss *vs.* dentate.
[6]Adjusting for age, gender, and race-center.
[7]Adjusting for covariates in model 1 and education.
[8]Adjusting for covariates in model 2, cigarette use, and alcohol use.
[9]Adjusting for covariates in model 3 and health history.

unadjusted and adjusted models (Tables 2, 3). Even when associations were statistically significant, odds ratios were no greater than 1.3. We did not observe a statistically significant effect of cognitive decline scores on periodontitis, dental visits, and the use of dental floss (Tables 2-4).

DISCUSSION

In these middle-aged adults, declines in two cognitive measures were modestly associated with lack of toothbrushing, but not with other dental behaviors or clinical gingivitis or periodontitis. Cognitive decline in all tests was associated with greater levels of tooth loss. Associations with tooth loss were attributable, in part, to confounding effects of education and general health status, which tended to be poorer in people who experienced cognitive decline. The result regarding toothbrushing is consistent with the study hypothesis, although it was not corroborated by the findings regarding gingivitis or dental plaque for DSS. The observed association with tooth loss was counter to expectations and suggests instead that this indicator of treatment for past dental disease may be a marker of elevated risk for cognitive decline.

One limitation of this study was the absence of oral health measures at baseline, which meant that changes in cognition could be related only to oral health at follow-up instead of changes in oral health between baseline and follow-up. If cognition truly affects oral health, and if change in cognition is associated with the level of cognition at baseline, then we would expect baseline levels of oral health to differ according to levels of change in cognition. If that were the case, observed associations between changes in cognition and levels of oral health at follow-up might simply reflect poorer oral health at baseline for people who subsequently experienced a decline in cognition. To avoid this problem, we computed the change in cognition using residuals, which meant that the change in cognition was not related to baseline levels of cognition.

Self-reported behaviors probably become less reliable in people who experience cognitive decline. People who report infrequent toothbrushing might simply have forgotten that they truly did brush their teeth. Maybe this is why we observed an effect of cognitive decline on reported toothbrushing, but not on plaque or gingivitis. An effect between cognitive decline and dental flossing was not observed, but this may be explained by a 'floor effect', meaning that, although people are cognitively intact, they are less likely to floss their teeth routinely. Therefore, a relatively small change in cognitive function cannot make a difference in the frequency of flossing. For dental visits and periodontitis, the non-significant associations may be partly due

Table 3. Association between a Six-year Change in Cognitive Decline[1] and Oral Hygiene Care

	OR (upper, lower 95% CI)			
	Toothbrushing[2] (n = 8,782)		Dental Flossing[3] (n = 8,782)	
Cognitive Function	No brushing	Brushing once a day	No flossing	Flossing once a week
Delayed word recall				
Model 1[4]	1.00 (0.84, 1.19)	1.08 (1.02, 1.13)	1.07 (1.02, 1.13)	1.03 (0.95, 1.12)
Model 2[5]	0.96 (0.80, 1.15)	1.06 (1.01, 1.11)	1.05 (1.00, 1.11)	1.03 (0.95, 1.11)
Model 3[6]	0.96 (0.80, 1.15)	1.06 (1.00, 1.11)	1.05 (1.00, 1.10)	1.03 (0.95, 1.12)
Model 4[7]	0.95 (0.78, 1.13)	1.06 (1.00, 1.11)	1.04 (0.99, 1.09)	1.03 (0.95, 1.12)
Digit symbol substitution				
Model 1[4]	1.33 (1.14, 1.56)	1.02 (0.97, 1.07)	1.04 (1.00, 1.10)	1.05 (0.97, 1.14)
Model 2[5]	1.31 (1.11, 1.55)	1.00 (0.95, 1.05)	1.02 (0.96, 1.07)	1.04 (0.96, 1.13)
Model 3[6]	1.31 (1.11, 1.55)	1.00 (0.95, 1.05)	1.01 (0.96, 1.06)	1.04 (0.96, 1.13)
Model 4[7]	1.29 (1.08, 1.53)	0.99 (0.94, 1.04)	1.01 (0.96, 1.06)	1.04 (0.96, 1.13)
Word fluency				
Model 1[4]	1.31 (1.10, 1.55)	1.09 (1.04, 1.14)	1.08 (1.03, 1.13)	1.07 (0.99, 1.16)
Model 2[5]	1.23 (1.02, 1.47)	1.06 (1.01, 1.11)	1.04 (0.99, 1.09)	1.06 (0.98, 1.14)
Model 3[6]	1.22 (1.02, 1.46)	1.06 (1.01, 1.11)	1.04 (0.99, 1.09)	1.05 (0.97, 1.14)
Model 4[7]	1.21 (1.01, 1.45)	1.06 (1.01, 1.11)	1.03 (0.99, 1.08)	1.05 (0.97, 1.14)

OR, Odds ratios; CI, confidence interval.
[1]A six-year change in cognitive scores was expressed as race- and gender-specific 'studentized' residuals.
[2]OR and 95% CI from multinomial logistic regression models estimated the associations between cognitive decline, and odds of no toothbrushing and brushing once *per* day *vs.* brushing twice *per* day.
[3]OR and 95% CI from multinomial logistic regression models estimated the associations between cognitive decline, and odds of no flossing and flossing once *per* week *vs.* brushing twice *per* week.
[4]Adjusting for age, gender, and race-center.
[5]Adjusting for covariates in model 1 and education.
[6]Adjusting for covariates in model 2, cigarette use, and alcohol use.
[7]Adjusting for covariates in model 3 and health history.

to a threshold effect, whereby oral health measures will be affected only when there are very large reductions in cognition.

The decline in executive function as measured by DSS and WF was associated with infrequent toothbrushing. These findings add to the body of knowledge regarding the contributions of the early stages of cognitive decline to oral health. Unlike in older adults with severely impaired cognition, failure to perform routine oral hygiene care in middle-aged adults is less likely to be attributable to functional impairment (Chalmers *et al.*, 2003, 2005; Yu and Kuo, 2008; Ellefsen *et al.*, 2009; Syrjälä *et al.*, 2012). Instead, non-compliance with routine oral hygiene care may be an initial sign of altered cognitive processes (*e.g.*, planning, reasoning, initiation, or decision-making). Associations between impaired executive function and greater risks of adverse health outcomes (Pavlik *et al.*, 2003; Rosano *et al.*, 2008), health behaviors (Dong *et al.*, 2010) and oral health (Stewart *et al.*, 2008; Yu and Kuo, 2008) have also been shown.

The effect sizes observed in this study are modest. For example, never brushing the teeth was reported as only 1.6% (n = 137), and, thus, the observed odds ratio of 1.3 is equivalent to a net increase of 0.45%, which is associated with one unit (*i.e.*, one standard deviation) of the cognitive decline scores (Appendix 2). Although executive functioning is a high-order cognitive skill that controls goal-directed behaviors (Drag and Bieliauskas, 2010), it is only one factor contributing to successful oral health care. Other factors, such as lifestyle or personality, may also be important. The effect of cognitive decline on self-neglect behavior and deteriorating oral health may become more apparent after a longer follow-up period.

Interpretations of the study results should be made with caution due to the possibility of reverse causation that arises because several study measurements are permanent markers of oral disease history (*e.g.*, tooth loss and attachment level) and baseline oral health status was not available, as mentioned previously. Dentate participants who received periodontal examinations were more likely to be healthier and to have better cognitive ability than those who did not, which could lead to underestimation of the association between cognitive decline and periodontitis (Appendix Table 6). Further, despite the extensive characterization of this cohort, uncontrolled confounding cannot be ruled out.

Previous studies among the elderly have raised the issue of bidirectional associations between poor oral health and impaired cognition (Stewart and Hirani, 2007; Starr *et al.*, 2008; Stewart *et al*., 2008; Kaye *et al.*, 2010; Batty *et al*., 2011). That is, periodontitis and tooth loss may be not only consequences of cognitive impairment, but also risk factors for cognitive impairment. In the present study, most edentulous participants tended to lose many teeth early in life (*i.e.*, they received their first false teeth at an average age of 36.2 yrs), which was about 20 yrs before the first cognitive assessment (average age of 58.3 yrs). The observed association with cognitive decline likely supports the hypothesis that tooth loss in early life is a risk indicator for

Table 4. Association between a Six-year Cognitive Decline[1] and Dental Utilization

	OR (upper, lower 95% CI)			
	Last Dental Visit[2] (n = 8,782)		Reasons to Visit a Dentist[3] (n = 8,782)	
Cognitive Function	>36 mos	12- < 36 mos	Do not visit a dentist	When problems occur
Delayed word recall				
Model 1[4]	1.07 (0.99, 1.16)	1.04 (0.98, 1.12)	1.13 (0.92, 1.39)	1.11 (1.05, 1.17)
Model 2[5]	1.03 (0.95, 1.11)	1.02 (0.96, 1.09)	1.09 (0.88, 1.34)	1.07 (1.01, 1.13)
Model 3[6]	1.02 (0.94, 1.11)	1.02 (0.95, 1.09)	1.08 (0.87, 1.33)	1.06 (1.01, 1.13)
Model 4[7]	1.01 (0.93, 1.09)	1.01 (0.94, 1.08)	1.05 (0.85, 1.30)	1.05 (0.99, 1.11)
Digit symbol substitution				
Model 1[4]	1.06 (0.98, 1.14)	1.06 (0.99, 1.14)	1.21 (0.99, 1.48)	1.12 (1.06, 1.18)
Model 2[5]	1.01 (0.93, 1.09)	1.04 (0.97, 1.11)	1.14 (0.93, 1.41)	1.08 (1.02, 1.14)
Model 3[6]	1.00 (0.92, 1.08)	1.03 (0.96, 1.10)	1.13 (0.92, 1.40)	1.06 (1.01, 1.13)
Model 4[7]	0.97 (0.89, 1.06)	1.01 (0.94, 1.08)	1.09 (0.88, 1.34)	1.04 (0.98, 1.10)
Word fluency				
Model 1[4]	1.10 (1.02, 1.18)	1.05 (0.98, 1.12)	1.23 (1.01, 1.50)	1.11 (1.05, 1.17)
Model 2[5]	1.03 (0.95, 1.11)	1.01 (0.95, 1.08)	1.15 (0.93, 1.41)	1.05 (0.99, 1.11)
Model 3[6]	1.02 (0.94, 1.10)	1.01 (0.95, 1.08)	1.15 (0.93, 1.41)	1.05 (0.99, 1.10)
Model 4[7]	1.00 (0.92, 1.08)	0.99 (0.93, 1.06)	1.10 (0.89, 1.36)	1.02 (0.97, 1.08)

OR, Odds ratios; CI, confidence interval.
[1]A six-year change in cognitive scores was expressed as race- and gender-specific 'studentized' residuals.
[2]OR and 95% CI from multinomial logistic regression models estimated the associations between cognitive decline, and odds of last dental visit > 36 mos and 12- < 36 mos *vs.* < 12 mos.
[3]OR and 95% CI from multinomial logistic regression models estimated the associations between cognitive decline, and odds of not visiting a dentist and visiting a dentist only when problems occur *vs.* visiting a dentist on a regular basis.
[4]Adjusting for age, gender, and race-center.
[5]Adjusting for covariates in model 1 and education.
[6]Adjusting for covariates in model 2, cigarette use, and alcohol use.
[7]Adjusting for covariates in model 3, and health history.

cognitive decline in later life, which has been explained by mechanisms involving inflammatory load in early life (Gatz *et al*., 2006), malnutrition (Kim *et al*., 2007), and loss of neuro-sensory function in the animal model (Onozuka *et al*., 1999). An alternative interpretation derives from the observation that poor oral health and cognitive decline share common risk factors, such as cardiovascular diseases and low socio-economic status (Singh-Manoux *et al*., 2008; Matthews *et al*., 2011; Xu and Lu, 2011). It has been proposed that low socio-economic status in adulthood associated with poor oral health at an older age may reflect low cognitive ability in childhood (Sabbah *et al*., 2009).

It is difficult to compare these results regarding change in cognitive function with results from studies that measured cognitive function at one time (Stewart *et al.*, 2008; Sabbah *et al.*, 2009; Matthews *et al.*, 2011). There is also a lack of uniformity in cognition domains measured, instruments used, or handling of cognitive scores for statistical analysis. Our results cannot be extrapolated to the U.S population, since study participants were recruited from only four areas in the United States. Strengths of this study include the large sample of community-dwelling middle-aged adults, repeated assessments of cognitive function, and comprehensive examination of periodontal health (*i.e*., full-mouth examination).

Despite the intuitive plausibility of a relationship between cognitive decline and oral health, no study has examined this relationship in an adult population without dementia. These findings shed new light on this likely complex relationship. Specifically, we show that even small reductions in cognitive function were associated modestly with some oral health behaviors, although not with periodontal disease. However, we caution that the association might not be causal, and other relationships might represent reverse-causation: Similar levels of cognitive decline were associated with greater odds of edentulism, a condition that usually occurred decades before the cognitive decline measured here.

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