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Health and Disability

Natural teeth and cognitive function in humans

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A number of neurobiological, psychological and social factors may account for cognitive impairment. In animal studies a relation between dental status and cognitive performance has been found. It is unclear whether such a relation exists for humans. In a first step we compared the performance of 1,351 participants (53% women, 47% men; age $M = 54.0$) with natural teeth to 487 edentulous participants (59% women, 41% men; age $M = 71.3$) on 12 cognitive tests. The natural teeth group had a lower mean age, fewer women, more years of education, higher mini-mental state (MMSE), and performed significantly higher on several cognitive tests. In a subsequent analysis, the cognitive performance of a subset of the participants (50–85 years) was examined. In this analysis, 211 had natural dentition and 188 were edentulous. The groups were matched for gender, age, social variables, diseases, stress and MMSE. The cognitive disadvantage of the edentulous group was still apparent. The results suggest that functional natural teeth relate to relatively preserved cognitive functioning in older age.

Key words: Cognition, edentulous, humans, memory, natural teeth.

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INTRODUCTION

Normal aging is associated with impairment of cognitive functions such as memory and attention (Nilsson *et al.*, 1997). A number of neurobiological, psychological, and social factors may contribute to these age-related cognitive impairments (Bäckman, Small & Wahlin, 2001; Gerstorf, Herlitz & Smith, 2006). Rowe and Kahn (1987) have stressed that the effects of aging itself tend to be exaggerated, and the modifying effects of diet, exercise, personal habits and psychosocial factors are underestimated. They also conclude that social network factors such as having close friends are important in health and well-being. Some of the most important factors predictive of cognitive impairment are health, interest in intellectual and physical activities, and remaining active in the society. Sex differences in cognition have also been found, and women seem to have better declarative memory than men (Maitland *et al.*, 2004). Of particular interest is the number of years in formal education which has been regarded as a proxy for socioeconomic status (Nilsson *et al.*, 1997; Holmgren, Molander & Nilsson, 2006).

Social and economic variables have also been strongly associated with dental status. Österberg *et al.* (1998) reported that individuals with low income and education visited the dentist less frequently, and Marcus *et al.* (1996) reported low socioeconomic status and old age to be important risk factors for total tooth loss. Despite similar results in other studies (Hugosson *et al.*, 1995; Ahlqvist *et al.*, 1999) dental status has received minimal attention in the context of aging and cognition. This is a noteworthy omission since many older adults suffer from poor oral health, such as a large number of missing teeth (Kiyak, 2000).

The results from animal studies support a relation between dental status and cognition (Kubota *et al.*, 1988; Kato *et al.*, 1997; Onozuka *et al.*, 1999, 2000, 2002; Watanabe *et al.*, 2001, 2002). Studies in humans have shown that chewing increased the blood flow in widespread regions of the brain (Momose *et al.*, 1997; Sesay *et al.*, 2000; Onozuka *et al.*, 2003), and elderly women with normal cognitive function have demonstrated better masticatory function than cognitively impaired women (Miura *et al.*, 2003). In humans the periodontal ligaments of the teeth are richly innervated by the trigeminal nerve. The nerve is a mixed nerve that supplies the skin of the face, the mucous membranes and the teeth with sensory fibres, and the masticatory muscle with motor fibres (Nakamura & Sessle, 1999). By mapping the body's surface sensations onto the somatosensory cortex, the representation of the teeth, gums, jaw, tongue and lips are disproportionally large (Penfield & Rasmussen, 1952). The importance of this large somatosensory area on cognition is still unknown but studies have suggested that cortical representation of the oral region has a broad and essential role in the modulation of taste perception (Nitschke *et al.*, 2006), and in the mirror-neuron system (MNS) when viewing mouth actions in others (Möttönen *et al.*, 2004).

In related work from the Betula project we have begun to characterize successful aging in terms of health, cognition, and socioeconomic factors (Habib, Nyberg & Nilsson, 2007). The older participants that were classified as successful had higher cognitive functioning, higher levels of education, better living conditions, and better subjective health. We also found that the successful aging group had a larger percentage of natural teeth, which possibly is a marker of overall health. Based on this observation, the aim of this paper is to more closely examine the relationship between the presence of natural teeth and cognitive function. Results from animal (Kubota *et al.*, 1988; Kato *et al.*, 1997; Onozuka *et al.*, 1999, 2000, 2002; Watanabe *et al.*, 2001, 2002) and human studies (Kondo *et al.*, 1995; Momose *et al.*, 1997; Sesay *et al.*, 2000; Onozuka *et al.*, 2003) support our hypothesis that the individuals with preserved teeth will have higher cognitive performance after controlling for various important background factors such as age, gender, health and socioeconomic status.

METHOD

Pariticipants

This cross-sectional study is a part of a large-scale longitudinal population-based study (Betula study) in which the chief objective is to examine the development of health and memory in adulthood and old age and to determine risk factors for dementia. The present study focuses on the association between cognition and dental status. The general design of the Betula study, analyses of attrition and selective drop-out, and overall age changes in health and memory have been reported elsewhere (Nilsson *et al.*, 1997). Only those aspects of the design that are of relevance for the present study will be described here. In this cross-sectional study two independent samples (S2, S3) from the test wave 1993–95 were included. Each sample included 1,000 participants aged 35 (only S3), 40, 45, 50, 55, 60, 65, 70, 75, 80 and 85 (only S2) years with 100 participants in each age cohort. Participants in the study were randomly and independently drawn from the population registry in Umeå, a city of about 108,000 residents in northern Sweden. A total of 1,961 participants from S2 and S3 were considered for the present analyses (cf., Habib, Nyberg & Nilsson, 2007). By using the mini-mental state (MMSE) cut-off score of 24 (Folstein, Folstein & McHugh, 1975), 85 participants with possible dementia or other neurological disease were excluded.

Years of education, living conditions (e.g. number of rooms in apartment/house), occupation, and having close friends were recorded. The variables years of education, living conditions, and occupation were used as indicators of socioeconomic status (SES) and having close friends as an indicator of social network. Occupation was classified from 1 (manual worker) to 6 (entrepreneur) according to Statistiska Centralbyrån, Sweden (SCB:MIS 1982:4). The general stress level was assessed by using the question "*Are you stressed in general?*". The participants had to rate their general stress level on a Likert scale graded from 0 to 10 with the endpoints 0 = not stressed at all and 10 = very stressed. The participants underwent a health examination that included registration of 23 diseases. The diseases were cardio-vascular disease, high blood pressure, blood disease, stroke, diabetes, neurological disease, psychiatric disease, head injury, encephalitis, back problem, tumor disease, thyroid disease, hormone disease, gastro-intestinal disease, gynecological disease, skin disease, allergy, lung disease, eye disease, ear, nose, and throat disease, arthritis, bone fracture and infectious disease. The presence or absence of natural teeth was registered, which allowed us to divide the participants into a *natural teeth group* of 1,351 persons (53% women, 47% men; age $M = 54.0$; yrs of education $M = 11.3$) with natural teeth, and an *edentulous group* of 487 persons (59% women, 41% men; age $M = 71.3$; yrs of education $M = 7.1$) without natural teeth. We have retrospectively contacted about 100 participants to confirm that their self-reports were accurate, and less than 5% of the answers indicated a minor mismatch in that the participants had a few remaining natural teeth rather than none. Critically, all of them lacked molars. Thus, this follow-up suggested that our classification of participants into the two groups based on their self-reports was accurate (i.e. *natural vs. edentulous group*).

In the next stage of analysis, the participants in the two groups were matched for age, gender, SES, social network, MMSE, various diseases and general stress level. Edentulous individuals were found in every age-group although just a few were represented in the younger age-groups, but in order to reduce the effect of age variation in the matched groups only the participants ≥50 years of age were included. The matching procedure resulted in a natural teeth group of 211 persons and an edentulous group of 188 persons of comparable age and gender distribution.

Cognitive tests

Cognitive assessment was based on an extensive battery of tests (Nilsson *et al.*, 1997). The present analyses were based on 12 different tests that probed retrospective (recall and recognition) and prospective episodic memory, semantic memory (word fluency), procedural memory/problem-solving (Tower-of-Hanoi), and visuo-spatial ability (block design).

Face recognition. Early in the test session, participants silently viewed 16 photographs of children's faces (8 seconds/photo). Below each photo, a Swedish first and family name was typed. Participants were asked to memorize the face together with the family name. Approximately 45 minutes into the session (a delay during which other cognitive tests were administered) participants were shown 24 photographs of 12 studied and 12 non-studied faces, randomly intermixed. The participant was asked to make an old/new judgment in response to each face. For each face judged to be old, and for each missed target face, they were asked to identify the names from a list of four alternatives (first and family name). Number of hits minus false alarms for faces was entered in the analyses.

Recall of actions and sentences. Participants were presented with two lists of 16 verb-noun sentences, each denoting a simple action (e.g., lift the book). For one list, participants were requested to enact each sentence, using the specified object (8 seconds/item). The other list was studied without enactment. A free recall test of the sentences followed after each list (enacted/actions and without enactment/sentences).

Recognition of action and sentences. About 30 minutes after the recall test, the participants were presented 32 nouns. Of these, 8 were from the enacted study list and 8 from the non-enacted study list, and the remaining 16 were non-studied words (8 distractors per target category). Participants indicated items they recognized by saying YES. Number of hits minus false alarms for each item type (action/sentences) was entered in the analyses.

Recall of test session. At the end of the test session, the participants were asked to recall (describe) the tests they had performed during the second test session, in any order. The total number of activities identified as performed previously served as the measure entered in the analyses.

Recall focused/divided attention. Participants were presented with four lists, each including 12 nouns. The items in each list were read aloud by the experimenter at a pace of 2 seconds/item.

Following presentation of the last item of each list, participants recalled as many of the nouns as possible in any order at a given pace (2 seconds/item), indicated by a metronome. For one list, the task was performed under conditions of full attention at study and retrieval. Study/retrieval of words in the other lists was paired with performing a secondary task. This task consisted of sorting red and black cards into two piles on the basis of color (2 seconds/item). In one condition, division of attention occurred at study of the nouns, but not at retrieval. This test was used here.

Prospective memory. Before the test session the participants were asked to remind the test leader, after completing the test session, that s/he should sign a form. They were given a score of 4 if they managed to do this with no support, 3 or 2 if they succeeded after reminders and 0 if they failed.

Word fluency. Four tests, in which the participants generated as many words as possible in one minute were included in the test battery. In the first test, used here, the participants said aloud as many words as possible with an initial letter A.

Block design. The standard test from the Wechsler battery (Wechsler, 1981) was used where the maximum score was 51.

Tower-of-Hanoi. The Tower of Hanoi puzzle was constructed from a rectangular block of wood (29.5 × 102 cm). Three wooden pegs (9 cm high) were inserted into the base 9 cm apart. Five disks made of wood and graduated in size were used (8, 7, 6, 5, and 4 cm in diameter, respectively). In the starting position the disks were placed on the leftmost peg, with the largest disk at the bottom and the smallest on top. The experimenter told the participant that the goal was to duplicate this formation on another peg. Hence, the right as well as the middle peg served as the goal peg. The disks could be moved to any peg given three restrictions: (a) one disk only could be moved at a time, (b) a larger disk could not be placed on a smaller disk, and (c), a disk to be moved always had to be placed on a peg (i.e. a disk could not be removed entirely from the puzzle). Participants were requested to solve the task in as few moves as possible, and as fast as possible. With five disks the minimum number of moves is 31 (Rönnlund, Lövdén & Nilsson, 2001).

Statistical methods

In order to assess the strength of the relationship between measures of age, gender, SES, social network, diseases, stress, and performance on the cognitive tests, correlation analyses were first performed on the unmatched group ($N = 1{,}838$) and subsequently on five age groups (i.e. 35–45, 50–55, 60–65, 70–75, 80–85 years) using Pearson's correlation coefficient and Spearman's rho. The performance of the natural teeth ($N = 1{,}351$) and edentulous ($N = 487$) groups on the tests of cognition was assessed with multivariate analysis of variance (MANOVA) with age, gender, SES, social network, diseases, stress, and MMSE as covariates. Partial eta squared was used to estimate the effect size. Next, a stepwise multiple regression analysis was performed on all the participants ($N = 1{,}838$) in order to examine the relationship of age, gender, SES, social network, disease, stress, and edentulousness on cognition. In the stepwise regression analysis age was entered in step 1, gender, SES variables and social network in step 2, diseases and stress level in step 3, and edentulousness in step 4. The total amount of variance (adjusted R^2) predicted by the final model for each cognitive test was analysed. Finally, independent *t*-tests, Mann-Whitney test, and chi-square tests were performed on the matched natural teeth ($N = 211$) and edentulous ($N = 188$) group on age, gender, SES, social network, stress, diseases, MMSE and the cognitive tests. An analysis of variance (ANOVA) was used to calculate partial eta squared. The statistical analyses were computed in SPSS version 13.0. The significance level was set at $p < 0.01$ in the MANOVA and $p < 0.05$ in the subsequent tests.

RESULTS

Correlation of age, gender, SES, social network, stress, diseases, and the cognitive tests

The correlation analyses performed on age, gender, SES, social network, stress, diseases, and the cognitive tests in the unmatched group ($N = 1{,}838$) showed that age and the three SES indicators were strongly associated with all the cognitive tests and gender and the social network indicator was significantly associated with most of the cognitive tests (Table 1). Stress and 19 of the 23 diseases that were included were significantly correlated with one or several cognitive tests (data not shown). Only the variables associated with one or several cognitive tests were included in the following analyses (Table 2).

After dividing the participants into five age groups (35–45, 50–55, 60–65, 70–75, 80–85 years) the correlation analyses

Table 1. *Correlation coefficients (r) between age, gender, socioeconomic status and social network variables and cognitive tests*

Cognitive tests	Age	Gender	Years of education	Living condition	Occupation	Having close friends
Face recognition	−0.435**	−0.110**	0.401**	0.200**	0.164**	−0.083**
Recall actions	−0.580**	−0.051*	0.472**	0.263**	0.136**	−0.096**
Recognition actions	−0.290**	−0.028	0.256**	0.164**	0.095**	−0.033
Recall sentences	−0.488**	−0.042	0.466**	0.257**	0.182***	−0.118**
Recognition sentences	−0.301**	−0.095**	0.292**	0.164**	0.112**	−0.065**
Recall focused attention	−0.392**	−0.091**	0.355**	0.209**	0.114**	−0.067**
Recall divided attention	−0.374**	−0.063**	0.356**	0.201**	0.140**	−0.067**
Recall of test session	−0.529**	−0.053*	0.577**	0.309**	0.232**	−0.084**
Prospective memory	−0.400**	0.060*	0.301**	0.207**	0.102**	−0.043
Word fluency (A-1 min)	−0.313**	−0.092**	0.443**	0.232**	0.212**	−0.070**
Block design	−0.579**	0.138**	0.483**	0.299**	0.198**	−0.094**
Tower of Hanoi	0.233**	−0.095**	−0.182**	−0.143**	−0.101**	0.025

* $p < 0.05$; ** $p < 0.01$.

Table 2. *Stepwise multiple regression analysis on the cognitive tests and MMSE with age in step 1, gender, socioeconomic variables, and social network in step 2, diseases and stress level in step 3 and edentulousness in step 4. Contribution of variance (%), Standardized Beta Coefficients (B) and* p-*values are presented*

	Face recognition		Recall actions		Recognition actions		Recall sentences		Recognition sentences		Recall focused attention		Recall divided attention	
	%	B	%	B	%	B	%	B	%	B	%	B	%	B
Age	18.9	–0.313***	33.7	–0.465***	8.4	–0.219***	23.8	–0.339***	9.1	–0.161***	15.4	–0.238***	14.0	–0.217***
Gender	2.0	–0.148***	0.8	–0.095***	0.5	–0.068**	0.5	–0.089***	1.3	–0.121***	1.2	–0.115***	0.8	–0.109***
Years of education	3.6	0.182***	3.1	0.201***	1.3	0.127***	5.3	0.224***	2.2	0.148***	2.6	0.162***	3.1	0.162***
Living condition	0.0	ns	0.3	0.059**	0.3	0.065**	0.3	0.059**	0.3	0.050*	0.4	0.059*	0.3	0.045
Occupation	0.7	0.087***	0.0	ns	0.0	ns	0.6	0.076**	0.0	ns	0.0	ns	0.2	0.044
Having close friends	0.0	ns	0.0	ns	0.0	ns	0.2	–0.045*	0.0	ns	0.0	ns	0.0	ns
Cardio-vascular disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.2	–0.051*	0.0	ns	0.0	ns
High blood pressure	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Blood disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Stroke	0.2	–0.049*	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.4	–0.063**	0.4	–0.058**
Diabetes	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Neurological disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Head injury	0.3	–0.055**	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Encephalitis	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Back problem	0.0	ns	0.0	ns	0.3	0.055*	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Thyroid disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.2	–0.047*
Hormone disease	0.0	ns	0.0	ns	0.4	0.060**	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Gastro-intestinal disease	0.0	ns	0.3	0.054**	0.0	ns	0.0	ns	0.2	0.047*	0.0	ns	0.0	ns
Gynecological disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Allergy	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Lung disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Eye disease	0.3	–0.057**	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Arthritis	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.2	0.045*	0.0	ns
Bone fracture	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.2	0.049*	0.0	ns
Infectious disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Rated stress	0.0	ns	0.0	ns	0.2	–0.050*	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Edentulous	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.4	–0.078**	0.4	–0.082**	0.3	–0.070**
Total %	26.0		38.2		11.4		30.7		13.7		20.8		19.3	

Table 2. *Continued*

	Recall of test session		Prospective memory		Word fluency (A-1 min)		Block design		MMSE		Tower of Hanoi	
	%	B	%	B	%	B	%	B	%	B	%	B
Age	28.0	–0.291***	16.0	–0.291***	9.8	–0.081**	33.5	–0.431***	13.3	–0.213***	5.4	0.206***
Gender	0.8	–0.091***	0.0	ns	1.3	–0.119***	0.9	0.098***	0.0	ns	0.3	–0.051*
Years of education	11.4	0.338***	0.8	0.072**	10.4	0.313***	3.6	0.169***	3.8	0.180***	0.0	ns
Living condition	0.7	0.073***	0.4	0.058*	0.7	0.067**	0.5	0.058**	0.4	0.056*	0.3	–0.062*
Occupation	0.4	0.070***	0.0	ns	0.5	0.075**	0.4	0.064**	0.2	0.051*	0.5	–0.050*
Having close friends	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Cardio-vascular disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
High blood pressure	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.2	0.049*	0.0	ns
Blood disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Stroke	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Diabetes	0.0	ns	0.0	ns	0.2	–0.037	0.0	ns	0.2	–0.048*	0.0	ns
Neurological disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Head injury	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Encephalitis	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Back problem	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Thyroid disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Hormone disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Gastro-intestinal disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Gynecological disease	0.2	0.052**	0.0	ns	0.2	0.053**	0.3	0.062**	0.0	ns	0.0	ns
Allergy	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Lung disease	0.0	ns	0.2	0.044*	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Eye disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Arthritis	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Bone fracture	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.4	–0.063**
Infectious disease	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.3	–0.054*
Rated stress	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns	0.0	ns
Edentulous	0.3	–0.063**	0.7	–0.101***	0.4	–0.075**	0.2	–0.059**	0.3	–0.067*	0.0	ns
Total %	41.8		18.1		23.5		39.4		18.4		7.2	

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Table 3. *The total amount of variance (adjusted* R^2*), degrees of freedom (df),* F*-ratios and* p*-values in the final model of the stepwise multiple regression analysis for each cognitive test and MMSE*

Cognitive tests	Adjusted R^2	df	F	p
Face recognition	0.257	7,1830	91.8	<0.0001
Recall actions	0.380	6,1831	189.0	<0.0001
Recognition actions	0.111	7,1830	33.7	<0.0001
Recall sentences	0.307	7,1830	117.1	<0.0001
Recognition sentences	0.135	7,1830	41.9	<0.0001
Recall focused attention	0.209	10,1827	49.4	<0.0001
Recall divided attention	0.189	8,1829	54.5	<0.0001
Recall of test session	0.415	7,1830	187.3	<0.0001
Prospective memory	0.179	5,1832	80.9	<0.0001
Word fluency (A-1 min)	0.231	8,1829	70.1	<0.0001
Block design	0.392	7,1830	170.1	<0.0001
MMSE	0.182	7,1830	59.4	<0.0001
Tower of Hanoi	0.070	6,1831	23.9	<0.0001

showed that the SES indicator years of education was correlated with most of the cognitive tests in all age groups. The SES indicator living condition was also correlated with several cognitive tests in all age groups and the SES indicator occupation was correlated with several cognitive tests in all age-groups except the oldest age group (80–85 years) where only block design was correlated. Finally the social network indicator was correlated with just a few cognitive tests.

Comparison of unmatched groups

Taking all cognitive tests into account, participants with natural teeth performed at a significantly higher level than the edentulous group on the cognitive tests ($F_{(13, 1798)} = 3.03$; $p < 0.001$; Wilks' Lambda = 0.979; partial eta squared = 0.021). This observation provided support for a relation between dental status and cognition.

The stepwise multiple regression analysis showed that the edentulous participants performed significantly poorer on MMSE and seven cognitive tests: Recognition sentences, Recall focused attention, Recall divided attention, Recall of test session, Prospective memory, Word fluency (A-1 min), and Block design (Table 2). There were no significant differences between the groups on Recall actions, Recognition actions, Recall sentences, Face recognition, and Tower of Hanoi (Table 2). The regression analysis also showed that age and years of education accounted for most of the variance and that edentulousness accounted for only a small portion of the variance (Table 2).

The total amount of variance (adjusted R^2) predicted by the final model for each cognitive test using stepwise multiple regression analyses is presented in Table 3.

Comparison of matched groups

After matching the two groups (50–85 years) on age, gender, education level, living conditions, occupation, having close friends, stress, diseases, and MMSE, they did not significantly differ in the subsequent analyses on any of the background factors that we considered, although a borderline significance was found on occupation (Table 4). The between-group differences on the cognitive tests revealed significant differences in favor of the natural teeth group on four of the cognitive tests and borderline-significance on two tests (Table 5). The effect size was largest for the Recognition sentences test (partial eta squared = 0.030).

DISCUSSION

Our results provide evidence that the presence of natural teeth in humans is related to higher cognitive functioning. Both cognitive function and good oral health are known to be associated with socioeconomic factors, but after matching the natural teeth and edentulous groups for important associated factors including socioeconomic status, the relationship between dentition and cognition still held.

In this study we have analyzed the relationship between cognition and three socioeconomic variables (years of education, occupation, living conditions) and one aspect of social network (having close friends). The link between socioeconomic status, social network, and cognitive function is well established (Nilsson *et al.*, 1997; Bäckman *et al.*, 2001; Holmgren, Molander & Nilsson, 2006). This was also confirmed in our study (Table 1). The SES indicator years of education had the strongest correlation with the cognitive tests in all age-groups. This finding is in concordance with other studies (Nilsson *et al.*, 1997; Holmgren, Molander & Nilsson, 2006). Despite the observed relationship between SES and social network with cognition, we found that the presence of natural teeth was a significant predictor of cognitive performance above and beyond these other factors. Thus, our results indicate that natural teeth and mastication can be important for cognitive function but the exact mechanisms are still unclear.

Socioeconomic status is of course important in good oral health, but the national dental insurance system in Sweden has reduced its importance compared to many other countries.

Table 4. *Group characteristics after matching the natural teeth and edentulous groups regarding age, gender, socioeconomic status, social network, MMSE, stress level, and diseases*

Variable	Natural teeth	Edentulous	*p* (one-tailed)
Number	211	188	
Sex women/men	52/48%	51/49%	0.493
	Mean (*SD*)	Mean (*SD*)	
Age (range: 50–85 years)	69.43 (8.29)	68.30 (9.54)	0.103
Years of education	7.95 (2.85)	8.13 (2.47)	0.255
Living condition	3.85 (1.33)	3.69 (1.30)	0.111
Occupation (1–6)	3.22 (1.58)	3.02 (1.68)	0.093
MMSE	27.46 (1.52)	27.35 (1.58)	0.233
Rated stress (1–10)	1.56 (1.55)	1.48 (1.50)	0.312
	Frequency		
Having close friends	191	168	0.413
Cardiovascular disease#	85	80	0.360
High blood pressure#	73	57	0.211
Blood disease#	16	12	0.394
Stroke#	13	14	0.377
Diabetes#	8	13	0.121
Neurological disease#	27	32	0.148
Head injury#	22	27	0.149
Encephalitis#	2	4	0.290
Back-problems#	121	117	0.186
Thyroid disease#	22	22	0.402
Hormone disease#	10	8	0.505
Gastro-intestinal disease#	108	99	0.423
Gynecological disease#	116	100	0.399
Allergy#	71	67	0.378
Lung disease#	25	25	0.387
Eye disease#	58	53	0.482
Arthritis#	30	24	0.392
Bone fracture#	114	110	0.212
Infectious disease#	154	129	0.198

"Have you ever consulted a doctor or been treated in hospital for any of the following diseases?"
* $p < 0.05$.

Table 5. *Cognitive test performance in the matched natural teeth and edentulous group*

	Natural teeth	Edentulous		
Cognitive test	Mean (*SD*)	Mean (*SD*)	*p* (one-tailed)	Partial eta squared
Face recognition	4.88 (2.65)	4.77 (2.77)	0.356	0.000
Recall actions	7.08 (2.95)	6.89 (2.81)	0.259	0.005
Recognition actions	6.29 (1.65)	6.14 (1.75)	0.189	0.005
Recall sentences	3.82 (2.30)	3.43 (2.10)	0.038*	0.015
Recognition sentences	4.65 (2.07)	4.05 (1.97)	0.002*	0.030
Recall focused attention	4.87 (1.53)	4.77 (1.60)	0.261	0.004
Recall divided attention	3.31 (1.33)	3.13 (1.36)	0.091	0.008
Recall of test session	9.69 (3.77)	8.96 (3.66)	0.026*	0.014
Prospective memory	3.05 (0.98)	2.89 (0.94)	0.050*	0.013
Word fluency (A-1 min)	10.29 (4.55)	9.75 (4.22)	0.110	0.003
Block design	22.55 (8.17)	21.39 (9.57)	0.097	0.008
Tower of Hanoi	489.91 (274.73)	482.62 (282.71)	0.397	0.000

* $p < 0.05$.

Treatment costs are not free but the insurance covers a certain amount of the expenses. The leading principle has always been that of "high cost protection". Patients have to pay a lower percentage of costs for extensive treatment than for routine services. Nevertheless, considered internationally, low socioeconomic status, health and old age are important risk factors for total tooth loss.

The present cross-sectional study shows that preserved natural teeth are related to higher cognitive performance in humans between 50 and 85 years of age. However, although the MANOVA showed a significant group effect, the effect size was small to modest. It should also be emphasized that while there was a trend towards a higher level of performance for participants with preserved natural teeth on the majority of cognitive measures, the magnitude of the effect varied across tests and was non-significant for some of them. No single underlying factor appeared to account for this pattern (such as episodic vs. semantic processing or more supported vs. less supported tests). Instead, in view of our previous multivariate findings (Habib, Nyberg & Nilsson, 2007), we interpret the findings as showing a weak but consistent effect on most examined cognitive tests. Taken together, our findings are consistent with the hypothesis that functional natural teeth help to maintain cognitive functioning. This underlines the importance of adequate dental care in the elderly. Geriatric dentistry should be an area of health priority especially given that many older adults have poor oral health.

Convergent support for the hypothesis of a relationship between cognition and dental health comes from human and animal studies (e.g., Kondo *et al.*, 1995; Momose *et al.*, 1997; Watanabe *et al.*, 2002). Aged molarless mice have shown a decrease in learning ability and impairment of spatial memory (Onozuka *et al.*, 1999, 2000). Kato *et al.* (1997) suggested that the dysfunctional effect of loss of molar teeth on spatial memory is due to dysfunction of the cholinergic neuronal system (Kato *et al.*, 1997; Onozuka *et al.*, 2002). Trigeminal input has a facilitatory effect on transmission in various regions of the cerebral cortex (Ellrich, Andersen, Messlinger & Arendt-Nielsen, 1999). The periodontal membrane nerve in primates disappeared from the alveoli after extraction, and chromatolysis in nerve cells in the trigeminal ganglion were observed 70 days after extraction (Kubota *et al.*, 1988).

Natural teeth may also contribute to good cognitive function as people with inadequate natural dentition have lower intakes of vitamins, proteins, and calories than participants with adequate natural dentition (Nowjack-Raymer & Sheiham, 2003) suggesting that compromised oral health may lead to under-nutrition and deterioration of general health (Kiyak, 2000). A shortcoming of this study was that sub-clinical diseases and other health problems were not measured, although we did investigate associations between cognitive function and 23 diagnosed diseases.

In the present study, dental status was based solely on reliable self-reports and divided participants into two odontologically heterogeneous groups. Clinical data such as the size of the dental arch, number of decayed and missing teeth, and the presence of periodontal disease were not available. For example, participants with only a few teeth were included into the natural teeth group together with participants with 32 teeth. This crude division of the participants was of course a shortcoming of the present study. Longitudinal analyses including comprehensive dental clinical data will therefore be needed to further shed light on the causal relation between dental status and cognition in adulthood and aging. Multiple factors are known to cause cognitive decline. Our findings suggest an additional one which may play a role in understanding the complexity of cognition.

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