



## The relationships between cognitive ability and dental status in a national sample of USA adults

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### ABSTRACT

There are very few studies on the relationship between cognitive ability and dental status in middle aged and younger adults. We postulate that lower cognitive ability is directly related to poorer dental status and that this relationship operates through the relationship between cognitive ability and health-related behaviors. The objectives of this study are (1) to examine the relationship between two measures of cognitive ability, Symbol Digit Substitution Test (SDST) and Serial Digit Learning Test (SDLT) and decayed, missing, filled and sound tooth surfaces, (2) to examine the relationship between cognitive ability and two health-related behaviors, dental visits and smoking, (3) and to test if the aforementioned relationship is independent of socioeconomic position. Data were from the Third National Health and Examination Survey. We examined the relationship between SDST and SDLT, and the oral health indicators and the behavioral factors using a series of regression models. Individuals with lower cognitive ability had higher means of decayed and missing tooth surfaces and lower means of sound and filled tooth surfaces. Poorer cognitive ability was associated with poorer behaviors; lower levels of dental attendance and higher levels of smoking. The relationship between cognitive ability and dental status was further demonstrated in the regression analysis. For a higher unit of SDST the rate ratio for decayed tooth surfaces was 1.91 (CI 1.53–2.38) which attenuated to 1.40 (CI 1.13–1.73) after adjusting for age, sex, ethnicity, income, dental attendance and smoking, but remained significant. Similar results were obtained for all oral health outcomes. This study found a relationship between cognitive ability and dental status and related behaviors among middle aged and younger adults. The relationship was independent of income and ethnicity. These findings support the theories put forward on a relationship between cognitive ability and health operating through health-related behaviors.

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### 1. Introduction

There are positive correlations between higher intelligence and better health outcomes.

Intelligence and cognitive ability are related to a number of chronic diseases such as hypertension, diabetes, cardiovascular diseases, as well as mortality (Gregg et al., 2000; Chertkow, 2002; Knopman et al., 2001; Singh-Manoux, Sabia, Kivimaki, Shipley,

Ferrie, & Marmot, 2009; Bassuk, Wypij, & Berkman, 2000; Dewey & Saz, 2001; Deary & Der, 2005; Batty, Deary, & Gottfredson, 2007; Gottfredson & Deary, 2004; Gottfredson, 2004; Hart, Taylor, Smith, Whalley, Starr, & Hole, 2005; Kuh, Richards, Hardy, Butterworth, & Wadsworth, 2004; Martin & Kubzansky, 2005; van Oort, van Lenthe, & Mackenbach, 2005). A systematic review of studies on the relationship between intelligence and mortality found that all the nine studies reviewed reported that adults with higher scores on cognitive function had lower rates of later mortality (Batty et al., 2007). There is also an association between cognitive ability and some oral status indicators such as periodontal disease, number of teeth and being edentulous (Kim et al., 2007; Stewart & Hirani, 2007; Stewart, Sabbah,

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Tsakos, D'Aiuto, & Watt, 2008; Sabbah, Watt, Sheiham, & Tsakos, 2009; Noble et al., 2010). However, most of the dental studies focused on the relationship between impaired cognitive ability in older age and periodontal disease and tooth loss. Only one study examined the relationship between cognitive ability and dental caries in older age (Chalmers, Carter, & Spencer, 2002). In a large national study, NHANES III, Stewart et al. (2008) found that poor oral health was associated with worse cognitive function throughout adult life. One 6-year prospective study reported that adverse dental health was a strong predictor of physical and mental decline and greater mortality (Shimazaki, Soh, Saito, Yamashita, Koga, & Miyazaki, et al., 2001).

There are at least four explanations of the relationship between cognitive ability, and morbidity and mortality (Batty, et al., 2007; Lubinski, 2009; Arden, Gottfredson & Miller 2009). (1) Reverse causality, illnesses and their treatment side-effects may affect intelligence. However, studies which examined intelligence in early life and occurrence of disease in later life challenge this hypothesis (Batty, et al., 2007).

(2) Socioeconomic factors could influence both intelligence and health (Singh-Manoux, Ferrie, Lynch, & Marmot, 2005). (3) The third explanatory theory argues that intelligence could influence health through choice of lifestyle and behavior (Gottfredson, 2004; Gottfredson & Deary, 2004; Deary, 2005; Batty et al., 2007; Deary 2008; Link, Phelan, Miech, & Westin, 2008; Lubinski 2009; Anstey, Low, Christensen, & Sachdev, 2009; Anstey, Low, Christensen, & Sachdev, 2009). (4) Intelligence and health could both be influenced by common genetic factors (Arden, Gottfredson & Miller 2009).

Most of the oral health studies considered that oral health affects cognitive ability, especially in older age. The relationship between cognitive ability and oral status has been usually attributed to co-morbidity, to an effect of oral health on cognitive ability through inflammatory pathways linked to periodontal disease (Stewart & Hirani, 2007; Stewart et al., 2008; Noble et al., 2010), or through poorer nutrition caused by having fewer teeth (Stewart et al., 2008). In an attempt to assess whether studies on oral health can contribute to the debate on the relationship between cognitive ability and morbidity, Sabbah et al. (2009) presented evidence that cognitive ability explained part, but not all, of the socio-economic inequalities in periodontal disease. In the present study we postulate that adults with the worst cognitive ability will have poorer dental health as manifested by more untreated dental caries and fewer sound teeth because cognitive ability affects health-related behaviors (Gottfredson & Deary, 2004; Deary, 2005; Link et al., 2008; Lubinski, 2009). To test this hypothesis we examined the relationship between two indicators of cognitive ability on the one hand, and dental status; decayed, missing, filled and sound teeth, and two health related behaviors, smoking and dental visits, on the other hand, among American adults. The objectives of the study are to: (1) examine the relationship between cognitive ability, and dental visits and smoking, (2) examine the relationship between cognitive ability and dental status, (3) test whether the relationship between cognitive ability and dental status is explained by socioeconomic position and behaviors.

## 2. Methods

Data for this research are from the Third National Health and Nutrition Examination Survey (NHANES III) (U.S. Department

of Health and Human Services 1997), a cross-sectional survey conducted in 1988–1994. NHANES III used a stratified multistage probability sampling design representative of the non-institutionalized civilian American population. The survey included demographic and health-related behavioral data and a comprehensive dental examination. Detailed description of the database and oral health examination are reported elsewhere (U.S. Department of Health and Human Services, DHHS (1997). Four variables related to dental caries were used in this study (1) missing tooth surfaces due to disease (dental caries or periodontal disease), (2) decayed tooth surfaces, (3) filled tooth surfaces, (4) sound tooth surfaces, and (5) sum of sound and filled surfaces.

NHANES III included data on cognitive ability from the Neurobehavioral Evaluation System (Krieg, Chrislip, Letz, Otto, Crespo, & Brightwell et al., 2001). Such data have been previously published in relation to general and oral health (Suhr, Stewart, & France, 2004; Stewart et al., 2008). In a sub-sample of the participants aged 20 to 59 years, the Symbol Digit Substitution Test (SDST) and Serial Digit Learning Test (SDLT) were administered. Both tests were administered in English or Spanish and were preceded by a practice phase. The SDST examines information processing speed, concentration and motor control. The test measures coding speed in seconds and is used as part of the Wechsler Adult Intelligence Scale (2004). In the test, a series of 9 symbols matched to the digits 1–9 was presented to the subject. Performance in symbol digit substitution test was scored as the average time in seconds needed to correctly match the numbers and symbols on the best 2 out of 4 trials. The SDLT aims to assess immediate recall and learning ability. This is a short-term memory test that requires subjects to reproduce a sequence of 10 numbers presented on a computer screen. The test was stopped when the subject listed the digits in the correct order twice in a row or after 8 trials. Scores were based on the number of errors made during the trials. Higher scores in both tests indicate poorer cognitive ability. Details on the validity of these tests have been reported elsewhere (Krieg et al., 2001). Other variables included in this study were sex, age, ethnicity, frequency of dental visits, being a current smoker and poverty-income ratio. Details of the variables and the survey are described elsewhere (Sabbah et al., 2009).

Oral health-related behaviors were dental visits (regular dental visits 1 or more time per year versus less frequent) and smoking status. Frequency of dental visits is a common indicator of oral health related behaviors as most of them are for regular preventive check-up (Wamala, Merlo & Bostrom, 2006). Smoking status indicates whether the participant is a current smoker or not. Family income indicated by poverty-income ratio was used as an indicator of socioeconomic position. Although income is viewed as a fallible measure of social position, it is an acceptable measure in the USA (Krieger, Williams, & Moss 1997). The analysis also adjusted for age, sex and ethnicity (White, African Americans, Mexican Americans and other ethnicities).

## 3. Statistical analysis

The analysis was conducted using survey command in STATA, and using the final central nervous system sampling weight to account for the complexity of the survey (U.S. Department of

**Table 1**

Distribution of caries related conditions, cognitive tests and main explanatory variables among 20–59 years old Americans (NHANES III, 1988–1994).

	Males	Females
Mean age (95%CI)	37.02 (36.45, 37.60)	37.18 (36.64, 37.72)
Percent reporting dental visits $\geq 1$ per year (95%CI)	44.8%(41.7, 48.0)	56.6% (53.4, 59.8)
Percent current smokers (95%CI)	38.4% (35.3, 41.6)	28.2% (25.6, 30.9)
Mean poverty–income ratio (95%CI) <sup>a</sup>	3.15 (2.98, 3.32)	3.04 (2.84, 3.24)
Mean Symbol Digit Substitution Test (95%CI) <sup>b</sup>	2.75 (2.69, 2.81)	2.61 (2.55, 2.67)
Mean Serial Digit Learning Test (95%CI) <sup>b</sup>	4.44 (4.08, 4.80)	4.52 (4.17, 4.88)
Mean number of missing tooth surfaces due to caries or periodontal disease (95%CI)	7.52 (6.75, 8.28)	7.16 (6.30, 8.02)
Mean number of decayed tooth surfaces (95%CI)	1.99 (1.59, 2.40)	1.30 (1.07, 1.53)
Mean number of filled tooth surfaces (95%CI)	16.57 (15.16, 17.98)	18.90 (17.44, 20.36)
Mean number of sound tooth surfaces (95%CI)	88.53 (86.66, 90.41)	85.39 (83.13, 87.65)
Mean number of sound and filled tooth surfaces (95%CI)	105.11 (103.16, 107.05)	104.29 (101.45, 107.14)

<sup>a</sup> Higher score of poverty–income ratio indicates higher income.<sup>b</sup> Higher score in the cognitive tests indicates worse cognitive performance.

Health and Human Services 1997; Krieg et al., 2001). First we examined the distribution of the two cognitive tests, the five indicators of oral health, and the indicators of behaviors (dental visits and smoking). The percentages of participants reporting dental visits (One or more times/year), being current smokers, and the mean numbers of missing, filled, decayed sound tooth surfaces were examined by tertiles of cognitive tests.

A series of negative binomial regression tests were used to examine the relationship between each of the oral health variables (dependent variable) and the total score obtained in each of the cognitive tests, adjusting for sex, age and ethnicity (Model 1), then introducing income and smoking in Model 2 and dental visits in Model 3. To test the relationship between a composite measure of cognitive ability and oral health, a variable indicating the mean z scores of the original two cognitive variables (SDST, SDLT) was created. The relationship between this aggregate variable and all oral health outcomes was examined, adjusting for sex, age, ethnicity, income, smoking and dental visits.

#### 4. Results

A total of 4390 participants aged 20 to 59 years were included in the analysis. Table 1 shows the distribution of cognitive tests, oral health outcomes and other explanatory

variables by sex. Table 2 exhibits the distribution of oral health outcomes and behaviors by tertiles of cognitive tests. Generally, people with the best performance scores on cognitive tests had more health enhancing behaviors and better positive dental clinical measures, while those with the worst cognitive performances had more health compromising behaviors and poorer dental status (Fig. 1). For example, approximately 60% of those with the best cognitive performances reported dental visits at least once a year compared to 39% of those with the worst SDST scores (Table 2). There were also large difference in percentages of current smokers by cognitive score; 27% of those with the best and 40% of those with worst SDST scores (Table 2).

There were marked differences in dental status between those with the best and the worst cognitive ability scores. Those with the best SDST scores, had a mean of 3.65 missing, 0.98 decayed and 97 sound tooth surfaces. On the other hand, the mean numbers of missing, decayed and sound dental surfaces in those with the worst SDST scores was 12.2, 2.42 and 72 sound surfaces, respectively (Table 2, Fig. 1).

Table 3 shows the adjusted relationship between dental status and cognitive test scores. The rate ratio indicates the probability of increase or decrease in a tooth condition for one unit increase in the cognitive test (indicating poorer cognitive ability). For an additional one unit increase in the SDST score,

**Table 2**

Distribution of oral health outcomes and behaviors, by tertiles of cognitive tests among 20–59 years old Americans (NHANES III, 1988–1994).

	Tertiles of Symbol Digit Substitution Test performance scores			Tertiles of Serial Digit Learning Test performance scores		
	Best	Middle	Worst	Best	Middle	Worst
Percent reporting dental visits $\geq 1$ per year (95%CI)	60.0% (56.2, 63.7)	48.2% (44.0, 52.5)	38.8% (34.0, 43.9)	59.8% (55.5, 63.8)	50.5% (47.2, 53.9)	36.7% (31.9, 41.8)
Percent reporting being a current smoker (95%CI)	27.5% (23.8, 31.2)	36.1% (32.6, 39.8)	40.3% (36.5, 44.3)	30.4% (26.5, 34.7)	35.3% (32.1, 38.7)	37.1% (33.5, 40.1)
Mean missing tooth surfaces due to caries or periodontal disease (95%CI)	3.65 (3.01, 4.28)	8.25 (7.27, 9.23)	12.22 (10.80, 13.64)	4.87 (4.13, 5.60)	7.50 (6.40, 8.60)	10.73 (9.06, 12.39)
Mean decayed tooth surfaces (95%CI)	0.98 (0.65, 1.31)	1.95 (1.54, 2.36)	2.42 (1.95, 2.90)	1.03 (0.77, 1.29)	1.95 (1.58, 2.33)	2.24 (1.78, 2.70)
Mean filled surfaces (95%CI)	18.57 (17.01, 20.03)	19.48 (17.76, 21.20)	14.84 (12.63, 17.05)	19.74 (18.22, 21.26)	18, 69 (17.13, 20.24)	14.11 (12.54, 15.69)
Mean sound surfaces (95%CI)	97.68 (95.97, 99.39)	82.45 (80.00, 84.94)	72.04 (68.63, 75.44)	93.12 (91.22, 95.03)	84.53 (82.08, 86.98)	78.37 (74.60, 82.14)
Mean sound and filled teeth (95%CI)	116.24 (114.69, 117.80)	101.93 (99.38, 104.47)	86.88 (83.24, 90.52)	112.86 (111.04, 114.69)	103.23 (100.46, 105.98)	92.48 (88.23, 96.74)

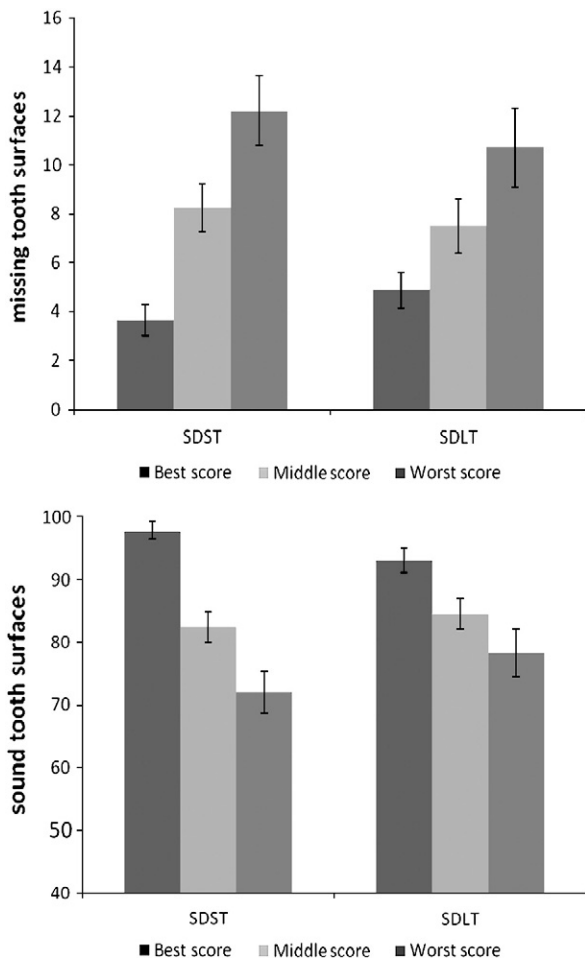


Fig. 1. Mean number of missing and sound tooth surfaces ( $\pm 95\%CI$ ) by tertiles of the SDST and SDLT cognitive tests.

Table 3

Adjusted associations between caries related conditions and cognitive test scores among 20–59 years old Americans (NHANES III, 1988–1994).

		Symbol Digit Substitution Test <sup>a</sup>	Serial Digit Learning Test performance <sup>a</sup>
Rate ratio for missing tooth surfaces (95%CI)	Model 1	1.52*** (1.31, 1.77)	1.05*** (1.03, 1.08)
	Model 2	1.32*** (1.20, 1.45)	1.04** (1.02, 1.06)
	Model 3	1.28*** (1.16, 1.42)	1.03** (1.02, 1.05)
Rate ratio for decayed tooth surfaces (95%CI)	Model 1	1.91*** (1.53, 2.38)	1.07*** (1.04, 1.11)
	Model 2	1.48** (1.19, 1.85)	1.04* (1.01, 1.08)
	Model 3	1.40** (1.13, 1.73)	1.02 <sup>NS</sup> (0.99, 1.05)
Rate ratio for filled tooth surfaces (95%CI)	Model 1	0.79*** (0.72, 0.87)	0.96*** (0.95, 0.98)
	Model 2	0.83*** (0.77, 0.90)	0.97*** (0.96, 0.98)
	Model 3	0.84*** (0.78, 0.91)	0.98*** (0.97, 0.99)
Rate ratio for sound tooth surfaces (95%CI)	Model 1	0.94*** (0.92, 0.97)	0.99*** (0.98, 0.99)
	Model 2	0.95** (0.92, 0.98)	0.99* (0.99, 0.99)
	Model 3	0.96* (0.93, 0.99)	0.99* (0.99, 0.99)
Rate ratio for sound and filled tooth surfaces (95%CI)	Model 1	0.91*** (0.88, 0.94)	0.98*** (0.98, 0.99)
	Model 2	0.93*** (0.91, 0.96)	0.98*** (0.98, 0.99)
	Model 3	0.94*** (0.91, 0.97)	0.99*** (0.98, 0.99)

Model 1: adjusted for sex, age, ethnicity and the respective cognitive test.

Model 2: additionally adjusted for income and smoking.

Model 3: additionally adjusted for frequency of dental visits.

\*\*\*  $p < 0.001$  \*\*  $p < 0.01$  \*  $p < 0.05$  <sup>NS</sup> insignificant.

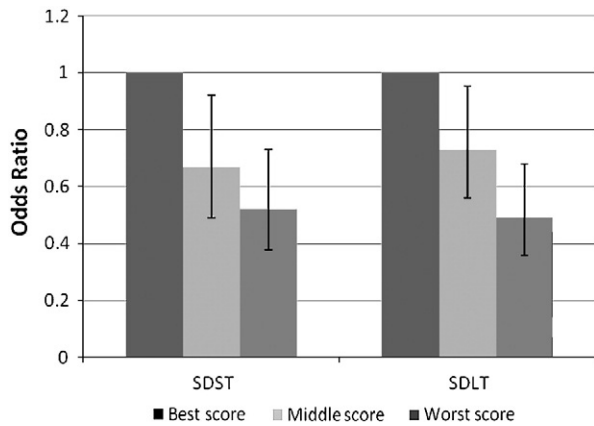
<sup>a</sup> Higher score in the cognitive tests indicates worse cognitive performance. The rate ratio indicates the probability of increase or decrease in the tooth condition for one unit increase in the cognitive test.

the rate ratio of decayed tooth surfaces was 1.91. Adjusting for higher income, smoking and dental attendance attenuated the rate ratio for decayed tooth surfaces to 1.40. However, the association remained statistically significant. Similar relationships between all dental status indicators and both cognitive tests were observed throughout the analysis (Table 3). Importantly, poorer cognitive abilities (higher cognitive test scores) were consistently associated with higher rates of poor dental status and lower rates of positive oral health, as indicated by numbers of sound teeth. The relationships were statistically significant in all the models with the exception of the third fully adjusted model for the relationship between decayed surfaces and SDLT (Table 3). There was a stepwise relationship between positive health behavior (frequent dental visits), positive oral health (sound and filled tooth surface) and performance in cognitive tests (Figs. 2 and 3). Both graphs are based on regression analysis adjusted for sex, age, ethnicity, and sequentially for tertiles of SDST and SDLT.

The composite cognitive variable, indicating the mean z scores of SDST and SDLT tests showed a much stronger and consistently significant association with all measures of oral health after adjusting for sex, age, ethnicity, income, smoking and dental visits. For a higher unit in this composite cognitive variable the rate ratios were 1.31 (CI 1.07, 1.60) for decayed tooth surfaces, 1.38 (CI 1.20, 1.58) for missing tooth surfaces, 0.79 (CI 0.73, 0.86) for filled tooth surfaces, 0.95 (CI 0.92, 0.98) for sound tooth surfaces and 0.92 (CI 0.89, 0.95) for the sum of filled and sound tooth surfaces.

## 5. Discussion

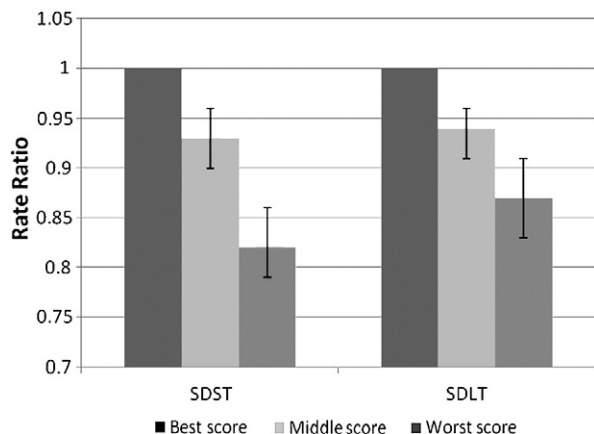
We examined the relationship between dental status, namely missing teeth, dental caries, dental fillings and sound tooth surfaces, with two cognitive tests, in a national representative sample of USA population aged 20–59 years. The analysis showed that poorer cognitive ability was directly



**Fig. 2.** Persons with middle and worst cognitive ability are less likely to visit a dentist ( $\geq$ once a year) than those with best cognitive ability, adjusting for age, sex and ethnicity (odds ratio  $\pm$  95%CI).

associated with poorer dental status, namely missing and decayed tooth surfaces, and inversely associated with better dental status, namely filled and sound tooth surfaces. Similar findings were reported by Stewart et al., (2008) for periodontal health and loss of teeth in the same NHANES III survey as we analyzed. We also demonstrated that the relationship between poorer dental status and cognitive ability is independent of socioeconomic position and health behaviors. Furthermore, poorer cognitive ability was inversely associated with health-enhancing behaviors.

The results of the study indicate that cognitive ability is related to dental status in adults and implies that cognitive ability possibly affects dental health through behavioral pathways. Other dental studies have shown a direct relationship between poor cognitive ability and poor oral health. However, most of them were conducted among older adults with impaired cognitive abilities (Shimazaki et al., 2001; Chalmers et al., 2002) and mainly focused on periodontal disease and tooth loss (Kim et al., 2007; Stewart & Hirani 2007). Furthermore, the aforementioned studies attributed the association between cognitive ability and oral health to an



**Fig. 3.** Persons with middle and worst cognitive ability have lower rates of filled and sound tooth surfaces than those with best cognitive ability, adjusting for age, sex and ethnicity (Rate ratio  $\pm$  95%CI).

effect of oral health on cognitive ability through inflammatory pathways (Noble et al., 2010) and through an effect on nutrition (Stewart et al., 2008) whereas we postulate that the association between cognitive ability and oral health is via good cognitive function affecting health enhancing behaviors and adherence with medical/dental advice; visiting a dentist regularly in the present study.

Some have argued that cognitive ability is a personal trait that affects health through an effect on socioeconomic position (Gottfredson & Deary, 2004; Deary, 2005; Batty et al., 2009). Gottfredson (2004) argued that the general ability to learn, reason and solve problems is the fundamental cause of socioeconomic inequalities in health. Furthermore, impaired cognitive function possibly influences health-related decision making (Lubinski 2009), compliance with medical advice and adherence to health enhancing behaviors (Gottfredson & Deary, 2004; Deary, 2005), and benefiting from recent knowledge related to health and related behaviors (Phelan & Link 2005; Lubinski 2009). Our findings demonstrate that poorer cognitive ability was associated with higher levels of dental diseases, lower levels of positive dental health and related behaviors. This observation to some extent supports the theory that cognitive ability affects health by influencing the ability to make appropriate health enhancing decisions (Lubinski, 2009).

This study tested the hypothesis about the direct relationship between impaired cognitive function and poorer health put forward by Gottfredson & Deary (2004), Deary, (2005) and Lubinski, (2009) in relation to dental status and demonstrate a relationship between cognitive ability and dental status independent of socioeconomic position and health-related behaviors, in a nationally representative community sample of middle aged and young adults in the USA. However, as with all cross-sectional surveys, the findings of this paper should be interpreted with caution. Unfortunately, the analysis did not include a number of dental health enhancing behavioral factors such as tooth-brushing, and the use of fluoride because they were not included in the survey protocol.

Poorer cognitive ability was directly associated with poorer dental health status and inversely associated with positive dental health in the present study. Furthermore, poorer cognitive ability was associated with higher levels of health compromising behaviors such as smoking and lower levels of health enhancing behaviors. The results support theories that suggest that the relationship between cognitive ability and health is through behavioral pathways (Lubinski 2009).

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