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ORIGINAL ARTICLE

Oral diseases are associated with cognitive function in adults over 60 years old

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Abstract

Objective: To investigate the bidirectional association between oral diseases and cognitive function comprehensively.

Subjects and Methods: This cross sectional study utilized data from the National Health and Nutrition Examination Survey. Oral diseases include periodontitis, dental caries, and tooth loss (end point of oral disease resulting in tooth extraction). Cognitive function included three domains: memory, processing speed, and executive function. A global cognitive score was then derived from sum of the three cognitive domains. Oral cognition associations were examined using various statistical models: (1) Regress oral disease on cognitive function; (2) Regress cognitive function on oral disease; and (3) Structural equation modelling treating cognition and oral disease as latent variables.

Results: There were 2508 participants aged 60+ who had both oral and cognitive information. Associations between various oral disease and global cognitive score were observed (Odds ratio $OR_{cog->periodontitis}$ 0.95, 95% Confidence Interval [0.92, 0.99]; $\beta_{cog->caries}$ −0.13, [−0.23, −0.04]; $\beta_{cog->tooth\ loss}$ −0.03 [−0.04, −0.01]; $\beta_{tooth\ loss->cog}$ −0.04 [−0.06, −0.02]; $\beta_{caries->cog}$ −0.03 [−0.06, −0.01]; $\beta_{periodontitis->cog}$ −0.39 [−0.69, −0.10]). Significant correlation was also found between these oral disease and cognitive function using structural equation model (r −0.22, [−0.34, −0.10]).

Conclusions: This study found robust bidirectional associations between oral disease and cognitive function using various modelling approaches among the aging population.

KEYWORDS
aging, cognitive function, dental health, epidemiology, oral disease

1 | INTRODUCTION

Oral diseases include dental caries, periodontitis, and tooth loss (which is the result of oral disease that leads to tooth extraction). In recent decades, some evidence has emerged supporting the association between oral disease and cognitive decline/dementia (Kang et al., 2020; Kang, Wu, et al., 2019). It has been suggested that the association is possibly due to shared inflammation pathways

between oral diseases and cognitive decline (Kamer et al., 2008; Noble et al., 2013), where the inflammation might be caused by chronic oral bacterial infection and dysbiosis (Dominy et al., 2019; Singhrao et al., 2014). On the other hand, cognitive decline could influence oral hygiene behaviors, therefore, reciprocal direction of associations may be observed. However, few studies have explored both directions of such associations, as shown in several systematic reviews (Lin, 2018; Oh et al., 2018; Shen et al., 2016; Tonsekar et al., 2017). Mixed results and conclusions from the literature might be due to inaccurate measures in oral health or cognitive functions, study design, population differences, methodological variation, and sample selection issues (e.g., sample size and bias; Larvin, Gao, et al., 2023a; Wu et al., 2016). Therefore, more high-quality original studies using well-designed and clinically examined oral and cognitive data, with detailed information on participants' demographic characteristics, lifestyle, and medical history, are valuable contributing to the knowledge development in this area.

While biological/clinical experiments, or long-term follow-up life course studies, would be the ideal ones for assessing the association between oral disease and cognitive function, these studies are usually costly, time consuming, and sometimes unethical to conduct. Hence, large-scale epidemiological studies are the alternatives, which are more feasible, cheaper, practical, and efficient to carry out. In this cross sectional study, we used data from the National Health and Nutrition Examination Survey (NHANES), a nationally representative health survey in the United States, to comprehensively investigate the association between various oral diseases and various cognitive function domains.

2 | METHODS

2.1 | Study design

The study followed the STROBE guidelines (Von Elm et al., 2007). NHANES is a biennial national survey designed to examine and collect the information on both health and nutritional status across the non-institutionalized United States population using a stratified, multistage, probability sampling design. Data has been collected using various methods including questionnaires, interviews, and physical examinations (Statistics NCfH, n.d.). The methods and design for the survey are available via the link: https://www.cdc.gov/nchs/nhanes/index.htm

2.2 | Study participants

Participants aged 60 or over from NHANES 2011–12 and 2013–14 were included in the analysis as these two cycles contain detailed dental clinical examination (six sites per tooth, 28 permanent teeth without wisdom teeth) and participants aged 60 or over received cognitive tests in three different domains (memory, processing speed, and executive function). Participants under 60 years old, or with incomplete cognitive tests or oral examination were excluded from this study. The flowchart of participants selection is presented in Figure 1.

Participants' consents were obtained by NHANES and the related documentation can be found via the link (https://www.cdc.gov/nchs/nhanes/genetics/genetic_participants.htm).

2.3 | Cognitive function

Cognitive function include memory measured by The Consortium to Establish a Registry for Alzheimer's Disease Word Learning subtest (CERAD W-L, raw score range: 0–40) (Morris et al., 1989), processing speed measured by the Digit Symbol Substitution test (DSST, raw score range: 0–105) (Bienias et al., 2003; Plassman et al., 2007; Proust-Lima et al., 2006), and executive function measured by the animal fluency test (raw score range: 0–40) (Strauss et al., 2006). Participants were required to pass a pretest before the formal tests for the processing speed and executive function. The scores obtained for each cognitive domain were then all scaled to 0–10. Then, the global cognitive function (GCF) score (0–30) is derived based on the sum of scores form all cognitive domains with equal weight. The detailed methodology was documented in NHANES (2011/2012: https://wwwn.cdc.gov/Nchs/Nhanes/2011-2012/CFQ_G.htm; 2013/2014: https://wwwn.cdc.gov/Nchs/Nhanes/2013-2014/CFQ_H.htm).

2.4 | Oral diseases

Oral diseases were reflected by periodontitis, dental caries, and tooth loss. Periodontitis was clinically assessed and classified as "none, mild, moderate, severe" using a standard case definition for surveillance of periodontitis (Eke et al., 2012; Holtfreter et al., 2015). Dental caries is reported as the number of decayed, missing, and filled teeth (DMFT, scale 0–28). Tooth loss is measured by the number of remaining teeth count between 0 (edentulous) and 28 (all teeth present without wisdom teeth). The detailed description of oral disease and classification can be found elsewhere (Kang, Smith, et al., 2019).

2.5 | Covariates

Based on previous studies, we included "common risk factors" for oral disease and cognitive decline as covariates (Hong et al., 2018; Kang et al., 2020; Kang et al., 2022; Kang, Wu, et al., 2019; Larvin et al., 2020, 2022; Larvin, Gao, et al., 2023a; Larvin, Kang, et al., 2021a, 2021b, 2023b; Larvin, Wilmott, et al., 2021): demographic variables (age, sex, ethnicity, education qualification, marital status, and poverty index ratio), anthropometric measures (body mass index [BMI, kg/m^2], waist measurement), lifestyle factors (smoking status, cigarette number in the past 30 days, at least 12 alcohol drinks consumed in the past year, substance misuse, physical

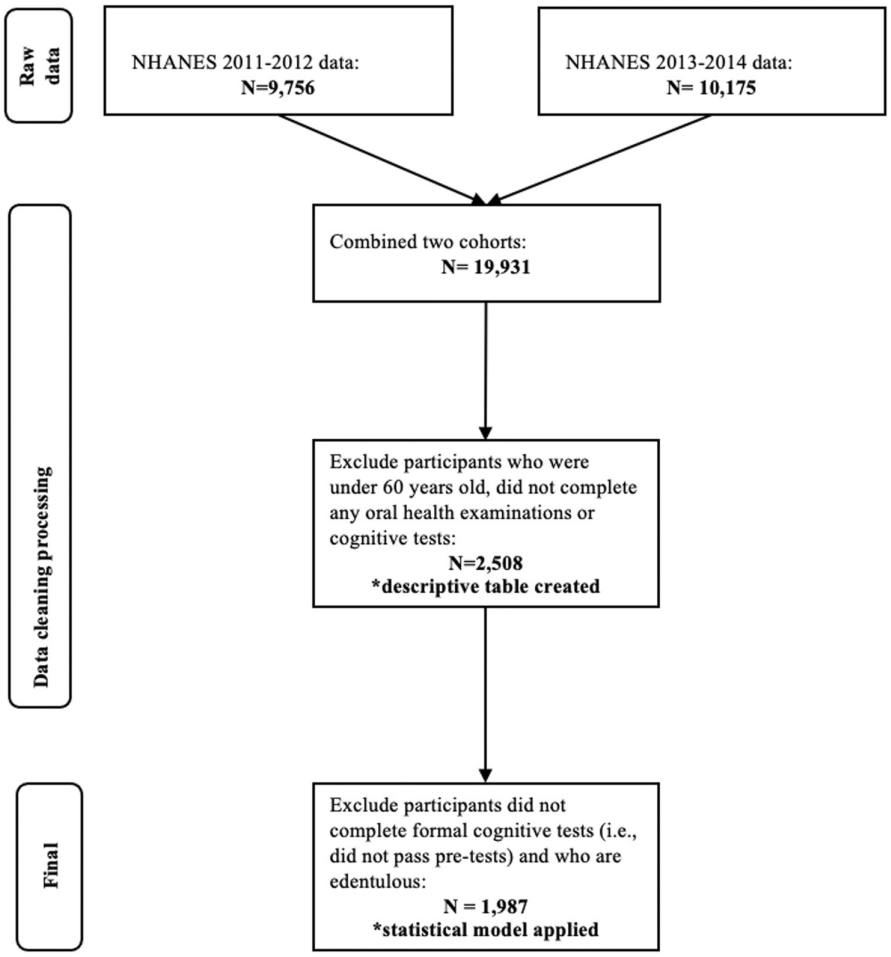

FIGURE 1 Flowchart of sample selection from raw data in NHANES (2011–2014) to the final sample. *N*, number of participants.

activity, intake of sugar, carbohydrate, and energy); comorbidities (cardiovascular diseases [including congestive heart failure, coronary heart disease, angina, and heart attack], diabetes, liver disease, arthritis, depression and sleep disorder); dental hygiene behavior (time since last dental visit, tooth brushing frequency per day, use dental floss). Data for both "time since last dental visit" and "dental floss" were available in NHANES 2011–2014 and toothbrush frequency data was only available in 2013–2014.

2.6 | Statistical analyses

Descriptive statistics were performed presenting cognitive function in quartiles among participants' characteristics. Continuous variables were presented as mean (SD) or median (interquartile range) and categorical variables were reported as frequency (%).

Participants who did not passed cognitive function pretests (pretest for animal fluency test and DSST test) or those who were edentulous were excluded at modelling stage, because no data were collected for them in formal cognitive tests and no periodontitis presented in edentulous. If a variable had more than 50% missing data, it will be excluded in the modelling. Moreover, 184 participants with recorded diastolic blood pressure < 50Hmm were considered as outlier and coded as missing data. Periodontitis was further grouped as binary (yes/no) in modelling stage for simplicity. Due to the significant amount of missing data in smoking status ($n = 1230$) and drug use ($n = 1168$), both were grouped into three categories (nonsmoker, ever smoker, unknown), where "unknown" stand for missing response. Cigarette numbers (missing response = 2169) and tooth-brushing frequency (not measured in participants aged 60+) were excluded due to insufficient data (missing response = 2169).

To test the relationship between each oral disease (periodontitis, dental caries, and tooth loss) and each cognitive function domain (memory, processing speed, and executive function), appropriate regression models were performed when treating cognitive function and oral disease as outcomes, respectively. Null models were tested first, and gradually adjusted for demography, lifestyle, anthropometry, presence of comorbidities, and dental hygiene behaviors in the fully adjusted models.

Finally, since the cognitive function consists of multiple domains and there are also multiple oral diseases, a structural equation model (SEM) was applied to understand the overall associations by assuming two latent variables: cognition and oral disease, in which model the variables consist of the latent variables was considered with equal weight without bias. Memory, executive function, and processing speed were the three observed variables for latent variable cognition, and dental caries and periodontitis were the two observed

variables for latent oral disease variable (tooth loss was highly correlated with dental caries therefore not used as another observed variable). All the covariates adjusted in the regression models were also adjusted in the SEM. The comparative fit index (CFI more than 0.9 would indicate good model fit) and root-mean-square estimate (RMSEA, less than 0.06 as an indication of a good fit) were used to examine the model fit (Bentler, 1990).

The variables which contained small proportion of missing data were handled via multiple imputation methods and coefficients were combined using Rubin's rule (Rubin, 2004). Data were also analyzed on complete cases (those with missing data) and sensitivity analysis was conducted to assess the impact of missing data. Statistical analyses were performed in R version 4.1.1 (https://cran.r-project.org/) with various packages. Significance level were set at 0.05.

3 | RESULTS

Overall, 2508 (50.1% male; mean age 69.3, SD 6.7) participants aged over 60 fulfilled the inclusion criteria (Figure 1). Full descriptive tables are in Tables S1–S3. Excluding edentulous participants and those who did not pass the cognitive pretest, 1987 participants remained. The average global cognitive score was 14.1 (SD 3.9) out of 30, and 49.4% participants had periodontitis (Table 1).

For cognitive function as outcome, fully adjusted models showed that the participants with periodontitis (β = −0.39, 95% CI [−0.69, −0.10]), more missing teeth (β = −0.04, 95% CI [−0.06, −0.02]), or more caries (DMFT β = −0.03, 95% CI [−0.06, −0.01]) were likely to have lower global cognitive score. In particular, the higher number of missing teeth was associated with lower executive function (beta −0.01, 95% CI [−0.02, −0.00]) and processing speed (β = −0.02, 95% CI [−0.03, −0.01]). The higher number of DMFT is related to lower processing speed (β = −0.01, 95% CI [−0.02, −0.01]) only. Having periodontitis was associated with poorer memory (β = −0.15, 95% CI [−0.30, 0.00] and processing speed (β = −0.16, 95% CI [−0.28, −0.04]) (Table 2). Tables summarize results from each stage of adjustments and can be view in Table S4.

For oral disease as outcome, three different regression models were applied based on the distribution of oral health outcomes: linear model for the number of DMFT, negative binomial model for the number of missing teeth, and binomial logistic regression for periodontitis (Histogram is available in Figure S1). In the fully adjusted models, the effect of global cognitive score on periodontitis (OR 0.95, 95% CI [0.92, 0.99]), the number of missing teeth (β = −0.03, 95% CI [−0.04, −0.01]), and DMFT (β = −0.13, 95% CI [−0.23, −0.04]) was demonstrated. Periodontitis was associated with poorer memory (OR = 0.93, 95% CI [0.87, 1.00] and processing speed (OR = 0.88, 95% CI [0.81, 0.96]). A higher number of DMFT was negatively associated with processing speed (β = −0.36, 95% CI [−0.58, −0.14]); while executive function (OR = −0.06, 95% CI [−0.09, −0.03]) and poorer processing speed (β = −0.07, 95% CI [−0.11, −0.04]) were strongly associated with the higher number of missing teeth (Table 3). Tables summarize results from each stage of adjustments and can be view in Table S5.

Finally, SEM showed association between the two latent variables: oral disease and cognitive function, after full adjustment (correlation $r = -0.22$, 95% CI [−0.34, −0.10]) (i.e., better cognitive function associated with better oral health—high value in oral disease indicate worse oral health) (Figure 2). The results showed that the data were well fitted in the model (CFI = 0.99, RMSEA = 0.05, SRMR = 0.02).

TABLE 1 Overall sample characteristics and characteristics in highest and lowest cognitive function quartiles: NHANES, 2011–2014.

		Cognitive function	
	Overall	<25%	≥75%
N	2508	605	606
Demographic			
Gender, male (%)	1257 (50.1)	352 (58.2)	235 (38.8)
Age, mean (SD)	69.3 (6.7)	71.8 (7.0)	66.3 (5.5)
Race (%)			
Mexican American	225 (9.0)	63 (10.4)	39 (6.4)
Other Hispanic	264 (10.5)	97 (16.0)	35 (5.8)
Non-Hispanic White	1149 (45.8)	200 (33.1)	393 (64.9)
Non-Hispanic Black	624 (24.9)	193 (31.9)	87 (14.4)
Other	246 (9.8)	52 (8.6)	52 (8.6)
Education, College or Above (%)	1241 (49.5)	142 (23.5)	466 (76.9)
PIR, Mean (SD)	2.6 (1.6)	1.9 (1.4)	3.4 (1.6)
Cognitive function			
Memory, Mean (SD)	6.0 (1.8)	4.1 (1.3)	7.7 (1.0)
Executive function, Mean (SD)	3.6 (1.5)	2.3 (1.0)	5.20 (1.3)
Processing speed, Mean (SD)	4.4 (1.6)	2.7 (1.0)	6.2 (1.0)
Global cognitive function, Mean (SD)	14.1 (3.9)	9.1 (1.8)	19.1 (1.8)
Oral health			
Missing teeth, Mean (SD)	11.9 (10.2)	16.1 (9.9)	7.0 (8.6)
DMFT, Mean (SD)	18.4 (7.3)	20.3 (7.5)	16.0 (6.6)
Periodontitis severity (%)			
None	1268 (50.6)	291 (48.1)	354 (58.4)
Mild–Moderate	978 (39.0)	239 (39.5)	206 (34.0)
Severe	262 (10.4)	75 (12.4)	46 (7.6)

Abbreviations: *N*, number of participants; PIR, poverty index ratio; SD, standard deviation. *Note*: PIR is defined as the ratio of total family income to the US poverty level; <25%, the participants with global cognitive function scores that are the lowest 25% in the overall sample size; ≥75%, participants with global cognitive function scores that are the highest 25% in the overall sample size. There were missing data in the following variables: education (<0.1%), income ratio (8.2%), processing speed (0.4%), and executive function (3.1%).

TABLE 2 Oral health's association with cognitive function outcomes: NHANES 2011–2014 ($n = 1987$).

		Cognitive outcomes (β[a], 95% CI)			
	Model	Memory	Executive function	Processing speed	Global cognitive score
Missing teeth	Unadjusted	−0.04 [−0.05, −0.03]***	−0.05 [−0.06, −0.04]***	−0.08 [−0.09, −0.07]***	−0.17 [−0.19, −0.15]***
	Adjusted[b]	−0.00 [−0.01, 0.01]	−0.01 [−0.02, −0.00]**	−0.02 [−0.03, −0.01]***	−0.04 [−0.06, −0.02]***
DMFT	Unadjusted	−0.03 [−0.04, −0.02]***	−0.04 [−0.03, −0.01]***	−0.04 [−0.05, −0.02]***	−0.09 [−0.11, −0.06]***
	Adjusted[b]	−0.01 [−0.02, 0.00]	−0.01 [−0.02, 0.00]	−0.01 [−0.02, −0.01]**	−0.03 [−0.06, −0.01]**
Periodontitis	Unadjusted	−0.57 [−0.72, −0.41]***	−0.79 [−0.53, −0.26]***	−0.79 [−0.94, −0.65]***	−1.75 [−2.10, −1.41]***
	Adjusted[b]	−0.15 [−0.30, 0.00]*	−0.08 [−0.22, 0.05]	−0.16 [−0.28, −0.04]**	−0.39 [−0.69, −0.10]**

Abbreviations: *N*, number of participants; CI, confidence interval; DMFT, the number of missing, decayed, filled tooth.

[a]Linear regression models were used to obtain coefficients: oral health factor as predictor, cognitive function as outcome. The beta represents the coefficient estimate of per tooth increase or per unit of DMFT increase or having periodontitis on each cognitive function.

[b]Adjusted for demographic variables (age, sex, ethnicity, education qualification, marital status, and poverty index ratio), anthropometric measures (BMI, waist measurement), lifestyle factors (smoking status, alcohol intake, substance misuse, physical activity, intake of sugar, carbohydrate, and energy), comorbidities (cardiovascular diseases, diabetes, liver disease, arthritis, depression, and sleep disorder), dental hygiene behavior (time since last dental visit, use dental floss).

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

TABLE 3 Cognitive function's association with oral health outcomes. NHANES ($n = 1987$), 2011–2014.

		Periodontitis	DMFT	Missing teeth
		OR, 95% CI	Beta, 95% CI	Beta, 95% CI
	Models	Logistic	Linear	Negative binomial
Memory	Unadjusted	0.82 [0.77, 0.86]***	−0.42 [−0.58, −0.25]***	−0.10 [−0.12, −0.07]***
	Adjusted[a]	0.93 [0.87, 1.00]*	−0.15 [−0.33, 0.02]	−0.01 [−0.04, 0.02]
Executive function	Unadjusted	0.94 [0.89, 1.00]*	−0.35 [−0.54, −0.16]***	−0.15 [−0.18, −0.12]***
	Adjusted[a]	0.95 [0.88, 1.03]	−0.17 [−0.38, 0.03]	−0.06 [−0.09, −0.03]***
Processing speed	Unadjusted	0.91 [0.86, 0.95]***	−0.54 [−0.71, −0.36]***	−0.22 [−0.25, −0.19]***
	Adjusted[a]	0.88 [0.81, 0.96]**	−0.36 [−0.58, −0.14]**	−0.07 [−0.11, −0.04]***
Global cognitive score	Unadjusted	0.88 [0.86, 0.91]***	−0.23 [−0.30, −0.16]***	−0.08 [−0.09, −0.07]***
	Adjusted[a]	0.95 [0.92, 0.99]**	−0.13 [−0.23, −0.04]**	−0.03 [−0.04, −0.01]***

Abbreviations: *N*, number of participants; CI, confidence interval; DMFT, the number of missing, decayed, filled tooth.

[a]Adjusted for demographic variables (age, sex, ethnicity, education qualification, marital status, and poverty index ratio), anthropometric measures (BMI, waist measurement), lifestyle factors (smoking status, alcohol intake, substance misuse, physical activity, intake of sugar, carbohydrate, and energy), comorbidities (cardiovascular diseases, diabetes, liver disease, arthritis, depression, and sleep disorder), dental hygiene behavior (time since last dental visit, use dental floss).

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

Sensitivity analysis using complete cases was performed and results remain robust (Supplement Table S6 and S7 for modelling results, Figure S2 for SEM results of sensitivity analysis).

4 | DISCUSSION

Our study revealed robust associations between oral diseases (dental caries, periodontitis, and tooth loss) and poor global cognitive function in individuals over 60 years of age. Interestingly, we found that processing speed is associated with every oral disease, but memory or executive function is only associated with certain oral disease.

To date, hundreds of original studies have examined the association between oral diseases and cognitive function/decline. Our results are supported by some of them: previous findings showed the negative effect of poor oral health on the cognitive function (Demmer et al., 2020; Kang, Wu, et al., 2019; Winning et al., 2022), especially the bidirectional relationship over a 6-year follow-up (Kang et al., 2020). The studies successfully found the association including this study are similar on large sample size (more than 1000 participants), well-adjusted statistical model (e.g., with consideration on essential health behaviors and health status), and participants aged 45–60 or over (mid to old age). However, there are still many other previous studies failed to find such association. For example, some found no differences on dementia outcome

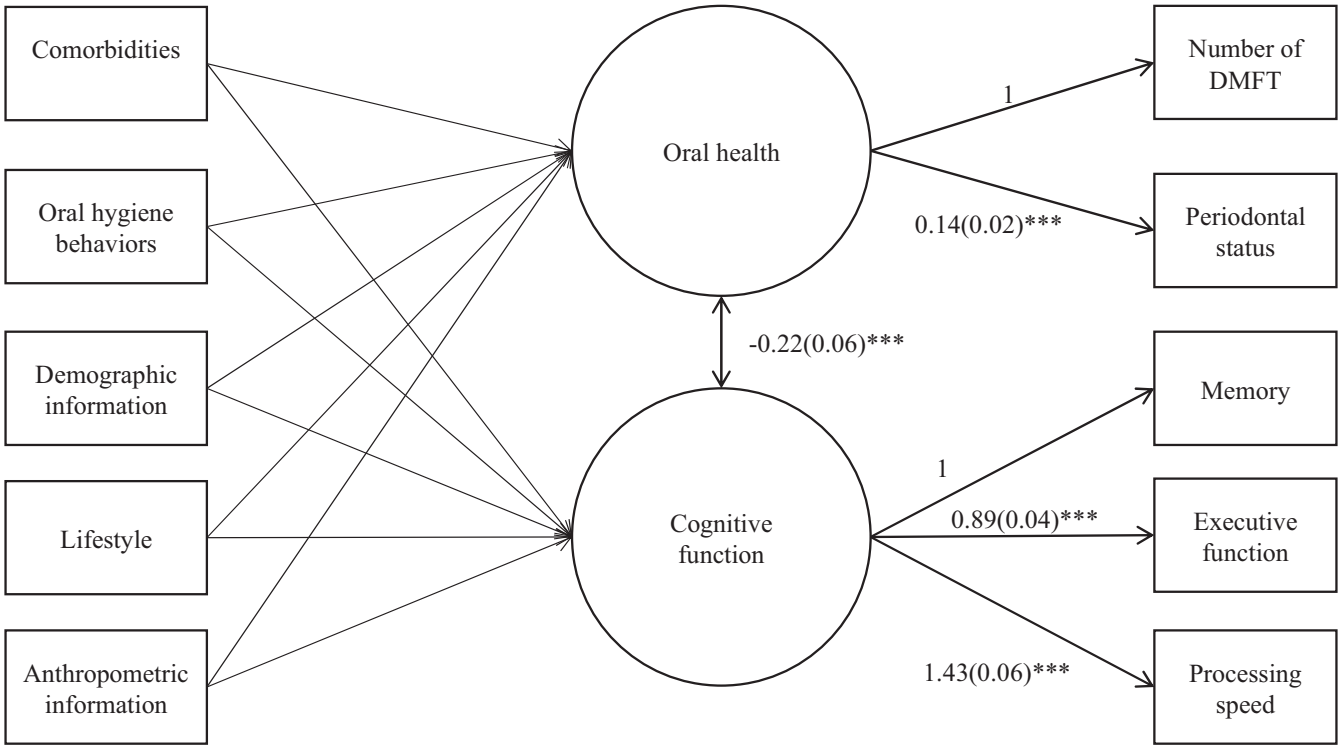

FIGURE 2 Structure Equation model considering oral health and cognitive function as two latent variables. The cycle represented the latent variable; the rectangle represented observed values. The coefficient estimate and standardized error were marked next to the solid line, which indicated the association. Covariates were summarized and represented by its category in this diagram: demographic variables (age, sex, ethnicity, education qualification, marital status, and poverty index ratio), anthropometric measures (BMI, waist measurement), lifestyle factors (smoking status, alcohol intake, substance misuse, physical activity, intake of sugar, carbohydrate, and energy), comorbidities (cardiovascular diseases, diabetes, liver disease, arthritis, depression, and sleep disorder), dental hygiene behavior (time since last dental visit, use dental floss). ***$p < 0.001$.

between periodontitis group and non-periodontitis group (Holmer et al., 2022). Compared to our study, this study did not consider the effect from smoking and sample size in final follow-up and analysis despite of large sample size at beginning. The definition of periodontitis is also different where they consider deep pocket depth only but our study and some other study use both clinical attachment loss and pocket depth simultaneously. This could also lead to different conclusions. Varied study qualities and mixed evidence have also been noted from a recent systematic review, where they discussed how study design factors can influence the prevalence and risk estimates of cognitive disorders in relation to oral diseases. These factors include cross sectional versus longitudinal study designs, inconsistent definitions of oral diseases (especially periodontal disease), self-reported vs clinical assessed oral diseases/cognitive decline or dementia, varying sample sizes, confounding effects, and data quality (Larvin, Gao, et al., 2023). Our study will contribute to the expanding knowledge pool on the association between oral diseases and cognitive health by providing reliable, and robust evidence with adjustments on essential covariates.

The impact of oral diseases, from dental caries or periodontitis to its end stage—tooth loss, on cognitive function might be explained through the "nutrition pathway": oral disease or tooth loss can cause chewing disability, leading to limited diet selection and lack of nutrition intake (Kossioni, 2018). This can contribute to poorer cognitive function due to malnourishment (Shatenstein et al., 2012). However, this mechanism may only explain the association between oral diseases and cognitive impairment in those with severe tooth loss, especially those who do not use dentures (Witter et al., 1990). Hence, the "commonly inflammatory pathway" theory is more supported by existing evidence (Beydoun et al., 2020; Matsushita et al., 2020; Tonsekar et al., 2017). This theory suggested that oral pathogens such as *Porphyromonas gingivalis* which is responsible for chronic oral disease like periodontitis, may travel through blood vessels to the body and brain and contribute to neurodegeneration (Dominy et al., 2019). However, this theory is not fully convincing too, as there are still studies arguing that the exiting evidence supporting this mechanism is still limited and mixed in study quality (Thomson & Barak, 2021). Future high-quality biological studies are needed to further support this hypothesis. Other "life course" studies have proposed that it is the poorer health behavior and lifestyle choice (e.g., smoking and high sugar consumption) of people with lower cognitive function at a young age that result in worse oral health in older age. These individuals with lower cognitive function at a young age are also at higher risk of cognitive decline and dementia in older age (Thomson et al., 2019; Thomson & Barak, 2021). True, better

cognitive function may indicate better awareness and capability of dental care, whereas poor oral hygiene behaviors due to cognitive impairment could worsen the oral health conditions (Thomson et al., 2018; Wu et al., 2007). Our observed reciprocal relationship between oral health and cognitive function among people over 60 years old provided a snapshot evidence supporting the "oral-cognition" association, but it is still a long way to go to find the actual mechanism.

Furthermore, each cognitive domain showed different levels of association with each oral disease. Processing speed is related to all oral diseases, but periodontitis was associated with memory but not executive function. Tooth loss and dental carries were associated with executive function but not memory. However, this interpretation should be approached with caution in the absence of a plausible biological explanation. Future studies should explore specific cognitive domains and oral diseases to understand their shared pathogenicity and identify targeted populations for intervention.

Our study has several strengths. First, our study benefited from the nationally representative, high quality, large-scale NHANES data in the aging population with minimal selection bias. Clinical measurements of oral features and professional cognitive assessment contribute to a more reliable result. Confounding factors which ranged from demographic information to oral hygiene behaviors, multiple methods, questionnaire, interview, physical measurements were also used and guaranteed by the quality of the data (Statistics NCfH, n.d.). Secondly, our study utilized comprehensive and well-adjusted statistical modelling approaches. Especially, the use of SEM considered oral health and cognitive function as latent variables commonly with less bias from measurement (Tomarken & Waller, 2005). This further ensure the validity and reliability of the robustness in the results, and sensitivity analysis further demonstrated our result's robustness.

Our study also has some limitations. First, NHANES is cross sectional survey; thus, we cannot draw causal inference; the underlying mechanism and causality still needs investigation. Second, residual selection bias may occur by excluding edentulous participants or those who failed cognitive pretest. Third, there were different levels of data missing in several covariates (e.g., 46.57% data missing in drug use) which might be due to unwillingness of sharing this experience. Therefore, reporter bias might occur. While smoking was an important mediator/moderator in the association between oral disease and cognitive function, in our study, high proportion of missing data in smoking status made such insightful analyses not possible. Finally, it is worth noting that this study did not include the edentulous participants, but the residual damage of periodontitis could still remain in those patients. It is not fully understood biologically yet how the residual damage influence on the cognitive function status, but evidence from many studies have shown edentulism contributes to greater risks ofdementia (Stein et al., 2010) and cognitive decline (Naorungroj et al., 2015).

Oral health is undoubtable an important part of healthy aging, and oral care in the aging population should not be neglected. While we cannot conclude whether the association between oral disease and poor cognitive function is causal, prevention of oral disease is crucial for a better quality of life.

5 | CONCLUSIONS

Our study showed the associations between oral diseases and cognitive function in the aging population, emphasizing the importance of maintaining a good cognitive function and oral health. Our study also provides insight into the association between specific oral diseases and cognitive domains. Further studies are required to explore whether a causal association exists and to investigate the biological mechanism.

AUTHOR CONTRIBUTIONS

Chenyi Gao: Investigation; methodology; writing – original draft; writing – review and editing; software; formal analysis; data curation. **Harriet Larvin:** Writing – review and editing. **David Timothy Bishop:** Supervision; writing – review and editing; funding acquisition. **David Bunce:** Funding acquisition; writing – review and editing; validation; supervision. **Susan Pavitt:** Methodology; writing – review and editing; funding acquisition. **Jianhua Wu:** Conceptualization; funding acquisition; writing – review and editing; writing – original draft; methodology; supervision; data curation. **Jing Kang:** Conceptualization; investigation; funding acquisition; writing – original draft; writing – review and editing; methodology; supervision; resources.

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CONFLICT OF INTEREST STATEMENT

All authors have no conflicts of interest to disclose.

DATA AVAILABILITY STATEMENT

This study has used data from the National Health and Nutrition Examination Survey conducted by the Centers for Disease Control and Prevention in the United States. The data are free and anyone can access it from: https://wwwn.cdc.gov/nchs/nhanes/Default.aspx

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REFERENCES

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin*, *107*(2), 238–246. https://doi.org/10.1037/0033-2909.107.2.238

Beydoun, M. A., Beydoun, H. A., Hossain, S., El-Hajj, Z. W., Weiss, J., & Zonderman, A. B. (2020). Clinical and bacterial markers of periodontitis and their association with incident all-cause and Alzheimer's disease dementia in a large National Survey. *Journal of Alzheimer's Disease*, *75*(1), 157–172. https://doi.org/10.3233/JAD-200064

Bienias, J. L., Beckett, L. A., Bennett, D. A., Wilson, R. S., & Evans, D. A. (2003). Design of the Chicago Health and Aging Project (CHAP). *Journal of Alzheimer's Disease*, *5*(5), 349–355. https://doi.org/10.3233/JAD-2003-5501

Demmer, R. T., Norby, F. L., Lakshminarayan, K., Walker, K. A., Pankow, J. S., Folsom, A. R., Mosley, T., Beck, J., & Lutsey, P. L. (2020). Periodontal disease and incident dementia: The atherosclerosis risk in communities study (ARIC). *Neurology*, *95*(12), e1660–e1671. https://doi.org/10.1212/WNL.0000000000010312

Dominy, S. S., Lynch, C., Ermini, F., Benedyk, M., Marczyk, A., Konradi, A., Nguyen, M., Haditsch, U., Raha, D., Griffin, C., Holsinger, L. J., Arastu-Kapur, S., Kaba, S., Lee, A., Ryder, M. I., Potempa, B., Mydel, P., Hellvard, A., Adamowicz, K., … Potempa, J. (2019). Porphyromonas gingivalis in Alzheimer's disease brains: Evidence for disease causation and treatment with small-molecule inhibitors. *Science Advances*, *5*(1), eaau3333. https://doi.org/10.1126/sciadv.aau3333

Eke, P. I., Page, R. C., Wei, L., Thornton-Evans, G., & Genco, R. J. (2012). Update of the case definitions for population-based surveillance of periodontitis. *Journal of Periodontology (1970)*, *83*(12), 1449–1454. https://doi.org/10.1902/jop.2012.110664

Holmer, J., Eriksdotter, M., Häbel, H., Hed Myrberg, I., Jonsson, A., Pussinen, P. J., Garcia-Ptacek, S., Jansson, L., Sandborgh-Englund, G., & Buhlin, K. (2022). Periodontal conditions and incident dementia: A nationwide Swedish cohort study. *Journal of Periodontology (1970)*, *93*, 1378–1386. https://doi.org/10.1002/JPER.21-0518

Holtfreter, B., Albandar, J. M., Dietrich, T., Dye, B. A., Eaton, K. A., Eke, P. I., Papapanou, P. N., Kocher, T., & Joint EU/USA Periodontal Epidemiology Working Group. (2015). Standards for reporting chronic periodontitis prevalence and severity in epidemiologic studies: Proposed standards from the joint EU/USA periodontal epidemiology working group. *Journal of Clinical Periodontology*, *42*(5), 407–412. https://doi.org/10.1111/jcpe.12392

Hong, J., Whelton, H., Douglas, G., & Kang, J. (2018). Consumption frequency of added sugars and UK children's dental caries. *Community Dentistry and Oral Epidemiology*, *46*(5), 457–464. https://doi.org/10.1111/cdoe.12413

Kamer, A. R., Craig, R. G., Dasanayake, A. P., Brys, M., Glodzik-Sobanska, L., & de Leon, M. J. (2008). Inflammation and Alzheimer's disease: Possible role of periodontal diseases. *Alzheimer's & Dementia*, *4*(4), 242–250. https://doi.org/10.1016/j.jalz.2007.08.004

Kang, J., Palmier-Claus, J., Wu, J., Shiers, D., Larvin, H., Doran, T., & Aggarwal, V. R. (2022). Periodontal disease in people with a history of psychosis: Results from the UK biobank population-based study. *Community Dentistry and Oral Epidemiology*, *51*, 985–996. https://doi.org/10.1111/cdoe.12798

Kang, J., Smith, S., Pavitt, S., & Wu, J. (2019). Association between central obesity and tooth loss in the non-obese people: Results from the continuous National Health and nutrition examination survey (NHANES) 1999-2012. *Journal of Clinical Periodontology*, *46*(4), 430–437. https://doi.org/10.1111/jcpe.13091

Kang, J., Wu, B., Bunce, D., Ide, M., Aggarwal, V. R., Pavitt, S., & Wu, J. (2020). Bidirectional relations between cognitive function and oral health in ageing persons: A longitudinal cohort study. *Age and Ageing*, *49*(5), 793–799. https://doi.org/10.1093/ageing/afaa025

Kang, J., Wu, B., Bunce, D., Ide, M., Pavitt, S., & Wu, J. (2019). Cognitive function and oral health among ageing adults. *Community Dentistry and Oral Epidemiology*, *47*(3), 259–266. https://doi.org/10.1111/cdoe.12452

Kossioni, A. E. (2018). The Association of Poor Oral Health Parameters with malnutrition in older adults: A review considering the potential implications for cognitive impairment. *Nutrients*, *10*(11), 1709. https://doi.org/10.3390/nu10111709

Larvin, H., Gao, C., Kang, J., Aggarwal, V. R., Pavitt, S., & Wu, J. (2023a). The impact of study factors in the association of periodontal disease and cognitive disorders: Systematic review and meta-analysis. *Age and Ageing*, *52*(2), afad015. https://doi.org/10.1093/ageing/afad015

Larvin, H., Kang, J., Aggarwal, V. R., Pavitt, S., & Wu, J. (2021a). Multimorbid disease trajectories for people with periodontitis. *Journal of Clinical Periodontology*, *48*(12), 1587–1596. https://doi.org/10.1111/jcpe.13536

Larvin, H., Kang, J., Aggarwal, V. R., Pavitt, S., & Wu, J. (2021b). Risk of incident cardiovascular disease in people with periodontal disease: A systematic review and meta-analysis. *Clinical and Experimental Dental Research*, *7*(1), 109–122. https://doi.org/10.1002/cre2.336

Larvin, H., Kang, J., Aggarwal, V. R., Pavitt, S., & Wu, J. (2023b). Periodontitis and risk of immune-mediated systemic conditions: A systematic review and meta-analysis. *Community Dentistry and Oral Epidemiology*, *51*(5), 705–717. https://doi.org/10.1111/cdoe.12812

Larvin, H., Kang, J., Aggarwal, V. R., Pavitt, S., & Wu, J. (2022). The additive effect of periodontitis with hypertension on risk of systemic disease and mortality. *Journal of Periodontology*, *93*(7), 1024–1035. https://doi.org/10.1002/JPER.21-0621

Larvin, H., Wilmott, S., Kang, J., Aggarwal, V. R., Pavitt, S., & Wu, J. (2021). Additive effect of periodontal disease and obesity on COVID-19 outcomes. *Journal of Dental Research*, *100*(11), 1228–1235. https://doi.org/10.1177/00220345211029638

Larvin, H., Wilmott, S., Wu, J., & Kang, J. (2020). The impact of periodontal disease on hospital admission and mortality during COVID-19 pandemic. *Front Med (Lausanne)*, *7*, 604980. https://doi.org/10.3389/fmed.2020.604980

Lin, C. S. (2018). Revisiting the link between cognitive decline and masticatory dysfunction. *BMC Geriatrics*, *18*(1), 5. https://doi.org/10.1186/s12877-017-0693-z

Matsushita, K., Yamada-Furukawa, M., Kurosawa, M., & Shikama, Y. (2020). Periodontal disease and periodontal disease-related bacteria involved in the pathogenesis of Alzheimer's disease. *Journal of Inflammation Research*, *13*, 275–283. https://doi.org/10.2147/JIR.S255309

Morris, J. C., Heyman, A., Mohs, R. C., Hughes, J. P., van Belle, G., Fillenbaum, G., Mellits, E. D., & Clark, C. (1989). The consortium to establish a registry for Alzheimer's disease (CERAD). Part I. Clinical and neuropsychological assessment of Alzheimer's disease. *Neurology*, *39*(9), 1159–1165.

Naorungroj, S., Schoenbach, V. J., Wruck, L., Mosley, T. H., Gottesman, R. F., Alonso, A., Heiss, G., Beck, J., & Slade, G. D. (2015). Tooth loss, periodontal disease, and cognitive decline in the atherosclerosis risk in communities (ARIC) study. *Community Dentistry and Oral Epidemiology*, *43*(1), 47–57. https://doi.org/10.1111/cdoe.12128

Noble, J. M., Scarmeas, N., & Papapanou, P. N. (2013). Poor Oral health as a chronic, potentially modifiable dementia risk factor: Review of the literature. *Current Neurology and Neuroscience Reports*, *13*(10), 1–8. https://doi.org/10.1007/s11910-013-0384-x

Oh, B., Han, D. H., Han, K. T., Liu, X., Ukken, J., Chang, C., Dounis, K., & Yoo, J. W. (2018). Association between residual teeth number in later life and incidence of dementia: A systematic review and meta-analysis. *BMC Geriatrics*, *18*(1), 48. https://doi.org/10.1186/s12877-018-0729-z

Plassman, B. L., Langa, K. M., Fisher, G. G., Heeringa, S. G., Weir, D. R., Ofstedal, M. B., Burke, J. R., Hurd, M. D., Potter, G. G., Rodgers, W. L., Steffens, D. C., Willis, R. J., & Wallace, R. B. (2007). Prevalence

of dementia in the United States: The aging, demographics, and memory study. *Neuroepidemiology*, *29*(1–2), 125–132. https://doi.org/10.1159/000109998

Proust-Lima, C., Amieva, H., Dartigues, J.-F., & Jacqmin-Gadda, H. (2006). Sensitivity of four psychometric tests to measure cognitive changes in brain aging-population–based studies. *American Journal of Epidemiology*, *165*(3), 344–350. https://doi.org/10.1093/aje/kwk017

Rubin, D. B. (2004). Multiple imputation for nonresponse in surveys. In *Wiley classics library*. Wiley-Interscience 287p.

Shatenstein, B., Ferland, G., Belleville, S., Gray-Donald, K., Kergoat, M. J., Morais, J., Gaudreau, P., Payette, H., & Greenwood, C. (2012). Diet quality and cognition among older adults from the NuAge study. *Experimental Gerontology*, *47*(5), 353–360. https://doi.org/10.1016/j.exger.2012.02.002

Shen, T., Lv, J., Wang, L., Wang, W., & Zhang, D. (2016). Association between tooth loss and dementia among older people: A meta-analysis. *International Journal of Geriatric Psychiatry*, *31*(8), 953–955. https://doi.org/10.1002/gps.4396

Singhrao, S. K., Harding, A., Simmons, T., Robinson, S., Kesavalu, L., & Crean, S. (2014). Oral inflammation, tooth loss, risk factors, and association with progression of Alzheimer's disease. *Journal of Alzheimer's Disease*, *42*(3), 723–737. https://doi.org/10.3233/JAD-140387

Statistics NCfH National Health and Nutrition Examination Survey. https://www.cdc.gov/nchs/nhanes/index.htm

Stein, P. S., Kryscio, R. J., Desrosiers, M., Donegan, S. J., & Gibbs, M. B. (2010). Tooth loss, Apolipoprotein E, and decline in delayed word recall. *Journal of Dental Research*, *89*(5), 473–477. https://doi.org/10.1177/0022034509357881

Strauss, E., Sherman, E. M. S., & Spreen, O. (2006). *A compendium of neuropsychological tests: Administration, norms, and commentary*. Oxford University Press.

Thomson, W. M., & Barak, Y. (2021). Tooth loss and dementia: A critical examination. *Journal of Dental Research*, *100*(3), 226–231. https://doi.org/10.1177/0022034520957233

Thomson, W. M., Broadbent, J. M., Caspi, A., Poulton, R., & Moffitt, T. E. (2019). Childhood IQ predicts age-38 oral disease experience and service-use. *Community Dentistry and Oral Epidemiology*, *47*(3), 252–258. https://doi.org/10.1111/cdoe.12451

Thomson, W. M., Smith, M. B., Ferguson, C. A., Kerse, N. M., Peri, K., & Gribben, B. (2018). Oral status, cognitive function and dependency among New Zealand nursing home residents. *Gerodontology*, *35*(3), 185–191. https://doi.org/10.1111/ger.12337

Tomarken, A. J., & Waller, N. G. (2005). Structural equation modeling: Strengths, limitations, and misconceptions. *Annual Review of Clinical Psychology*, *1*(1), 31–65. https://doi.org/10.1146/annurev.clinpsy.1.102803.144239

Tonsekar, P. P., Jiang, S. S., & Yue, G. (2017). Periodontal disease, tooth loss and dementia: Is there a link? A systematic review. *Gerodontology*, *34*(2), 151–163. https://doi.org/10.1111/ger.12261

Von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2007). The strengthening the reporting of observational studies in epidemiology (STROBE) statement: Guidelines for reporting observational studies. *Annals of Internal Medicine*, *147*(8), 573–577.

Winning, L., Naseer, A., De Looze, C., Knight, S. P., Kenny, R. A., & O'Connell, B. (2022). Tooth loss and cognitive decline in community dwelling older Irish adults: A cross-sectional cohort study. *Journal of Dentistry*, *119*, 104077. https://doi.org/10.1016/j.jdent.2022.104077

Witter, D. J., Cramwinckel, A. B., van Rossum, G. M. J. M., & Käyser, A. F. (1990). Shortened dental arches and masticatory ability. *Journal of Dentistry*, *18*(4), 185–189. https://doi.org/10.1016/0300-5712(90)90107-P

Wu, B., Fillenbaum, G. G., Plassman, B. L., & Guo, L. (2016). Association between Oral health and cognitive status: A systematic review. *Journal of the American Geriatrics Society*, *64*(8), 1752. https://doi.org/10.1111/jgs.14572

Wu, B., Plassman, B. L., Liang, J., & Wei, L. (2007). Cognitive function and dental care utilization among community-dwelling older adults. *American Journal of Public Health (1971)*, *97*(12), 2216–2221. https://doi.org/10.2105/AJPH.2007.109934

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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