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Relationship between mild cognitive decline and oral motor functions in metropolitan community-dwelling older Japanese: The Takashimadaira study

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ABSTRACT

Background: Diminished oral motor function is considered to be a factor influencing cognitive decline, but this association has not been clarified. The aim of the present study was to clarify the association between cognitive and oral motor function in older people with either from normal cognitive function or mild cognitive decline.
Methods: A cross-sectional study was conducted across 1118 older people (445 men, 673 women) aged ≥70 years (mean age, 77.0 ± 4.7 years) who lived in a city of Tokyo Metropolis, Japan. Cognitive function was assessed using the Mini-Mental State Examination (MMSE). Older people who had an MMSE score of 23 points or lower were excluded. To investigate the relationship between cognitive and oral motor function, Pearson's correlation, multiple linear regression, and path analysis were performed.
Results: Pearson's correlation revealed that, among the oral motor functions assessed, masticatory performance, occlusal force, and tongue pressure were correlated with MMSE score. Multiple linear regression showed that tongue pressure and oral diadochokinesis (ODK) were significantly associated with MMSE score. Path analysis revealed that decreases in tongue pressure and in ODK were directly associated with decreases in MMSE score. Decreases in tongue pressure were also indirectly associated with decreases in MMSE score via decreases in ODK.
Conclusions: Among the oral motor functions assessed, tongue pressure and ODK were associated with cognitive function in older people ranging from those with normal cognitive function to those with mild cognitive decline. Diminished tongue pressure and ODK might thus lead to cognitive decline.

1. Introduction

The global population of patients with dementia is estimated to be 46.8 million, with over 9.9 million new cases of dementia diagnosed annually (Prince et al., 2015). The number of patients with dementia has also increased in Japan, where dementia has become the leading cause of conditions requiring care (Cabinet Office, Governmento of Japan, 2017). However, there is no established treatment for dementia (Livingston et al., 2017). Within this context, there have been several reports on the risk factors of decreasing cognitive function and the onset of dementia (Baumgart et al., 2015; Livingston et al., 2017; Suzuki et al., 2013). According to these reports, treatment of prodromal symptoms of dementia with decreased cognitive function is essential in delaying the onset of dementia.

Recently, an association with cognitive function was reported not only with physical function and medical history but also in oral motor function. For example, Watanabe et al. found an association between decreased oral diadochokinesis (ODK) and mild cognitive decline (Watanabe et al., 2018). Similarly, Ikebe et al. reported that decreased occlusal force might lead to decreased cognitive function (Ikebe et al., 2018). These reports suggested that oral motor function was associated with cognitive function. However, few studies investigated the interrelationship between mild cognitive decline as prodromal symptoms of dementia and decline in multiple oral motor functions. If the

Abbreviations: DVS, dietary variety score; GDS-S-J, Geriatric Depression Scale-Short Version-Japanese; HDL, high-density lipoprotein; I-ADL, instrumental activities of daily living; JST-IC, Japan Science and Technology Agency Index of Competence; MMSE, Mini-Mental State Examination; ODK, oral diadochokinesis; RSST, repetitive saliva swallowing test

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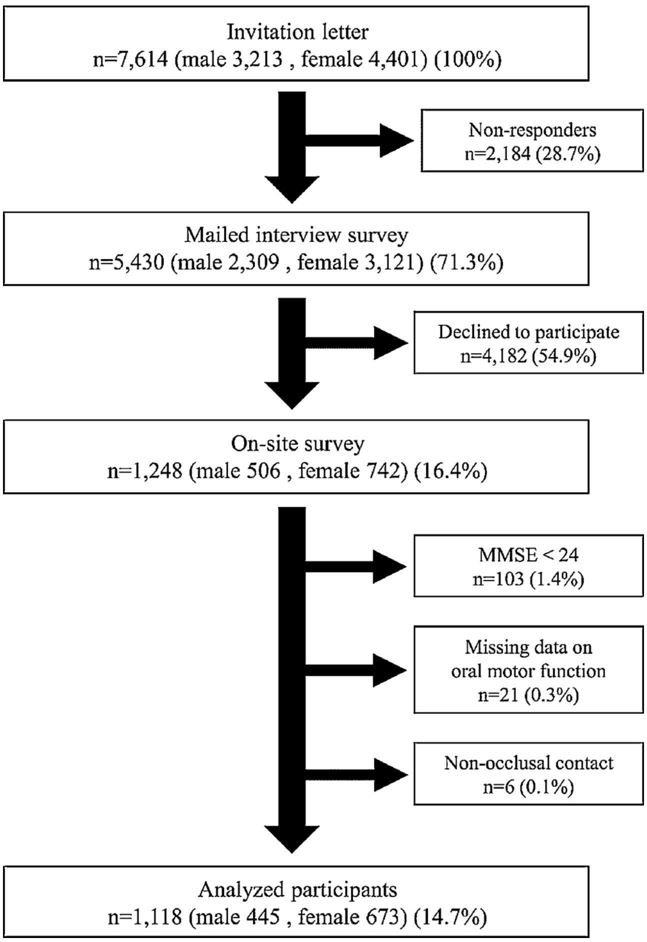

Fig. 1. Study flowchart and participant response rates.

interrelationship between cognitive function and oral motor function is clarified, it is possible that cognitive function may be maintained with proper maintenance of oral motor functions. In order to confirm the interrelationship between cognitive function and oral motor functions, it is first necessary to clarify the association between them.

The aim of the present study was to clarify the association between cognitive function and oral motor functions in older people ranging from those with normal cognitive function to those with mild cognitive decline.

2. Materials and methods

2.1. Design, setting, and participants

Data for this study were derived from a longitudinal cohort study, the Takashimadaira study, that aimed to develop a model of dementia friendly communities in the metropolitan area of Tokyo, Japan. Data collection was performed in two steps: a mailed interview survey and an on-site survey. The flow of these assessments is shown in Fig. 1.

The initial interview survey was conducted for all older citizens (aged ≥70 years, 7614 people) living in Takashimadaira, Itabashi-ku, Tokyo, Japan, wherein all participants were mailed a self-administered questionnaire. Thereafter, all participants were visited at home by an investigator who collected their questionnaires. For the 5430 people who completed the mailed questionnaire, an additional on-site, guided survey was offered. A total of 1248 people participated in this on-site survey, which examined cognitive function, oral motor functions, motor function, and blood biochemical markers. Cognitive function was assessed using the Mini-Mental State Examination (MMSE). In this study, older people ranging from those with normal cognitive function to those with mild cognitive decline were targeted. Participants with an MMSE score of 23 or less were considered to have general cognitive impairment. Therefore, only participants with an MMSE score between 24 and 30 were included in this study. Out of 1248 participants, there were 1145 participants with an MMSE score between 24 and 30, and 103 participants with MMSE score of 23 or less. Twenty-one participants who were unable to complete all parts of the oral motor function assessment and 6 participants without occlusal contact of natural teeth and without removable dentures were excluded from the analysis.

A total of 1118 participants (445 men and 673 women; mean age, 77.0 ± 4.7 years) were included in the analysis. During the on-site survey, participants were informed about the objectives and content of the survey in writing and verbally, and their written consent to participate in this study was obtained. This study was approved by the Ethics Committee of the Tokyo Metropolitan Institute of Gerontology (Approval No. 9 and No. 31 in 2016).

2.2. Mailed interview survey

2.2.1. Basic characteristics

Age, sex, household status (living alone, as a couple, or living with a family member other than the spouse), years of education, smoking and alcohol consumption, annual income (no annual income, < 1 million yen, < 1-3 million yen, < 3-7 million yen, < 7-10 million yen, and ≥10 million yen) were recorded.

2.2.2. Mental functioning

The depression status was assessed using the Geriatric Depression Scale-Short Version-Japanese (GDS-S-J; Sugishita & Asada, 2009).

2.3. On-site survey

The on-site survey included assessments for cognitive function, oral motor functions, and general motor functions, as well as laboratory tests for biochemical markers. Before conducting the on-site survey, the evaluators attended lectures and received practical training on the examination methods, use of examination equipment, and assessment standards, to standardize evaluator performance. The on-site survey was conducted under the supervision of physicians and dentists.

2.3.1. Basic characteristics

Body mass index, dietary variety, and instrumental activities of daily living (I-ADL) were assessed. Dietary variety was assessed using a dietary variety score (DVS; Kumagai et al., 2003). I-ADL was assessed using the Japan Science and Technology Agency Index of Competence (JST-IC; Iwasa et al., 2018).

2.3.2. Oral related factors

Four dentists and eight dental hygienists evaluated oral related factors. Oral motor functions assessed included masticatory ability, occlusal force, maximal tongue pressure, ODK, and swallowing function. Removable denture users underwent the examinations while wearing their dentures. Masticatory performance was assessed using gummy jelly (Test gummy jelly for evaluating masticatory performance; UHA Mikakuto Co., Ltd., Osaka, Japan) (Nokubi et al., 2013; Yasui et al., 2012). The occlusal force was assessed using pressure-sensitive sheets (Dental Prescale 50 H R type; Fuji Film Co., Tokyo, Japan) (Hidaka, Iwasaki, Saito, & Morimoto, 1999). The maximal tongue pressure was assessed using a tongue pressure measurement device (JMS tongue pressure device; JMS Co., Ltd., Hiroshima, Japan) (Tsuga, Maruyama, Yoshikawa, Yoshida, & Akagawa, 2011). ODK was evaluated using the articulatory velocity of */ta/* using an oral functions measurement device (KENKOU-KUN handy; Takei Scientific Instruments Co., Ltd., Niigata, Japan) (Watanabe et al., 2011). Swallowing function was assessed using a repetitive saliva swallowing test (RSST;

Oguchi et al., 2000). In addition, the number of present teeth and presence of removable dentures were recorded.

2.3.3. Physical and cognitive function

Cognitive function was assessed using the Japanese version of MMSE (Folstein, Folstein, & McHugh, 1975), which was administered by 10 trained registered nurses and clinical psychologists. Physical functions were assessed by four specialized researchers. Handgrip strength was measured using a Smedley dynamometer (Grip-A; Takei Scientific Instruments Co., Ltd., Niigata, Japan). It was measured twice for the dominant hand, and the highest measured value was used for analysis. Exercise ability was determined via a single measurement of gait speed over 5 m. Subjective hearing was assessed using the Questionnaire on Hearing 2002 (Suzuki et al., 2002, 2009).

2.3.4. Medical history

Participants were interviewed about any history or current presence of hypertension, stroke, heart disease, diabetes mellitus, hyperlipidemia, and Parkinson's disease by nurses.

2.3.5. Blood biochemistry

Samples of blood were collected from participants by registered nurses for a biochemical assessment. Serum albumin levels, high-density lipoprotein (HDL) cholesterol levels, red blood cell counts, hemoglobin levels, and Hemoglobin A1c levels, reported to be related to cognitive function were analyzed (Taniguchi et al., 2014; Zhang, Pereira, Luo, & Matheson, 2017). Analyses were carried out in one laboratory (Health Sciences Research Institute, Inc., Yokohama, Japan).

2.4. Statistical analyses

Statistical analyses were performed in three phases. First, the correlation between all assessed items was examined by Pearson's correlation analysis. Second, multiple linear regression analysis was

performed with MMSE score as the objective variable; oral motor functions as the explanatory variables; and factors associated with cognitive function, including I-ADL, the functional status, medical history, and biochemical markers, as confounding factors (Baumgart et al., 2015; Li et al., 2011; Suzuki et al., 2013; Taniguchi et al., 2014). Finally, path analysis was performed to examine the interrelationship between cognitive function and oral motor functions using factors that were significantly associated with cognitive function in the multiple linear regression analysis. All analyses were performed using IBM SPSS version 22 (IBM Corp., Armonk, NY, USA). IBM SPSS AMOS Version 20 (IBM Corp.) was used for path analysis. The significance level was set at $\alpha = 0.05$.

Table 1
Characteristics of older people living in metropolitan areas in Japan who participated in the study.

Characteristic (mean ± SD)	Overall (n = 1118)	Men (n = 445)	Women (n = 673)
Sociodemographics			
Age (years)	77.0 ± 4.7	77.0 ± 4.9	77.0 ± 4.5
Body mass index (kg/m^2)	23.0 ± 3.2	23.4 ± 2.9	22.7 ± 3.3
Living alone, (n) [%]	(452) [41.2]	(113) [25.8]	(339) [51.4]
Education (years)	12.7 ± 2.5	13.5 ± 2.8	12.2 ± 2.1
Current or past smoker, (n) [%]	(74) [6.6]	(59) [13.3]	(15) [2.2]
Drink alcohol, (n) [%]	(478) [42.8]	(274) [61.6]	(204) [30.3]
Dietary variety score	3.8 ± 2.4	3.3 ± 2.4	4.1 ± 2.4
JST-IC	10.5 ± 2.9	10.5 ± 3.0	10.4 ± 2.9
Income, (n) [%]			
No income	(22) [2.1]	(3) [0.7]	(19) [3.1]
< 1 million yen	(65) [6.3]	(8) [1.9]	(57) [9.4]
1-3 million yen	(616) [60.0]	(225) [53.6]	(391) [64.4]
3-7 million yen	(300) [29.2]	(168) [40.0]	(132) [21.7]
7-10 million yen	(16) [1.6]	(10) [2.4]	(6) [1.0]
≥10 million yen	(8) [0.8]	(6) [1.4]	(2) [0.3]
Oral functions			
Number of present teeth	19.5 ± 9.1	18.0 ± 9.9	20.5 ± 8.3
Removable dentures use, (n) [%]	(567) [50.7]	(261) [58.7]	(306) [45.5]
Masticatory performance	4.5 ± 2.7	4.4 ± 2.9	4.6 ± 2.6
Occlusal force (N)	312.5 ± 225.7	317.5 ± 241	309.3 ± 215.2
Tongue pressure (kPa)	30.2 ± 8.2	30.8 ± 9.0	29.8 ± 7.7
ODK (time/s)	6.0 ± 0.9	6.0 ± 0.9	6.0 ± 0.9
RSST	3.6 ± 1.8	4.1 ± 1.9	3.4 ± 1.6
Functional status			
Handgrip strength (kg)	25.8 ± 7.5	32.2 ± 6.3	21.5 ± 4.5
Gait speed (m/s)	1.3 ± 0.2	1.2 ± 0.2	1.3 ± 0.2
Subjective hearing	16 ± 6.9	15.8 ± 6.6	16.1 ± 7.0
GDS-S-J score	3.7 ± 3.3	3.7 ± 3.4	3.7 ± 3.2
MMSE score	27.7 ± 1.7	27.6 ± 1.7	27.8 ± 1.7
Medical history			
Hypertension, (n) [%]	(572) [51.3]	(238) [53.6]	(334) [49.8]
Stroke, (n) [%]	(94) [8.5]	(47) [10.7]	(47) [7.0]
Heart disease, (n) [%]	(233) [21.1]	(113) [25.6]	(120) [18.1]
Diabetes mellitus, (n) [%]	(159) [14.3]	(93) [21.0]	(66) [9.9]
Hyperlipidemia, (n) [%]	(462) [41.7]	(141) [32.1]	(321) [47.9]
Parkinson's disease, (n) [%]	(9) [0.8]	(3) [0.7]	(6) [0.9]
Biochemical markers			
Albumin (g/dL)	4.2 ± 0.3	4.2 ± 0.3	4.2 ± 0.3
HDL cholesterol (mg/dL)	64.4 ± 17.4	59.4 ± 15.8	67.7 ± 17.6
Red Blood Cell (×10^4/μL)	433.4 ± 42.8	446.2 ± 45.6	424.9 ± 38.6
Hemoglobin (g/dL)	13.4 ± 1.3	14.0 ± 1.3	13.0 ± 1.1
Hemoglobin A1c (%)	5.7 ± 0.6	5.8 ± 0.8	4.2 ± 0.5

JST-IC, Japan Science and Technology Agency Index of Competence; ODK, oral diadochokinesis; RSST, Repetitive Saliva Swallowing Test; GDS-S-J, Geriatric Depression Scale-Short Version-Japanese; MMSE, Mini-Mental State Examination; HDL, high-density lipoprotein.

3. Results

3.1. Subject characteristics

Subject characteristics are shown in Table 1. In total, 79.1% of subjects were educated beyond high school. The mean number of present teeth was 21.4 for ages 70–74 years, 19.8 for ages 75–79 years, 18.1 for ages 80–84 years, and 13.0 for ages 85 years or older. Of the total participants, 41.2% were living alone and 37.6% lived with a spouse.

3.2. Pearson's correlation analysis

Among the assessed oral motor functions, masticatory ability (r = 0.123), occlusal force (r = 0.098), tongue pressure (r = 0.123), and ODK (r = 0.132) were significantly correlated with MMSE score. Significant relationships for the other assessed items with MMSE score were as follows: age (r = −0.186), sex (r = −0.061), education (r = 0.193), JST-IC (r = 0.112), income (r = 0.075), number of present teeth (r = 0.122), presence of removable dentures (r = 0.147), gait speed (r = 0.116), subjective hearing (r = –0.072), diabetes mellitus (r = 0.062), HDL cholesterol levels (r = 0.068), and Hemoglobin A1c levels (r = 0.077).

3.3. Multiple linear regression analysis

The result of the multiple linear regression analysis is shown in Table 2. The oral motor functions that were found to be significantly associated with MMSE score, after adjusting for factors reported to be associated with dementia and cognitive function, were tongue pressure and ODK. The resultant adjusted R^2 was 0.088.

3.4. Path analysis

We used the path diagram depicted in Fig. 2 to examine our hypothesis that oral motor functions were associated with cognitive

Table 2
Multiple linear regression analysis for the relationship between MMSE score and oral related factors.

	B	β	T-value	VIF	P-value
Intercept	31.039		15.080		< 0.001*
Sociodemographics					
Age (years)	−0.057	−0.160	−4.106	1.487	< 0.001*
Sex (0: Women, 1: Men)	−0.255	−0.075	−1.295	3.281	0.196
Body mass index (kg/m^2)	0.002	0.003	0.087	1.362	0.931
Household status (0: alone, 1: family)	−0.156	−0.046	−1.276	1.260	0.202
Education (years)	0.098	0.144	4.024	1.254	< 0.001*
Current or past smoker (0: yes, 1: no)	−0.315	−0.048	−1.404	1.148	0.161
Drink alcohol (0: yes, 1: no)	0.027	0.008	0.225	1.219	0.822
Dietary variety score	0.016	0.023	0.644	1.204	0.519
JST-IC	0.012	0.021	0.563	1.424	0.573
Income	0.101	0.043	1.181	1.285	0.238
Oral functions					
Number of present teeth	−0.012	−0.065	−1.175	3.031	0.240
Removable dentures (0: used, 1: not used)	0.435	0.130	2.828	2.066	0.005*
Masticatory performance	0.024	0.039	0.818	2.213	0.414
Occlusal force (N)	0.000	−0.019	−0.442	1.772	0.659
Tongue pressure (kPa)	0.167	0.087	2.577	1.132	0.010*
ODK (time/s)	0.015	0.071	1.967	1.293	0.049*
RSST	−0.037	−0.040	−1.192	1.094	0.234
Functional status					
Handgrip strength (kg)	0.008	0.036	0.652	2.986	0.515
Gait speed (m/s)	0.065	0.009	0.246	1.409	0.806
Subjective hearing	−0.004	−0.018	−0.529	1.116	0.597
GDS-S-J score	0.016	0.033	0.884	1.332	0.377
Medical history					
Hypertension (0: yes, 1: no)	−0.169	−0.050	−1.462	1.170	0.144
Stroke (0: yes, 1: no)	−0.208	−0.034	−1.031	1.101	0.303
Heart disease (0: yes, 1: no)	−0.117	−0.028	−0.829	1.090	0.407
Diabetes mellitus (0: yes, 1: no)	0.241	0.050	1.236	1.579	0.217
Hyperlipidemia (0:yes, 1: no)	−0.067	−0.020	−0.579	1.121	0.562
Parkinson's disease (0: yes, 1: no)	0.399	0.019	0.598	1.031	0.550
Biochemical markers					
Albumin (g/dL)	−0.223	−0.038	−1.045	1.270	0.297
HDL cholesterol (mg/dL)	0.003	0.028	0.760	1.351	0.447
Red Blood Cell ($\times 10^4/\mu L$)	0.001	0.030	0.489	3.692	0.625
Hemoglobin (g/dL)	−0.081	−0.063	−0.943	4.332	0.346
Hemoglobin A1c (%)	−0.128	−0.048	−1.174	1.625	0.241

VIF, Variance Inflation Factor *P < 0.05.

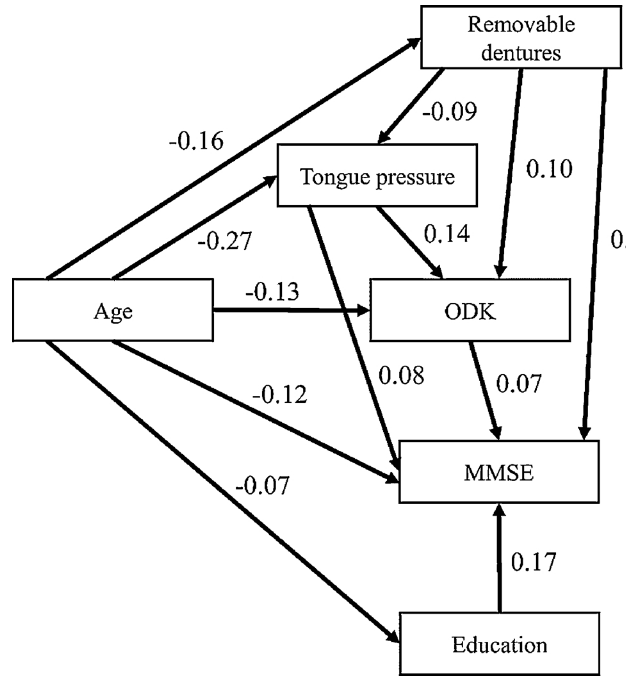

Fig. 2. Path analysis to examine the interrelationship between cognitive function and oral motor functions using factors significantly associated with cognitive function in multiple linear regression analysis.
The fit indices were 0.978 per the Bentler-Bonett normed fit index and 0.987 per the comparative fit index. The root mean square error of approximation was 0.034.

function. The path diagram showed that, among oral motor functions, decreases in tongue pressure and ODK were directly related to decreases in MMSE score. Decreased tongue pressure was not only directly associated with decreased MMSE score but also indirectly, with decreased MMSE score via decreases in ODK.

4. Discussion

When examining factors associated with cognitive function, the impact of multiple risk factors must be considered (Baumgart et al., 2015; Li et al., 2011; Suzuki et al., 2013; Taniguchi et al., 2014). However, only a limited number of studies have examined the association between cognitive function and oral motor function with risk factors taken into consideration (Ikebe et al., 2018; Watanabe et al., 2018). As such, this study is the first to examine the association between cognitive function and multiple oral motor functions in older people with either normal cognitive function or mild cognitive decline.

The mechanism by which cognitive decline is related to decreased tongue pressure and ODK remains unclear. In a previous cross-sectional study of community-dwelling people aged > 40 years, participants with higher maximal tongue pressure were reported to be more socially active (Nagayoshi et al., 2017). In another study of community-dwelling older people, Watanabe et al. considered that decreased oral motor skills might lead to unclear speech, rendering conversation-making difficult (Watanabe et al., 2018). It was also found that unclear speech due to dysarthria was also associated with decreased social participation in stroke patients (Brady, Clark, Dickson, Paton, & Barbour, 2011). In addition, a review by Kuiper et al. reported that decreased social participation was associated with the onset of dementia (Kuiper et al., 2015). These findings suggested that social participation was a factor that linked decreased tongue pressure to decreased cognitive function, and that decreased ODK and decreased cognitive function were related through social participation. Cross-sectional studies in Japanese populations have revealed that tongue pressure and ODK decrease with increasing age (Utanohara et al., 2008; Watanabe et al., 2017). Age-related decreased in tongue pressure and in ODK might thus be related to cognitive function through various factors beyond social participation, although these were not clarified in the present study. In the future, it is necessary to examine the mechanisms that connect decreased tongue pressure and ODK to cognitive decline.

The negative relationship between removable denture use and MMSE score demonstrated the potential negative effects on cognitive function of these devices. Various factors might be associated with this relationship between removable denture use and cognitive decline. However, the present study did not evaluate potential factors, such as type of prosthesis or condition of missing teeth. Moreover, the cause of tooth loss and subsequent denture use, as well as the support style, size, and quality of the dentures might be related to elements of cognitive decline (Cerutti-Kopplin, Emami, Hilgert, Hugo, & Padilha, 2015; Yamamoto et al., 2012). Considering these factors were not assessed, we could not identify any relationship between removable denture use and cognitive decline. This was a limitation of the present study, and future study of this relationship is required.

Despite a positive relationship between removable denture use and tongue pressure, a negative relationship with ODK was also revealed in the present study. A potential explanation for this is that removable dentures that cover the palate with their base might reduce the volume of the oral cavity and lead to increased tongue pressure. Additionally, narrowing of the tongue range of motion by wearing impropriety removable dentures might inhibit tongue dexterity and rapid tongue movement, leading to a negative relationship between removable denture use and ODK.

The present study revealed that tongue pressure and ODK are associated with cognitive function in older people with either normal cognitive function or mild levels of cognitive decline. The present study could not, however, clarify any causal relationship between these factors because of the cross-sectional design. However, because we designed a path model with a high level of fit, we thought that an interrelationship between cognitive function and oral motor function could be inferred.

Non-users of removable dentures, one of the variables included in the analysis, included study participants with almost complete dentition and those who required removable denture but did not use them. Of the 1118 study participants, 1111 (99.4%) maintained their dentition or were using removable dentures. The remaining 7 (0.6%) participants did not use removable dentures although it was not assessed whether they required their use or not. In fact, due to the large sample size of the present study, it was difficult to determine each individual participant's need for removable dentures. Therefore, we included all study participants in the analysis, including those who did not use removable dentures despite potentially needing them. However, since these individuals were expected to be a very small number of the large survey conducted, they were not expected to have had a significant impact on the results. Future studies should focus on including data on patients not using dentures despite requiring their use.

At present, oral hypofunction has begun to attract attention as a medical condition of increasing concern in Japan (Minakuchi et al., 2018). In the present study, among the diagnostic items for oral hypofunction that were assessed, tongue pressure and ODK were associated with cognitive function, as assessed by MMSE. Given this association, we concluded that oral hypofunction was related to cognitive function. Based on the results of our path analysis, we speculate that decreased tongue pressure is not only directly linked to mild cognitive decline, but also indirectly via decreased ODK, thus providing some insights into clinical utility. For example, tongue pressure might be improved with training (Oh, 2015). Thus, it might be possible to maintain cognitive function by maintaining and improving tongue motor function, such as tongue pressure and ODK, through therapeutic efforts.

5. Conclusions

Among the oral motor functions assessed in this study, tongue pressure and ODK were significantly associated with cognitive function in older Japanese people with either normal cognitive function or mild cognitive decline. The path analysis result revealed a possibility that decreased tongue pressure led to cognitive decline directly, or alternatively, indirectly via diminished tongue dexterity and movement velocity.

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Declarations of interest

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