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Increase in masseter muscle activity by newly fabricated complete dentures improved brain function

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Abstract

Purpose: To reveal effects of improvement of masseter muscle activity on brain function in elderly people wearing complete dentures.

Methods: Subjects were 14 edentulous patients with a chief complaint of the inconvenience of their complete dentures. The surface electromyographic (EMG) activity of the masseter muscles was measured. Brain activities were analyzed with functional magnetic resonance imaging (fMRI), employing chewing gum as the task program. Cognitive functions were evaluated with Trail Making Test Part A (TMT-A), Rey Auditory Verbal Learning Test (RAVLT) and Rey-Osterrieth Complex Figure Test (R-OCFT). Those evaluations were performed in which subjects wore their old dentures (OD) or newly fabricated dentures (ND).

Results: We compared ND condition with OD condition. The masseter muscle activity significantly increased in ND condition ($p < 0.05$, Wilcoxon signed rank test). The brain activity increased significantly in the superior frontal gyrus, precentral gyrus, putamen, inferior parietal lobule, cerebellum, inferior frontal lobe, and middle frontal gyrus under the ND condition than under the OD condition ($p < 0.01$, uncorrected, cluster size > 10 voxels). Results of TMT-A, RAVLT, and R-OCFT were also significantly improved ($p < 0.05$, Wilcoxon signed rank test).

Conclusions: In the edentulous elderly, the brain activity was increased following the improvement of the masseter muscle activity. Consequently, it is possible that the improvement of the masseter muscle activity might influence on the attention, verbal skills, and visual memory.

Keywords: Oral function, Cognitive function, Brain activity, Complete denture, Edentulous elderly

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1. Introduction

According to the World Alzheimer Report 2015 [1], 47 million people live with dementia worldwide, and the number of patients with dementia is expected to increase up to more than 131 million by 2050. Although the risk factors for dementia are known to be age, sex, depression [2], diabetes [3], smoking [4], and underactivity [5], the cause and exact mechanism of dementia remain unclear. Dementia is currently not curative. Dementia is managed with only symptomatic treatment. Therefore, the prevention of dementia is a critical issue. Several effective prevention methods for dementia have been reported, including regular exercise [6], intake of antioxidants or anti-inflammatory components of foods [7], maintenance of social networks [8], and working memory training [9]. Intervention studies of dementia prevention indicated that non-drug therapies, such as dietary modifications, exercises, and behavioral strategies may be effective. Verghese et al. reported that leisure activities such as reading, playing board games, playing musical instruments, and dancing, were associated

with a reduced risk of dementia [10]. Erickson et al. reported that exercise training increased the size of the hippocampus and improved memory in elderly people [11].

In the field of dentistry, several studies have reported on the relationship between oral and cognitive functions. Animal studies exploring the relationship between tooth loss and cognitive function indicated that reduction of mastication ability due to missing molar tooth might lead to impairment of spatial memory and degeneration of hippocampal neurons [12,13]. In human studies, Takeuchi et al. reported that the risk of dementia was 1.63 times greater in those with no teeth than those with 20 teeth or more [14]. Also, Kobayashi et al. observed that the volume of the hippocampus of edentulous elderly people was more significant reduction than that of dentulous elderly people. In addition, they suggested that the missing tooth caused the organic change of brain [15]. These reports show that maintaining as many teeth as possible may contribute to preventing dementia. On the other hand, Campos et al. reported that the masticatory function of patients with mild cognitive impairment was lower than that of healthy elderly people [16]. Lexomboon et al. also reported that the reduction of masticatory function affected the cognitive function [17]. Moreover, Takeshita et al. suggested that the oral function including maximum bite force might be a predictive factor of cognitive impairment [18].

According to those reports, there should be tight correlation between reduction of oral function and cognitive impairment. The dentist can recover the reduction of masticatory function and consequently maintain

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cognitive function by prosthetic treatment. However, there have been few studies which reported the relationships between oral function, brain activity, and cognitive function. Furthermore, the masseter muscle is trigeminal nerve dominant and masseter muscle activity might be more directly related to brain activity [19]. Therefore, we hypothesized that the recovery of the masseter muscles activity could contribute to maintenance of the cognitive function. The purpose of the present study is to clarify the influence of masseter muscle activity on brain activity and cognitive function.

2. Materials and methods

2.1. Subjects

Subjects of the present study were edentulous patients who are over the age of 65 years and visited the Iwate Medical University Hospital Dental Center with a chief complaint about inconvenience of their complete dentures. To determine the sample size, the statistical power analysis was performed. We defined the following factors: level of significance: 0.5, power: 0.8, and expected effect size: 0.8. As a result of this analysis, the sample size of this study should be at least 11 participants, and we recruited 14 participants. Regarding the denture design, fitness, jaw position, occlusal wear of artificial teeth, and repair mark, one prosthodontist inspected their complete dentures, according to the denture inspection guideline provided by Japan Prosthodontic Society. After the inspection, the prosthodontist divided their complete dentures into appropriateness, slight inappropriateness, inappropriateness, and considerable inappropriateness. Subjects included in the study were those who wore their inapposite or considerably inapposite dentures for at least one year and for whom the prosthodontist made new complete dentures according to the conventional method. Subjects excluded were those who had metals and magnets in their body, could not be evaluated for all examinations, were diagnosed IV or V of State trait anxiety inventory (STAI) which is the anxiety examination during cognitive examination. In addition, the new dentures were evaluated by another prosthodontist. New dentures that were diagnosed as slight inappropriateness, inappropriateness, or considerable inappropriateness were excluded.

The oral function, brain activity, and cognitive function were evaluated at the time of wearing the old dentures (OD) and three months after wearing the new dentures (ND). The analysis focused on comparing those two conditions. The present study was approved by the Ethical Committee for Human Research of the School of Dentistry, Iwate Medical University (No.01233).

2.2. Measurement of surface electromyographic (EMG) activity of masseter muscles

EMG activity of left and right superficial masseter muscles was measured using a mandibular movement measure system (K7 DIAGNOSTIC SYSTEM[®]R, Myo-Tronics, Inc., Tukwila, WA, USA). The first measurement was performed on the same day as the newly fabricated denture was provided. Subjects clenched as hard as they could for three seconds, and this task was repeated three times. The integral EMG per unit time was calculated, and we defined the average of the three measurements as masseter muscle activity.

2.3. Measurement of brain activity

The brain activity was analyzed with functional magnetic resonance imaging (fMRI), performed on a 7.0 T MR scanner (MR950, GE, Medical Systems, Milwaukee, WI, USA). The first measurement was performed on the same day as the newly fabricated denture was provided. The structural data was acquired by steady state T1-weighted 3D fast-spoiled gradient-recalled acquisition with the following parameters: repetition time (TR) = 3000 ms, echo time (TE) = 23 ms, flip angle (FA) = 12°, field of view (FOV) = 256×256 mm, slice thickness = 1.0 mm, slice gap = 0 mm, number of slices=60, matrix size =256×256 mm, and voxel size = 1.0×1.0×1.0 mm.

The echo planar imaging (EPI) sequence was used for the functional imaging with the following parameters: TR = 3000 ms, TE = 23 ms, FA = 80°, FOV = 210×210 mm, slice thickness = 2.2 mm, slice gap = 0.0 mm, matrix size = 96×96 mm, and voxel size = 2.18×2.18×2.2 mm. Subjects alternated restoration and the task of chewing gum. This alternateness was repeated three times in each scanning run. Figure 1 shows the task assignment. The gum had no odor or taste. We also evaluated whether the subjects felt pain and discomfort by the visual analogue scale (VAS).

2.4. Evaluation of cognitive function

Three validations of neuropsychological tests were used to assess frontal lobe functions, auditory-verbal memory, and visuospatial memory. TMT-A, which evaluates attention ability and RAVLT and R-OCFT, which evaluate memory in elderly people, were employed because previous studies reported that chewing could increase the level of brain activity in the areas of frontal lobe and hippocampus. Another reason was that patients with dementia display a multiplicity of cognitive deficiencies concerning memory, visuospatial cognition, language and attention ability, and hippocampus and frontal lobe are involved in memory and attention ability, respectively.

The first evaluation was performed on the same day as the newly fabricated denture was provided. All neuropsychological tests were scored by an experienced psychologist. The subjects were assessed for their anxiety with STAI before their neuropsychological tests.

The evaluation of the frontal lobe function (Trail Making Test Part A: TMT-A) measures scanning and visuomotor tracking abilities and involves cognitive processing as well as psychomotor speed. The subject was assigned to draw lines sequentially connecting 25 encircled numbers, which were distributed on a sheet of paper. The obtained score represents the amount of time required to complete the task [20].

Rey Auditory Verbal Learning Test (RAVLT) is a word list learning test. For the RAVLT, the subject was given 15 unrelated words by the psychologist and asked to recall as many those words as possible. The total recall score was defined as the sum of all correctly recalled items from the five trials [21]. The present study assessed immediate recall.

Rey-Osterrieth Complex Figure Test (R-OCFT) was used to assess visuospatial ability and visual memory. A complicated geometrical figure was presented to the subject, who was then requested to copy the figure as accurately as possible. When the copying was completed, the figure and the copy were removed from their sight. The subject should be given another sheet of paper and asked to draw the design from memory (immediate recall). Drawings were scored for accuracy using Taylor's scoring system (maximum score = 36) [22].

2.5. Data analysis

Regarding the oral function and cognitive function, we statistically compared the OD condition with the ones on ND condition using SPSS version 23 (IBM SPSS Statistics, IBM Corporation, Armonk, New York, USA). The significance level was set at $p < 0.05$.

Statistical analysis for the brain activity was performed using SPM12 (Wellcome Department of Imaging Neuroscience, London, UK) with MATLAB version R2014a (The MathWorks, Inc., Natick, Massachusetts, USA). All images were realigned first to correct for head motion and were confirmed that the motion of the head did not exceed 1.5 mm for any subject. After realignment, a custom template was created using Advanced Neuroimaging Tools (ANTs, <http://stnava.github.io/ANTs/>). Each subject's EPI was matched to this custom template; subsequently, the images were normalized to Montreal Neurological Institute (MNI) space using SPM. The normalized images were finally smoothed following convolution with a Gaussian kernel of 5 mm full-width-at-half-maximum to reduce the individual variability before statistical mapping. Chewing gum under the ND condition was compared with the ones on the OD conditions using a mixed-effect general liner model in SPM. The second-level (group) analysis was performed with a one-sample t-test. The statistical threshold was set at $p < 0.01$ (uncorrected, cluster size > 10 voxels). Analyzed brain area was identified by superimposing MNI coordinates on the anatomical

Fig. 1. The Task paradigm.

On periods represent the chewing gum or tapping conditions of the paradigm. Off periods are rest.

coordinates. Identification of brain activity area that showed a change due to an increase in muscle activity was performed using regression analysis. The significance level was set at $p < 0.01$, uncorrected for multiple

3. Results

3.1. Subjects

Eight of the 22 subjects who consented to the present study were excluded owing to the following reasons: 1, poor physical condition; 3, non-contactable; 1, refusal to continue in the present study; 1, unable to be evaluated for all the measurements; and 2, presence of metals and magnets in the body. In total, 14 subjects were included (four men, 10 women; mean age: 80.2 ± 5.9 years) in the present study.

3.2. EMG activity of masseter muscles

Masseter muscle EMG activity in the left and right masseter muscles under the ND condition was significantly higher than that under the OD condition {OD: $86.45 (46.79-111.36) \mu V \cdot S$; ND: $125.47 (94.80-173.00) \mu V \cdot S$; $p < 0.05$, Wilcoxon signed rank test; Fig. 2}.

3.3. Brain activity

The brain activity on the ND condition was significantly higher than that under the OD condition. Especially, brain activity in area of the superior frontal gyrus, precentral gyrus, putamen, inferior parietal lobule, cerebellum, inferior frontal lobe, and middle frontal gyrus increased significantly during the task (Fig 3, Table 1). Pain as measured using VAS scores was not significantly different between the OD and ND conditions {OD: 0 (0–5); ND: 0 (0–5); $p < 0.05$, Wilcoxon signed rank test}. Moreover, discomfort was also not significant {OD: 0 (0–0); ND: 0 (0–14.25); $p < 0.05$, Wilcoxon signed rank test}.

Regression analysis revealed a positive correlation between masseter muscles and brain activity, and the increase in brain activity of parahippocampal gyrus (CA1, CA3), postcentral gyrus, inferior temporal gyrus, hippocampus, and superior medial gyrus was remarkable (Fig. 4, Table 2).

3.4. Cognitive function

The time to complete TMT-A under the ND condition was significantly shorter than the one under the OD condition {OD: 143.5 (122.5–162.3) seconds; ND: 117.5 (95–132.5) seconds; $p < 0.05$, Wilcoxon signed rank test; Fig. 5A}. The total recall score of RAVLT under the ND condition was significantly higher than the one under the OD condition {OD: 37.5 (29.5–45.8) words; ND: 43 (38.5–53) words; $p < 0.05$, Wilcoxon signed rank test; Fig. 5B}. Additionally, the score of R-OCFT under the ND condition was significantly higher than the one under the OD condition {OD: 15.5 (6.8–17.9) point; ND: 18 (17–21.75) point; $p < 0.05$, Wilcoxon signed rank test; Fig. 5C}.

Fig. 2. Changes in Muscle activity.

Masseter muscle EMG activity in the left and right masseter muscles on the ND condition was increased significantly, compared to the one on OD ($*p < 0.05$, Wilcoxon signed rank test).

Fig. 3. Changes in brain activity.

The brain area that brain activity increased significantly on the ND condition compared with on OD condition during chewing gum {Contrast = ND – OD, $p < 0.01$ (uncorrected, cluster size > 10 voxels)}.

4. Discussion

Oral functions of patients who wear dentures are commonly evaluated by analyses of bite force [23,24], surface EMG signal recording [25–28] and masticatory performance [29,30]. Previous studies demonstrated that the integral EMG values of masticatory muscles could be a parameter that directly represents masticatory performance [25–28]. Surface EMG signal recording is useful for evaluating effects of denture treatment on masticatory muscle activity [31–33] because there is a positive correlation between the bite force and the surface EMG signal recording of the masseter and anterior temporalis muscles [34]. Moreover, the value for activity of the temporalis anterior muscle was still unstable at 3 months after wearing new dentures [35]. Thus, we measured the surface EMG record of the masseter muscle, which links directly to the brain, and evaluated the oral function of subjects in the OD and ND conditions. As a result, the EMG activity of the masseter muscles under the ND condition was significantly higher than the one under the OD condition.

Table 1. The brain area of significant increases in the fMRI signals during chewing gum.

R/L	Region of Activation	Montreal Neurological Institute				
		Maximal t Value	X	Y	Z	Z-score
R	Superior Frontal Gyrus	5.162590027	28.5	13.5	63	3.7419386
L	Superior Frontal Gyrus	4.922014713	-19.5	-7.5	70.5	3.63411323
R	Precentral Gyrus	4.764995575	42	-3	43.5	3.56110152
R	Putamen	4.422444344	27	13.5	9	3.39411739
L	Inferior Parietal Lobule	3.987716675	-48	-10.5	51	3.16574342
R	Cerebellum (X)	3.740415335	25.5	-30	-42	3.02691374
L	IFG (part of Orbitalis)	3.698326826	-28.5	19.5	-15	3.00260649

IFG, inferior frontal gyrus

Fig. 4. Regression analysis. Relationship between masseter muscle activity and brain activity ($p < 0.01$, uncorrected for multiple comparisons).

Table 2. The brain area of positive correlation between masseter muscle and brain activity.

R/L	Region of Activation	BA	Maximal t Value	Montreal Neurological Institute			
				X	Y	Z	Z-score
R	ParaHippocampal Gyrus	CA3	6.886117458	24	-18	-19.5	4.303163
R	ParaHippocampal Gyrus	CA1	3.304640293	33	-18	-25.5	2.73297
L	Postcentral Gyrus		4.223235607	-64.5	-16.5	25.5	3.24325
R	Inferior Temporal Gyrus		6.160713673	58.5	-19.5	-30	4.061938
R	Hippocampus		5.59612751	39	-19.5	-13.5	3.852636
L	Hippocampus	CA3	5.098816395	-21	-19.5	-19.5	3.64994
R	Superior Medial Gyrus		4.627786636	6	34.5	58.5	3.439759
L	Superior Medial Gyrus		4.599877834	3	49.5	45	3.426699

BA, Brodmann's area; CA, Cornu Ammoris

Positron emission tomography, near infrared spectroscopy, electroencephalography, and fMRI are the noninvasive ways to measure the brain activity. The principal advantage of fMRI is its higher spatiotemporal resolution than other measurement systems [36]. Several studies have reported brain activity which based on change of cerebral blood flow using fMRI [37–40]. In the present study, we also used fMRI to examine the brain activity of the frontal lobe and hippocampus that are related to the cognitive function. Regarding the scanning of fMRI, horizontal posture might be inappropriate for occlusal performance during scans. However, there is a report that the maximum bite force is

not affected by horizontal posture [41]. Thus, we considered that masseter muscle activity was not also affected by horizontal posture during fMRI scan. Since the subjects may experience pain and discomfort during the scan, we evaluated whether the subjects felt pain and discomfort using the VAS. The results showed no significant difference between the OD condition and the ND condition. Thus, we considered that we were able to evaluate the brain activity during scans without discomfort, pain, and other factors related to sensory stimulation caused by wearing dentures and/or postural changes. Yan et al. used fMRI to analyze the brain activity during clenching in three edentulous

Fig. 5A. Changes in TMT A. The ND condition was reduced the time to complete TMT-A significantly, compared to the one on OD ($*p < 0.05$, Wilcoxon signed rank test).

Fig. 5B. Changes in RAVLT scores. The total recall score of RAVLT on the ND condition was significantly higher than the one on OD ($*p < 0.05$, Wilcoxon signed rank test).

Fig. 5C. Changes in R-OCFT scores. The score of R-OCFT on the ND condition was significantly higher than on the one OD ($*p < 0.05$, Wilcoxon signed rank test).

subjects who wore implants supported fixed dentures. They suggested that the implants supported fixed dentures increased the blood oxygen level dependent (BOLD) signals of the primary sensorimotor cortex, prefrontal cortex, Broca's area, insula, and hippocampus. The authors concluded that activation of the primary sensorimotor cortex in patients with implant-supported dentures explained the improved tactility, stereognostic ability, and mastication function improved [40]. In addition, Hirano et al. used fMRI to analyze the brain activity when healthy volunteers chewed odorless and tasteless gum. The results showed that chewing activated the BOLD signals in the right premotor cortex, precuneus, thalamus, hippocampus, and inferior parietal lobe. They suggested that chewing might effectively engage the ventral prefrontal network; thus, reflecting high cognitive performance [37].

According to previous studies, we considered that the brain activity during mastication could be evaluated using fMRI. In the present study, the brain activity areas increased significantly on the task of chewing gum were the superior frontal gyrus, precentral gyrus, putamen, inferior parietal lobule, cerebellum, inferior frontal lobe, and middle frontal gyrus. Thus, our data were consistent with the stimulated brain areas described in previous studies [37,40].

Several studies have reported that the recovery of oral function might stimulate improvement of cognitive functions, governed by the frontal lobe and hippocampus [42–44]. A previous study reported that the brain activity of the anterior cingulate cortex and left frontal gyrus were increased and attentional networks were affected by chewing [44]. Chewing stimulated the neuronal activity within a network between the right prefrontal cortex and the hippocampus [38]. In contrast, the result of regression analysis between masseter muscle activity and brain activity, in this study, revealed that the positive correlation in the areas of para-hippocampal gyrus (CA1 and CA3), postcentral gyrus, inferior temporal gyrus, and hippocampus superior medial gyrus in this study. Few studies have reported the relationship between masseter muscle activity and brain activity. Thus, this new finding suggests that increase in masseter muscle activity, which was caused by wearing ND for three months, could stimulate the different areas from where are stimulated by the chewing. Moreover, increase in masseter muscle activity due to ND wearing might accelerate trigeminal sensory input, resulting in the upregulation of signal transduction to hippocampus and para-hippocampal gyrus (CA1, CA3), mediated by postcentral gyrus, superior medial gyrus, and entorhinal cortex. Those hypotheses might be a possible explanation for the different types of brain activity induced by increase in masseter muscle activity. However, further experiments, such as PET analysis to track neurotransmitters, are required to clarify the details of those neural transduction system.

Considering these studies, we observed changes of cognitive function using the neuropsychological tests to evaluate the frontal lobe and hippocampus function. Attentional ability was assessed using the TMT-A that measures the amount of time required to complete the task. TMT-A is the measurement of the maintenance of attention ability during the test; therefore, the time is longer if subjects have lower attention ability. On the other hand, if the subject's attention ability improves, the time is shorter. Since a previous study reported that TMT-A scores are related to the frontal lobe function [45], it could evaluate the relation between the frontal lobe and brain activity, and thus we used TMT-A in the present study. Also, we used RAVLT and R-OCFT to evaluate hippocampus related to the short

memory. Generally, RAVLT is used to evaluate the verbal memory. A previous study reported that RAVLT correlates with Wechsler Memory Scale-Revised Logical Memory and California Verbal Learning Test (CVLT) [46]; additionally, we used RAVLT because it is faster and easier to evaluate than CVLT. Moreover, we used R-OCFT because it can evaluate visuospatial constructional ability and visual memory, and it is not affected by biases in education level or culture. In the present study, the scores of TMT-A, RAVLT, and R-OCFT under the ND condition improved significantly, compared with those under the OD condition. Thus, we considered that attention ability, verbal memory, and visual memory improved.

A previous study reported that chewing is controlled by the central nervous system and sensory feedback from a variety of intraoral conditions and the characteristics of the food. Thus, chewing while wearing dentures may also be controlled by the central nervous system and sensory feedback from the oral mucosa or masticatory muscles. In the present study, the EMG activity of the masseter muscles under the ND condition might be increased following improvement of several factors, such as fitness, wear of artificial teeth, and denture design. Therefore, we considered that the sensory feedback from muscle or mucosa was upregulated and the brain activity areas of the frontal lobe, hippocampus, and so on were increased. Chen et al. reported that chewing might represent a useful approach in preserving and promoting the hippocampus-dependent cognitive function in older people [43]. In addition, the brain activity of hippocampus and parahippocampus are thought to be transmitted to the hippocampus via the frontal lobe or entorhinal cortex [48]. Those previous studies supported our results that increase in the EMG activity of the masseter muscles activated the brain activities of the hippocampus and frontal lobe.

Moreover, the present study clarified that appropriate prosthetic treatment could improve the EMG activity of the masseter muscles, resulting in activation in the frontal lobe and hippocampus. We also found that improvement of attention ability and memory related to the frontal lobe and hippocampus. Since the results of this study revealed a positive correlation between masseter muscle activity and brain activity of frontal lobe and hippocampus, we considered that improvement of cognitive function was associated with significant brain activity and cerebral blood flow increase of them by the masseter muscle activity. Intermediary factors of improvement of cognitive function are generally affected by brain activity, cerebral blood flow [49], brain volume [50], sleep [51], physical activity [11], and mental condition [52]. A previous study clarified the effects of chewing on cognitive function by measuring brain activity and neuropsychological tests [37]. We inferred that the brain area activated significantly under the ND condition and that cerebral blood flow increased at every meal. Therefore, we speculated that increase in the cerebral blood flow was a factor in the improvement of brain function. However, it was difficult to accurately evaluate the changes in brain activity and cognitive function using the protocol of the present study. Although continuous or frequent measurements could be conducted for researchers, it is too tough for elderly subjects to undergo repeated examinations. Moreover, Piancino et al. previously reported that it should take three months for most patients to acquire stable masseter muscle activity [35]. Thus, an interval of three months was deemed suitable for the neurophysiological tests and fMRI imaging. In addition, it is necessary to evaluate the behavioral, social psychology, and nutrition. Therefore, to clarify the mechanism by which the increase in the EMG activity of masseter muscles affects the brain activity and cognitive function, further experiments must be required, such as long-term observation of brain metabolism, brain volume, nervous system, systemic disease, physical activity, social activity, and nutrition.

5. Conclusions

The improvement of the EMG activity of the masseter muscles might affect attention, verbal memory, and visual memory. The findings of this study suggest that improvement of masseter muscle activity by prosthetic treatment may contribute to maintaining cognitive function.

Conflict of interests

No conflict of interests declared.

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References

- [1] World Alzheimer Report 2015. The Global Impact of Dementia. <https://www.alz.co.uk/research/world-report-2015> [accessed 17.05.03].
- [2] Jorm AF, van Duijn CM, Chandra V, Fratiglioni L, Graves AB, Heyman A, et al. Psychiatric history and related exposures as risk factors for Alzheimer's disease: a collaborative re-analysis of case-control studies. EURODEM Risk Factors Research Group. *Int J Epidemiol* 1991;20 Suppl 2:S43-7.
- [3] Biessels GJ, De Leeuw FE, Lindeboom J, Barkhof F, Scheltens P. Increased cortical atrophy in patients with Alzheimer's disease and type 2 diabetes mellitus. *J Neurol Neurosurg Psychiatry* 2006;77:304-7.
- [4] Rusanen M, Kivipelto M, Quesenberry CP, Jr., Zhou J, Whitmer RA. Heavy smoking in midlife and long-term risk of Alzheimer disease and vascular dementia. *Archives of internal medicine* 2011;171:333-9.
- [5] Mielke MM, Roberts RO, Savica R, Cha R, Drubach DI, Christianson T, et al. Assessing the temporal relationship between cognition and gait: slow gait predicts cognitive decline in the Mayo Clinic Study of Aging. *J Gerontol A Biol Sci Med Sci* 2013;68:929-37.
- [6] van Uffelen JG, Chinapaw MJ, van Mechelen W, Hopman-Rock M. Walking or vitamin B for cognition in older adults with mild cognitive impairment? A randomised controlled trial. *British journal of sports medicine* 2008;42:344-51.
- [7] Li FJ, Shen L, Ji HF. Dietary intakes of vitamin E, vitamin C, and beta-carotene and risk of Alzheimer's disease: a meta-analysis. *J Alzheimers Dis* 2012;31:253-8.
- [8] Fratiglioni L, Paillard-Borg S, Winblad B. An active and socially integrated lifestyle in late life might protect against dementia. *Lancet Neurol* 2004;3:343-53.
- [9] Borella E, Carretti B, Riboldi F, De Beni R. Working memory training in older adults: evidence of transfer and maintenance effects. *Psychol Aging* 2010;25:767-78.
- [10] Verghese J, Lipton RB, Katz MJ, Hall CB, Derby CA, Kuslansky G, et al. Leisure activities and the risk of dementia in the elderly. *The New England journal of medicine* 2003;348:2508-16.
- [11] Erickson KI, Voss MW, Prakash RS, Basak C, Szabo A, Chaddock L, et al. Exercise training increases size of hippocampus and improves memory. *Proc Natl Acad Sci U S A* 2011;108:3017-22.
- [12] Onozuka M, Watanabe K, Mirbod SM, Ozono S, Nishiyama K, Karasawa N, et al. Reduced mastication stimulates impairment of spatial memory and degeneration of hippocampal neurons in aged SAMP8 mice. *Brain Res* 1999;826:148-53.
- [13] Yamazaki K, Wakabayashi N, Kobayashi T, Suzuki T. Effect of tooth loss on spatial memory and trkB-mRNA levels in rats. *Hippocampus* 2008;18:542-7.
- [14] Takeuchi K, Ohara T, Furuta M, Takeshita T, Shibata Y, Hata J, et al. Tooth Loss and Risk of Dementia in the Community: the Hisayama Study. *J Am Geriatr Soc* 2017;65:e95-e100.
- [15] Kobayashi T, Kubota M, Takahashi T, Nakasato A, Nomura T, Furuya J, et al. Effects of tooth loss on brain structure: a voxel-based morphometry study. *Journal of prosthodontic research* 2018;62:337-41.
- [16] Campos CH, Ribeiro GR, Costa JL, Rodrigues Garcia RC. Correlation of cognitive and masticatory function in Alzheimer's disease. *Clin Oral Investig* 2017;21:573-8.
- [17] Lexomboon D, Trulsson M, Wardh I, Parker MG. Chewing ability and tooth loss: association with cognitive impairment in an elderly population study. *J Am Geriatr Soc* 2012;60:1951-6.
- [18] Takeshita H, Ikebe K, Gondo Y, Inagaki H, Masui Y, Inomata C, et al. Association of Occlusal Force with Cognition in Independent Older Japanese People. *JDR Clinical & Translational Research* 2016;1:69-76.
- [19] Iida T, Overgaard A, Komiya O, Weibull A, Baad-Hansen L, Kawara M, Sundren PC, List T, Svensson P. Analysis of brain and muscle activity during low-level tooth clenching—a feasibility study with a novel biting device. *J Oral Rehabil* 2014;41:93-100.
- [20] Reitan RM. The relation of the trail making test to organic brain damage. *Journal of consulting psychology* 1955;19:393-4.
- [21] Ferreira Correia A, Campagna Osorio I. The Rey Auditory Verbal Learning Test: normative data developed for the Venezuelan population. *Archives of clinical neuropsychology : the official journal of the National Academy of Neuropsychologists* 2014;29:206-15.
- [22] Kasai M, Meguro K, Hashimoto R, Ishizaki J, Yamadori A, Mori E. Non-verbal learning is impaired in very mild Alzheimer's disease (CDR 0.5): normative data from the learning version of the Rey-Osterrieth Complex Figure Test. *Psychiatry and clinical neurosciences* 2006;60:139-46.

- [23] Haraldson T, Karlsson U, Carlsson GE. Bite force and oral function in complete denture wearers. *J Oral Rehabil* 1979;6:41-8.
- [24] Okuma K, Hirano S, Hayakawa I. Occlusal pressure pattern analysis of complete dentures for evaluation of occlusal adjustment. *Journal of medical and dental sciences* 2004;51:197-203.
- [25] Pisani MX, Segundo AL, Leite VM, de Souza RF, da Silva MA, da Silva CH. Electromyography of masticatory muscles after denture relining with soft and hard denture liners. *Journal of oral science* 2013;55:217-24.
- [26] Michman J, Langer A. Clinical and electromyographic observations during adjustment to complete dentures. *The Journal of prosthetic dentistry* 1968;19:252-62.
- [27] Akagawa Y, Okane H, Kondo N, Tsuga K, Tsuru H. Comparative evaluation of chewing function with removable partial dentures and fixed prostheses supported by the single-crystal sapphire implant in the Kennedy Class II partially edentulous mandible. *Int J Oral Maxillofac Implants* 1989;4:205-10.
- [28] Tallgren A, Holden S, Lang BR, Ash MM, Jr. Jaw muscle activity in complete denture wearers--a longitudinal electromyographic study. *The Journal of prosthetic dentistry* 1980;44:123-32.
- [29] Geertman ME, Slagter AP, van Waas MA, Kalk W. Communion of food with mandibular implant-retained overdentures. *J Dent Res* 1994;73:1858-64.
- [30] Kapur KK. A clinical evaluation of denture adhesives. *The Journal of prosthetic dentistry* 1967;18:550-8.
- [31] Rastogi A, Srivastava S, Gaur A, Dupare A, Rastogi S, Kamatagi L. Electromyographic Evaluation of the Effect of Lined Dentures on Masticatory Muscle Activity in Edentulous Subjects. *Journal of clinical and diagnostic research : JCDR* 2015;9:Zc80-3.
- [32] Ashraf H. To Determine the Influence of the Complete Denture Prosthesis on Masticatory Muscle Activity in Elderly Patients: An in vivo Study. 2011, p. 35-40.
- [33] Nakamura T, Baba K, Minami I, Okano N, Ohya T. Electromyographic evaluation of masticatory function in denture wearers in related to existing occlusal support. *Journal of medical and dental sciences* 2004;51:173-7.
- [34] Bret A, Fuls, Kathryn X, Callaghan, Calaire D, Tewksbury, Geoffrey E. Gerstner. Relationships between chewing rate, occlusion, cephalometric anatomy, muscle activity, and masticatory performance. *Archives of Oral Biology* 2017;83:161-8.
- [35] Piancino MG, Farina D, Talpone F, Castroflorio T, Gassino G, Margarino V, Bracco P. Surface EMG of Jaw-elevator muscles and chewing pattern in complete denture wearers. *J Oral Rehabil* 2005;12:863-70.
- [36] Logothetis NK. What we can do and what we cannot do with fMRI. *Nature* 2008;453:869-78.
- [37] Hirano Y, Obata T, Kashikura K, Nonaka H, Tachibana A, Ikehira H, et al. Effects of chewing in working memory processing. *Neurosci Lett* 2008;436:189-92.
- [38] Onozuka M, Fujita M, Watanabe K, Hirano Y, Niwa M, Nishiyama K, et al. Age-related changes in brain regional activity during chewing: a functional magnetic resonance imaging study. *J Dent Res* 2003;82:657-60.
- [39] Kimoto K, Ono Y, Tachibana A, Hirano Y, Otsuka T, Ohno A, et al. Chewing-induced regional brain activity in edentulous patients who received mandibular implant-supported overdentures: a preliminary report. *Journal of prosthodontic research* 2011;55:89-97.
- [40] Yan C, Ye L, Zhen J, Ke L, Gang L. Neuroplasticity of edentulous patients with implant-supported full dentures. *European journal of oral sciences* 2008;116:387-93.
- [41] Tsuchida Y. Influences or head positions on masticatory muscle activities during voluntary contractions. *J Jpn Prosthodont* 1991;35:89-102.
- [42] Morokuma M. Influence of the functional improvement of complete dentures on brain activity. *Nihon Hotetsu Shika Gakkai zasshi* 2008;52:194-9.
- [43] Chen H, Iinuma M, Onozuka M, Kubo KY. Chewing Maintains Hippocampus-Dependent Cognitive Function. *Int J Med Sci* 2015;12:502-9.
- [44] Hirano Y, Obata T, Takahashi H, Tachibana A, Kuroiwa D, Takahashi T, et al. Effects of chewing on cognitive processing speed. *Brain and cognition* 2013;81:376-81.
- [45] Moll J, de Oliveira-Souza R, Moll FT, Bramati IE, Andreiulo PA. The cerebral correlates of set-shifting: an fMRI study of the trail making test. *Arquivos de neuro-psiquiatria* 2002;60:900-5.
- [46] Crossen JR, Wiens AN. Comparison of the Auditory-Verbal Learning Test (AVLT) and California Verbal Learning Test (CVLT) in a sample of normal subjects. *Journal of clinical and experimental neuropsychology* 1994;16:190-4.
- [47] Lund JP. Mastication and its control by the brain stem. Critical reviews in oral biology and medicine : an official publication of the American Association of Oral Biologists 1991;2:33-64.
- [48] Ono Y, Yamamoto T, Kubo KY, Onozuka M. Occlusion and brain function: mastication as a prevention of cognitive dysfunction. *J Oral Rehabil* 2010;37:624-40.
- [49] Burdette JH, Laurienti PJ, Espeland MA, Morgan A, Telesford Q, Vechlekar CD, et al. Using network science to evaluate exercise-associated brain changes in older adults. *Front Aging Neurosci* 2010;2:23.
- [50] Erickson KI, Raji CA, Lopez OL, Becker JT, Rosano C, Newman AB, et al. Physical activity predicts gray matter volume in late adulthood: the Cardiovascular Health Study. *Neurology* 2010;75:1415-22.
- [51] Zagaar M, Dao A, Levine A, Alhaider I, Alkadhi K. Regular exercise prevents sleep deprivation associated impairment of long-term memory and synaptic plasticity in the CA1 area of the hippocampus. *Sleep* 2013;36:751-61.
- [52] Bridle C, Spanjers K, Patel S, Atherton NM, Lamb SE. Effect of exercise on depression severity in older people: systematic review and meta-analysis of randomised controlled trials. *The British journal of psychiatry : the journal of mental science* 2012;201:180-5.

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