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ORIGINAL ARTICLE

Association between brain lateralization and mixing ability of chewing side

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Abstract *Background/purpose:* Previous studies have suggested that functional dominance in one part of the body can be correlated with functional dominance in another part. Thus, the present research aimed to determine whether brain laterality (handedness, footedness, earedness, and eyedness) was related to mixing ability and chewing side preference.
Materials and methods: Fifty-four volunteers who were not undergoing any form of dental treatment took part in this study. Self-defined brain laterality was determined through a questionnaire. The volunteers performed five tasks related to brain laterality, which was identified by the side used to perform three or more of the five tasks. Chewing side preference was determined by observing the main gum location on the occlusal area when volunteers chewed for 30 strokes. Mixing Ability Index (MAI) was measured by analyzing the degree of mixing of two differently colored waxes (height, 3 mm; diameter, 20 mm). Occlusion contact area was measured by taking the maximum intercuspation bite with polysiloxane.
Results: Thirty-nine volunteers (72%) showed significant agreement between brain dominance and chewing preference side. The association between brain dominance and MAI was not significant. The occlusal contact area of the dominant side (mean = 48.2 mm^2) was significantly wider than that of the nondominant side (25.7 mm^2).
Conclusion: Brain laterality can be explained by the side of functional (preference of the hands, eyes, ears, and feet, and survey) has a positive correlation with chewing preference side. MAI between the brain dominant and nondominant sides was not significant. This shows

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that mastication efficiency does not differ between dominant and nondominant sides. So, this study suggests that brain dominance is correlated with chewing preference, but it does not affect efficiency of mastication.

Introduction

The human brain consists of left and right hemispheres, and has laterality. Brain laterality attributes functional dominance to various body functions.[1] Neurophysiologists have reported that the functional dominance of the hands, ears, eyes, and feet are indirect criteria that represent brain laterality.[1] Furthermore, it has been reported that functional dominance in one part of the body can be correlated with functional dominance in another part. For example, a person with right-hand dominance possesses right-sided dominance in the eyes, ears, and feet.[1] The dominance of a certain side of the body causes a unilateral preference, and the preference is expressed by the function of organs through the language of the nervous system. All the organs of the body are innervated, as are the masticatory muscles. Mastication is an important step in digestion. If food particles become smaller by chewing, the particle surface is larger than before. Because a large surface has a chance to encounter the enzyme, chewing ability is related to digestive efficiency.

Many researchers have published studies on the correlation between brain laterality and chewing side preference.[2–5] Nissan et al[3,4] have reported that the side preferences of the hands, eyes, ears, and feet are correlated with chewing side preference. However, many factors, including missing teeth, implant-supported restoration, and complete denture, are not related to chewing side preference.[3,4] Diernberger et al,[6] however, have reported that disorders with accompanying pain, such as temporomandibular joint (TMJ) disorders, could affect chewing side preference.

Meanwhile, masticatory efficiency, which could be one of the causes of chewing side preference, is a complex mechanism controlled by various factors. Masticatory efficiency, which could be defined by the ability to pulverize food debris during mastication, has an association with occlusal contact area, masticatory muscle force, malocclusion, number of functioning teeth, intraoral movement ability, and TMJ disorders.

According to the research published so far, brain laterality exits, and chewing side preference is related to brain laterality.[7] Still, there are insufficient data concerning masticatory efficiency when brain laterality and chewing preference are considered. Research data of occlusal contact area, which could be the cause of masticatory efficiency or attrition, are also scarce.[8]

Thus, the objective of this research was to measure brain laterality using a questionnaire and functional preference tests of the hands, eyes, ears, and feet, and to compare the results to mastication laterality. Moreover, this research was conducted to identify any influence of chewing side preference on masticatory efficiency and occlusal contact area.

Material and methods

Study volunteers

There were 54 volunteers aged 25–35 years, including 38 men (average age, 30.5 ± 5.5 years) and 16 women (average age, 28.0 ± 3.8 years). Exclusion criteria included severe facial asymmetry, cross bite, missing teeth (not restoration), TMJ disorders, and any oral cyst or malignant disease. This study was reviewed and approved by the Institutional Review Board of Pusan National University Dental Hospital (PNUDH-2015-002). Written consent was granted by all study participants.

Brain laterality tests

To measure brain laterality as defined by the most frequently used side of the hands, feet, eyes, and ears, the experimental method suggested by Nissan et al[3,4] was redesigned and reconstructed to fit the location and circumstances of the study. The brain laterality tests were preceded by volunteers indicating their brain laterality through a survey (Table 1).

Questionnaire-reported preference

The volunteers were asked by questionnaire, "Between left and right, which side do you use mainly?" to determine which side they perceived to be dominant.

Table 1 Brain laterality test.

Laterality	Task
Hand	Hand used for making a drawing
	Hand used for erasing a picture
	Hand used for throwing a small rubber ball
Foot	Foot used for kicking a soccer ball
	Foot used for kicking a tennis ball
	Foot used for stepping onto a chair
Eye	Eye used for looking into an opaque bottle
	Eye used for looking into a square box
	Eye used for looking into a camera viewfinder
Ear	Ear used to listening behind a closed door
	Ear used to listening cellular phone
	Ear used for a single wire earpiece

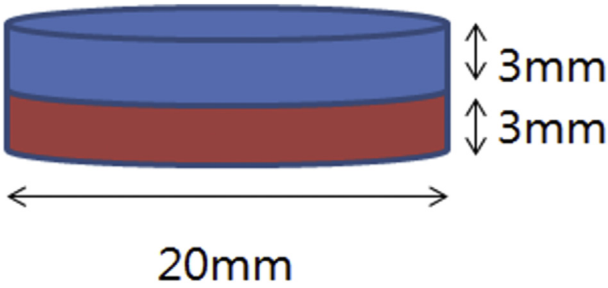

Figure 1 Stuck wax (red and blue cylindrical waxes were stacked on each other).

Brain dominance

If three out of five tests were in the same direction,that side was defined as the dominant side of the brain.

Chewing side preference test

Volunteers were asked to first place a piece of chewing gum (xylitol; Lotte confectionery, Seoul, Republic of Korea), the locations of the chewing gum during 30 strokes of mastication were examined. The side with $>$ 15 strokes was determined to be the chewing preference side.

Making the wax tablet and chewing wax

Following the study of van der Bilt et al,[9] two red and blue cylindrical waxes with 20 mm radius and 3 mm height were stacked together at 36.5°C (Figure 1). Volunteers were asked to chew the wax tablets three, five, seven, 10, 13, and 20 times on each side. Wax images were taken by a camera (30D; Canon, Tokyo, Japan). To minimize light reflection, a photo of both sides of the chewed waxes were taken using a camera in the 50 cm $\times$ 50 cm $\times$ 50 cm non-light-reflecting chamber. The background of the wax sample was black processed using MATLAB version 2014 b (The MathWorks, Inc., Massachusetts, USA) (Figure 2). The

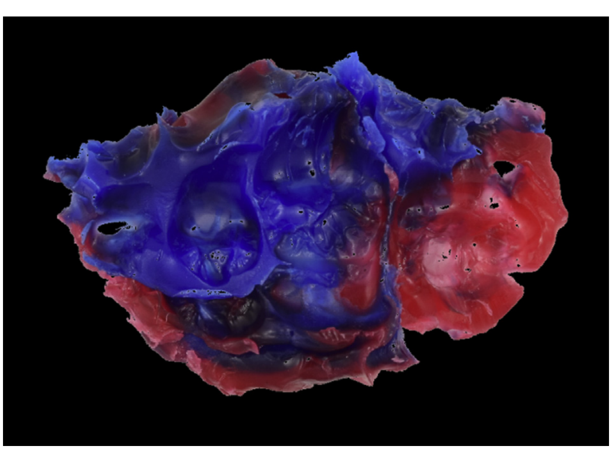

Figure 2 Wax sample for analysis by MATLAB (The MathWorks, Inc., Massachusetts, USA).

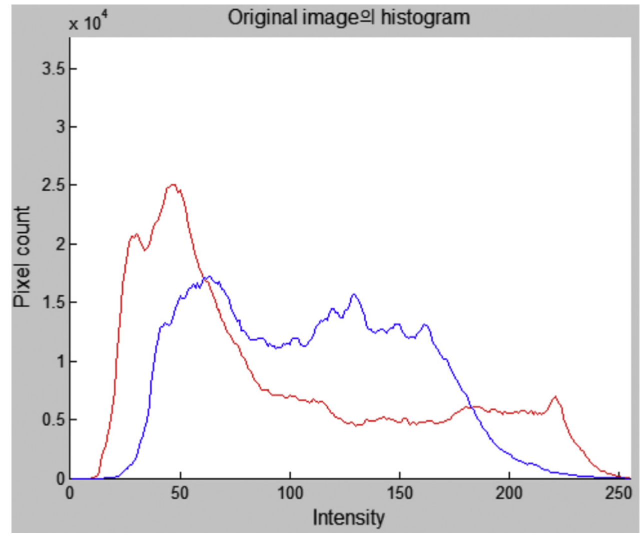

Figure 3 Wax sample pixel count before clipping. Red line was intensity of red color of wax sample and blue line was intensity of blue color of wax sample.

photographs were analyzed with MATLAB using van der Bilt's,[9] which manipulated color mix to analyze Mixing Ability Index (MAI). Red and blue intensity of wax was drawn (Figure 3). MAI was defined as the sum of the standard deviation (SD) of the red and blue light distribution by van der Bilt's[9] method. MATLAB can calculate the average and SD of red and blue light. As the two colors of wax were mixing, the SD of red and blue light was smaller. So the MAI value decreased as the red and blue colors were mixed because the SD of each color decreased.

Occlusal contact area

Bite impressions were taken at maximum intercuspation using blue polysiloxane. Images of the impressions were taken by a camera and analyzed by MATLAB. When we put bite impression (color blue) on the green paper, contact area reflected background color. Because the contact area was thin, the background green color was illuminated. MATLAB calculated the green color that was illuminated at a thickness of $<$ 0.45 mm.

Statistical analysis

To determine the correlation between brain laterality and mastication preference side, the χ^2 test was used. For verification of normality of MAI and contact area related to brain laterality, the Shapiro test was performed. The *t* test was used for the normal distribution, and if the distribution was not normal, the Wilcox-rank sum test was performed. The correlation between MAI and contact area was determined by Pearson's correlation analysis. All of the statistical analysis was done by the R language program version 3.2.2 (R Foundation for Statistical Computing, Vienna, Austria).

Table 2 Results of χ^2 tests for association between BDS and CSP.

	BDS	
	Same[a]	Opposite[b]
CSP, *n* (%)	39 (72)	15 (28)
P	< 0.05	

BDS = brain dominance side; CSP = chewing side preference.
[a] Dominance side was same between CSP and BDS.
[b] Dominance side was opposite between CSP and BDS.

Results

Side of brain dominance

In the survey, of 54 volunteers, 34 (63%) answered that they were right dominant, and 20 (37%) reported that they were left dominant. For the hand and foot dominance tests, 44 volunteers (81%) had right hand dominance, and 38 volunteers (70%) had right foot dominance. The results of the dominant eye and ear tests showed that more left side dominance was observed than right side dominance; 29 volunteers (54%) were left eyed, and 30 volunteers (56%) were left eared. The volunteers with right dominance (35, 65%) outnumbered those with left dominance (19, 35%).

Brain laterality and chewing side preference

There was a positive correlation between brain laterality brain dominance side (three of five same direction) and chewing side preference, and it was statistically significant ($P < 0.05$, Table 2). The preferred side of the volunteers' eyes and feet was associated with chewing side preference ($P < 0.05$, Table 3). However, three factors (questionnaire-reported preference, handedness and earedness) did not show any association ($P > 0.05$, Table 3).

Brain laterality and MAI

When the MAI of the dominant side of the brain was compared to the MAI of the nondominant side, the MAI of the dominant side was smaller than that of the nondominant side for three, seven, 10, and 13 chewing strokes, which indicated higher mixing ability on the dominant side, but the difference was not significant. Although the MAI of the nondominant side was smaller than that of the dominant side for five and 20 chewing strokes, indicating higher mixing ability of the nondominant side, the difference was not significant (Table 4).

Chewing side preference and MAI

Smaller MAI of the chewing preference side showed that the chewing preference side had higher mastication efficiency, but this finding was not statistically significant (Table 4).

Brain laterality and occlusal contact area

The correlation between the side of brain dominance and the side of occlusal contact was as follows. The occlusal contact area of the side of brain dominance (48.2 ± 52.5 mm^2) was larger than that of the nondominant side (25.7 ± 49.6 mm^2), and this difference was statistically significant.

Table 3 Results of χ^2 tests for association between CSP and five factors.

	Questionnaire-reported preference		Handedness		Earedness		Eyedness		Footedness	
	Same[a]	Opposite[b]	Same	Opposite	Same	Opposite	Same	Opposite	Same	Opposite
CSP, *n* (%)	32 (59)	22 (41)	34 (63)	20 (37)	32 (59)	22 (41)	37 (69)	17 (31)	38 (70)	16 (30)
P	0.17		0.06		0.17		<0.05		<0.05	

BDS = brain dominance side; CSP = chewing side preference.
[a] Dominance side was same between CSP and BDS.
[b] Dominance side was opposite between CSP and BDS.

Table 4 MAI differentiation between brain dominance side and non-brain dominance side and MAI differentiation between chewing preference side and non-chewing preference side.

	BDS MAI	NBDS MAI	P value	CSP MAI	NCSP MAI	P
	Mean ± SD	Mean ± SD		Mean ± SD	Mean ± SD	
3rd stroke	61.17 ± 3.3	61.65 ± 4.7	0.99	62.73 ± 3.24	63.15 ± 2.56	0.57
5th stroke	58.44 ± 3.2	57.85 ± 2.7	0.49	57.96 ± 2.61	58.36 ± 3.33	0.98
7th stroke	56.18 ± 4	56.74 ± 3.5	0.41	55.75 ± 3.65	57.22 ± 3.76	0.18
10th stroke	53.8 ± 2.6	54.38 ± 4.4	0.56	53.77 ± 3.52	54.5 ± 3.65	0.49
13th stroke	51.82 ± 5.4	53.31 ± 3.7	0.24	51.5 ± 4.85	53.53 ± 4.2	0.14
20th stroke	48.94 ± 4	47.09 ± 5.2	0.27	47.89 ± 3.89	48.17 ± 5.6	0.73
Slope	-0.83 ± 0.3	-0.88 ± 0.3	0.24	-0.86 ± 0.26	-0.85 ± 0.26	0.92
Intercept	62.25 ± 3.2	62.44 ± 3.1	0.72	62.75 ± 3.09	62.02 ± 3.11	0.39

BDS = brain dominance side; CSP = chewing side preference; MAI = mixing ability index; NBDS = non-brain dominance side; NCSP = non-chewing side.

Chewing side preference and occlusal contact area

The occlusal contact area of the chewing preference side (43.3 ± 54.7 mm^2) was larger than that of the nonpreferred side (41.3 ± 47.3 mm^2), but this was not statistically significant.

MAI and occlusal contact area

Correlation efficiency at three, five, seven, 10, 13, and 20 strokes was < 0.09 and P value was > 0.05 (data not shown). So, there was no correlation between mixing ability and the occlusal contact area at three, five, seven, 10, 13, and 20 strokes ($P > 0.05$).

Discussion

This study was designed to find correlations among brain laterality, chewing side preference, and MAI. The results of this study showed that there was a meaningful correlation between brain laterality and chewing side preference ($P < 0.05$). There was also significant correlation between chewing side preference and the functional laterality of eye and foot ($P < 0.05$), which coincided with the study of Nissan et al.[3,4] By contrast, the correlation between the survey, hand laterality, and chewing side preference was weak. This is because spoon and chopstick use in Asia or social education opportunities conceal the effects of brain laterality.

It is important that mastication is the first step of digestion. The occlusion reduces food particles and broadens the surface area. The larger the surface area of the food, the more frequent the contact between the enzyme and the food. Thus, the study of mastication efficiency is meaningful and provides objective indicators of mastication.[10] Mandibular movement for mastication is not an independent, but a complementary movement of left or right masticatory muscles.[11] Thus, in the case of chewing on the same side as brain dominance, the opposite side moves together too, and other various intraoral morphologies affect the mastication process. In a previous study, habitual and nonhabitual mastication side did not show any difference in electrical activity during mastication.[12] Therefore, although there was a chewing preference side depending on the brain dominance side, no relevant difference was observed on mastication efficiency, which is a complicated process. When comparing chewing preference side and mastication efficiency, it turned out that for three, five, seven, 10, 13, and 20 chewing strokes, mastication efficiency of the chewing preference side was higher than the efficiency of the nonpreferred side, but it was not statistically significant ($P > 0.05$). The result was similar when the side of brain dominance was compared with mastication efficiency, and was due to the complementary movement of the left and right mandibles. In other words, when food particles are pulverized inside the mouth, the movement of the mandible is a simultaneous process versus a unilateral one, and no significant difference on mastication efficiency was observed between chewing preference side and the nonpreferred chewing side. The activities of muscles work independently of the nonworking side. But intraoral masticatory movements are not unilateral, and they require simultaneous muscle movements on the nonworking side as well, so concentrated use of the chewing preference side does not create an absolute difference in masticatory efficiency. Many studies have reported that occlusal contact area, bite force, malocclusion, intraoral exercise functions, and TMJ disorders are factors affecting mastication efficiency.[13–15] The result of this research shows that the occlusal contact area of the side of brain dominance was significantly larger than that of the nondominant side ($P < 0.05$). Also, although it was not statistically significant, the occlusal contact area of the chewing preference side was larger than that of the nonpreferred side. The side of brain dominance and chewing preference create the possibility of tooth attrition, which can enlarge occlusal contact area. However, occlusal contact area is not a good effector for mastication efficiency. We think that mastication is an interaction in which left and right sides are linked, so, there are perhaps no significant differences in the mastication efficiency of the chewing preference side and the nonpreferred chewing side.

The functional and neurologic mechanisms of the human brain are enigmatic in many fields of study. In dentistry, the research is limited to the anatomical relationship of cranial nerves and masticatory muscle connections. If masticatory movements controlled by the brain are better understood as a result of this study, a patient's bite adjustments could be performed faster and more conveniently. This study suggests the following. Brain laterality can be explained by the side of functional preference of the hands, eyes, ears, and feet, as well as information collected by survey, and has a positive correlation with chewing preference side. However, the mechanism between brain lateralization and mastication efficiency was not clear and needs further study.

Conflict of interest

The authors have no conflicts of interest relevant to this article.

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