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Original Article

Masticatory mandibular movements for different foods textures related to onomatopoetic words

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This study aimed to investigate the effects of different sensory-evaluated food textures on masticatory movements, and to identify meaningful factors that correspond to different food textures. Masticatory movements of three healthy subjects were evaluated with a jaw movement tracking device using five different test foods: almond, hard and light rice crackers, apple, and chewing gum. The movements of the incisor point, working and non-working condyle and the entire mandible at the occlusal phase in the horizontal plane were analyzed. For harder foods, the incisor entered the intercuspal position from a rear and lateral, the working condyle showed anterior and noticeable medial movements as the entire mandible translated posteriorly and medially. For soft foods, the incisor movements were nearly coincidental with the lateral border movements, and the mandible rotated towards the inner side near the working condyle. Although the overall paths of the mandibular movements are individually different, it appeared that jaw movement at the final closure is particular to the food texture. From the standpoint of mandibular movements, it is suggested that masticatory movements during the occlusal phase in the horizontal plane is useful for revealing the relationship between mandibular movements and food textures that were evaluated with onomatopoetic words.

Key words: mastication, mandibular movements, food texture, horizontal plane, onomatopoetic texture words

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Introduction

It is commonly asserted that food texture is a factor which meaningfully contributes to the appreciation of foods.[1] Texture is defined as the attribute of a substance resulting from a combination of physical properties and perceived as the senses of touch (including kinaesthesis and mouthfeel), sight and hearing and the evaluation of the foods texture is driven in the course of mastication.[2]

According to Yoshikawa and Nishimaru,[3] who surveyed word association tests, there are more than 400 texture words in Japanese; whereas only 78 were found in English by Szczesniak and Skinner.[1] A great interest in food texture seems to raise many onomatopoetic words that express delicate intra-oral perceptions directly. Many investigations on food texture were based on some of the mechanical textural attributes in evaluation of the food texture. However, the texture word is supposed to be an available evaluation for comprehensive sensation during mastication.[4]

Moreover, intra-oral sensations are important for regulation of masticatory force and jaw movements during chewing.[5] Through sensory input from sensory receptors, mandibular movements are modulated to be appropriate to the food consistency.[6] Therefore it could be suspected that the masticatory movements involve characteristic factors that are correlate to the perception of food texture. Though previous studies on mandibular movements reported that food differences affect the chewing patterns in the frontal view, such as the vertical and lateral extent of the chewing loop,[7–9] their functional meanings have not been clarified enough in concern with food texture. Especially, the complicated mandibular movements at the occlusal phase during chewing have not been elucidated enough[10] as the inherent difficulty of measuring mandibular movements.

This study investigates the mandibular movements in the horizontal plane during occlusal phase precisely with the changes of food textures related to onomatopoetic texture words and aims to determine whether there are common underlying patterns.

Material and Methods

Subjects

Three healthy dentate subjects with a mean age of 30 years participated in this study (Table 1). All had sound dentition with stable occlusal contacts at the intercuspal position (IP), and no clinically detectable signs and subjective symptoms of dysfunction in the temporomandibular joints. All subjects exhibited a chewing pattern at the central incisors in the frontal plane that had gliding contacts at the occlusal phase where the closing and opening paths intercept the border movements. Subjects A and B exhibited approximately symmetrical smooth border movements. Subject C exhibited irregular paths on the right side (Fig. 1) and the notable facet was detected in distobuccla groove of the mandibular first molar on the working side, which guided the mandible from the rear and lateral direction.

Test Foods

Test foods were selected from the nomenclature by Yoshikawa and Nishimaru,[3] and Szczesniak and Skinner,[1] that classified the foods by texture words and the polyglot list.[4] Almond, one type each of hard and light rice cracker, apple and chewing gum were selected (Table 2). They belong to different mechanical textural attributes, that is: fracturability and gumminess, and both attributes have a high correlation with texture words, such as crunchy, crispy and chewy. The hard and light rice crackers and apple were cut into bite-size chunks, and the almonds and chewing gum were offered in their normal shapes and sizes.

Methods

Jaw movement during mastication was measured with a jaw movement tracking device MM-JI-E (Syohu Inc., Kyoto, Japan) which records movements in 6 degrees of freedom. This measuring system has a movement detector comprised of upper and lower face-bows connected on the right and left side of the apparatus that allows free jaw movement. The measuring system can linearly record the full range of jaw movements with an overall accuracy of 150 μm in any position[11] and shows its highest accuracy around the

Table 1. Profile of Subjects

Subject	Gender/ Age	Habitual chewing side	Teeth with occlusal contacts: Right lateral grinding		Teeth with occlusal contacts: Left lateral grinding	
A	M/27	R	18-12	28	18 17	22-25 28
			48-42	38	48 47	32-35 38
B	M/35	R	17 16 14	22 26		21 23-27
			47 46 44	31 37	41	33-37
C	F/28	L	17-13	26 27	17	22 23 26 27
			47-43	37	47	32 33 36 37

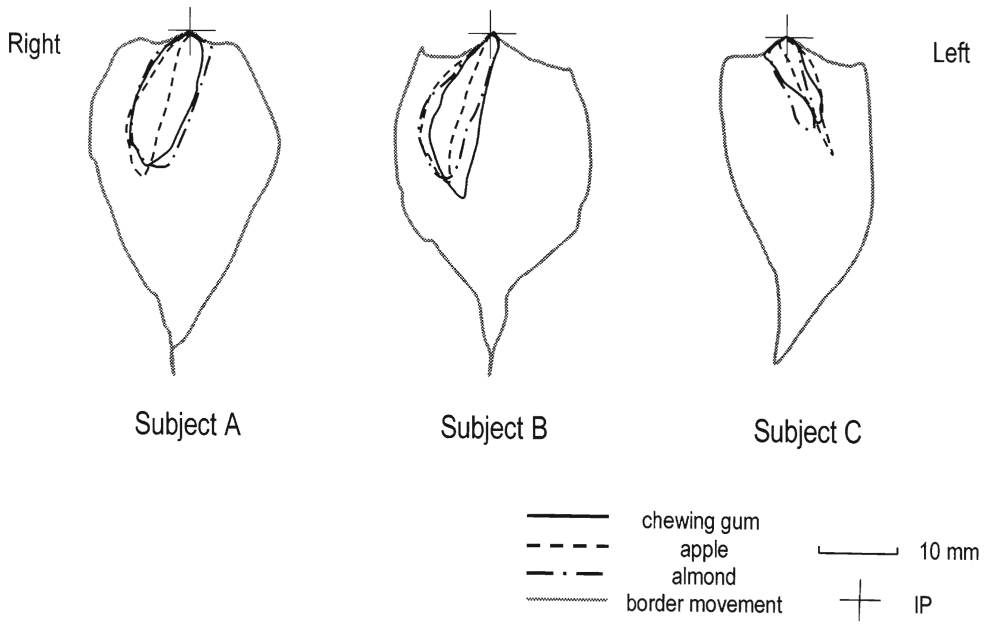


Fig. 1. The traces of the border and chewing paths in the frontal plane. The chewing movements of one typical representative stroke for each food are compared at the incisor point.

Table 2. Test Foods and Their Texture Profiles

Mechanical textural attributes	Degree	Texture words	(Japanese)	Foods
Fracturability	moderate	crunchy	(kari-kari)	almond
	high	crunchy	(bari-bari)	hard rice cracker
	high	crispy	(pari-pari)	light rice cracker
Gumminess	moderate	crispy	(saku-saku)	apple
	high	chewy	(necha-necha)	chewing gum

occlusal position. The face-bows were rigidly attached to custom-made cast clutches, which were cemented to the facial labial surface of the maxillary and mandibular teeth. These clutches were designed not to interfere with the remaining occlusal contacts and were adjusted enough to minimize any restriction on lip sealing in order to perform habitual chewing as possible.

The subjects were instructed to chew each test food on their habitual chewing side. The measurements of the masticatory movements were performed 3 trials for each food, and the five test foods were assigned in random order to give a total of 15 trials. The data in this experiment were taken at a single recording session to avoid problems caused by day-to-day reproducibility. Each trial was recorded for about 20 seconds with a sampling frequency of 100 Hz. For each trial, the data in the first two-thirds of the masticatory sequences were analyzed.

Analysis

With the purpose of analyzing the entire mandibular movements precisely, the incisor point (IC) and working and non-working condylar points (WC and NWC) were selected. The closing and opening paths at the occlusal phase in the horizontal plane were analyzed relative to border movement. In this study, the kinematic center of the temporomandibular condyle[12,13] represents the condylar point. To describe the chewing paths distinctively, the following parameters were analyzed. For the IC, the positions of closing paths at final closure were classified with respect to the lateral border path; the closing paths positioned rearward to the lateral border paths or the apex of the closing paths located rearward and lateral to the IP was defined as posterior-type (P-type), and closing paths approximately coinciding with, or anterior to, lateral border paths were defined as anterior-type (A-type) (Fig. 2). For the WC, the lateral components of the occlusal phase were calculated and statistically analyzed by one-way analysis of variance (ANOVA), and by the Scheffé test for post hoc comparisons. The lateral components were calculated between the two points at the stable condyle position and most lateral position in the posterior portion of the tracing. The entire mandibular movements were analyzed with the tracings at IC, WC, and NWC by means of corresponding labels at three different times.

Results

Figures 3a to 3c show representative chewing movements and border paths at three points of IC, WC, and NWC during the occlusal phase in the horizontal plane.

The incisor movements at the occlusal phase in the horizontal plane

The chewing movements at the IC during the occlusal phase were characterized by the lateral courses, which were approximately adjacent to the lateral border paths in every test food except apple. In apple chewing, for all subjects, the opening pathway was directed laterally toward the working side without gliding contacts.

As for the closing paths, they showed the same inclinable reference to the lateral border paths in every test food for all subjects. In subject A, when chewing apple and gum, the closing paths were approximately parallel to the lateral border paths and most of them showed A-type paths around the IP. With almond and rice crackers, P-type paths were observed more often. Subject B showed similar closing patterns to those observed in subject A. In subject C, though some chewing paths approached IP from the rearward aspect and were not parallel to the lateral border paths, the closing paths around IP showed both A and P types, as in the other subjects.

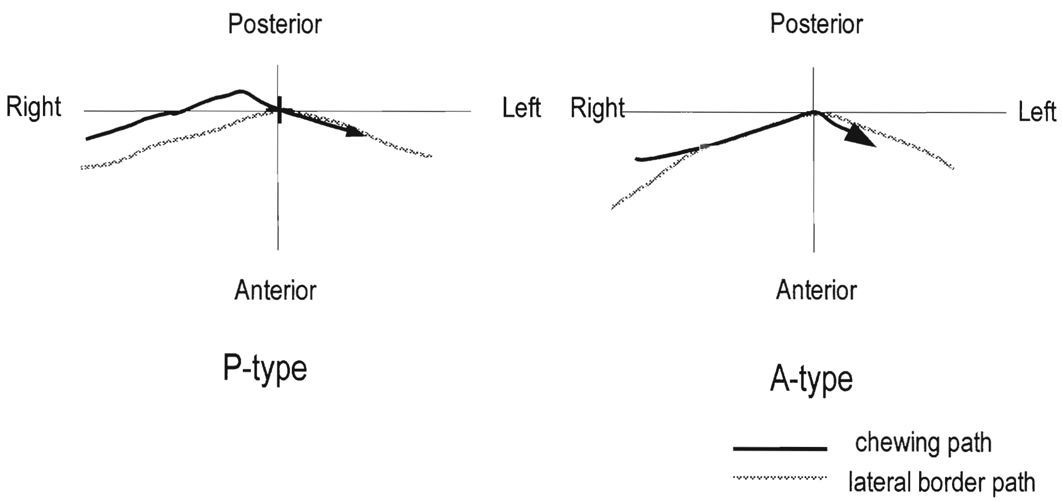
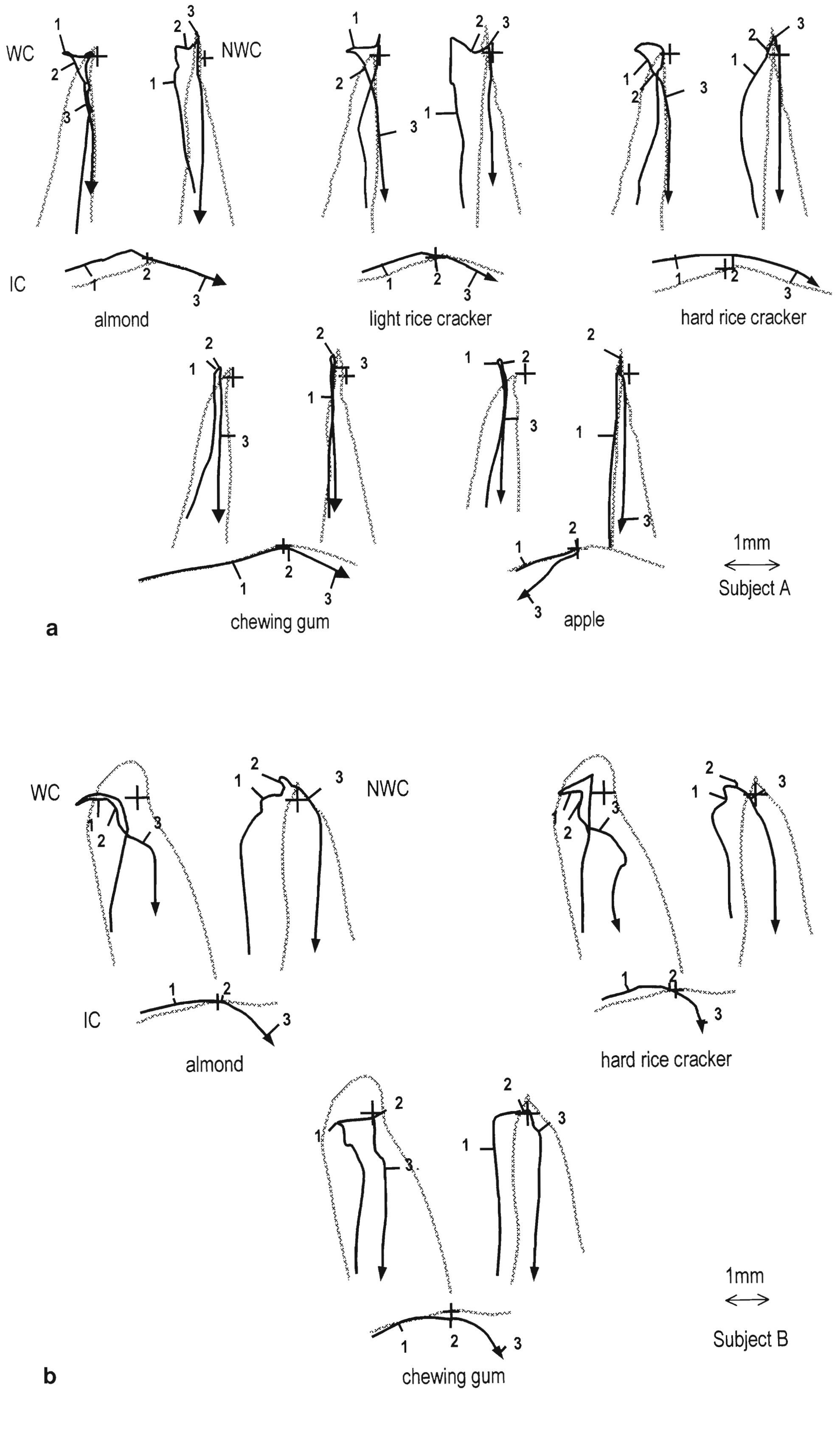


Fig. 2. The distinction of path type based on the closing paths at final closure.
P-type: The chewing paths at final closure position rearward to the lateral border paths, or the apex of the closing paths locates posterior and lateral to the IP.
A-type: The chewing paths at final closure approximately coincide with, or are anterior to the lateral border paths.
The intersection of the axes shows the intercuspal position. The arrow indicates the direction of opening.


WC
NWC
IC
almond
light rice cracker
hard rice cracker
chewing gum
apple
1mm
Subject A
a
WC
NWC
IC
almond
hard rice cracker
chewing gum
1mm
Subject B
b

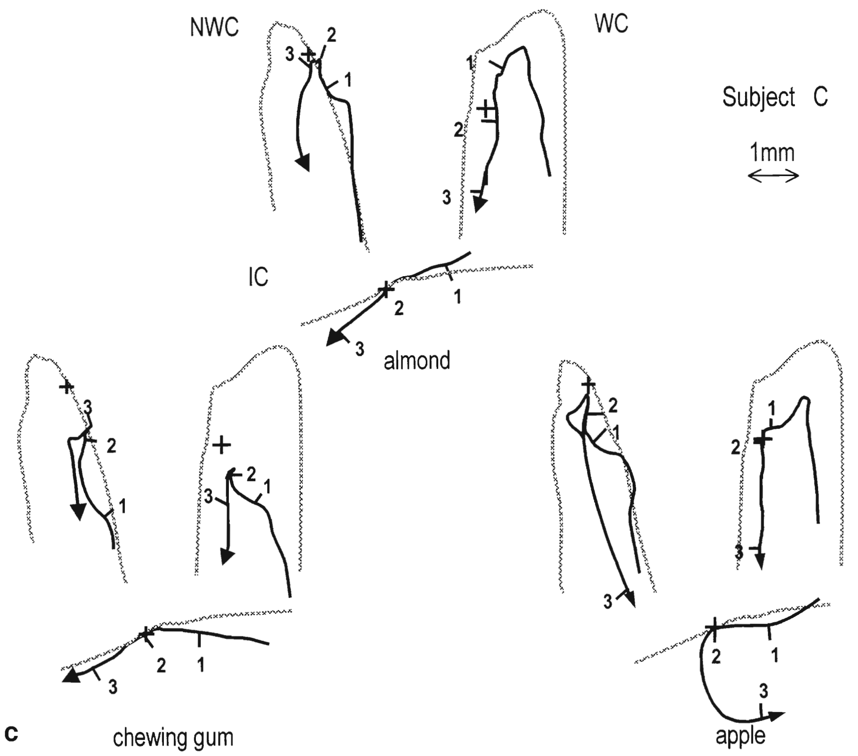


Fig. 3. The border movements and one typical representative chewing movements at IC, WC, and NWC, during the occlusal phase in the horizontal plane. The light lines indicate the border movements. The point labeled 1 indicates the time, at which the IC is 1mm lateral to the IP; 2: the IC is nearest to the IP; 3: the IC is 1 mm lateral from the IP. The crosses show the intercuspal positions.
a: Subject A
b: for chewing almond, hard rice cracker and gum. (Subject B)
c: for chewing almond, gum and apple. (Subject C)

Figure 4 graphically depicts the frequencies of the A and P types observed for each test food. The P-type paths appeared with higher frequencies in almond, and hard and light rice crackers, whereas A-type paths did the same in chewing gum and apple for all subjects.

The condylar movements at the occlusal phase in the horizontal plane

In the working condylar movements during chewing, closing paths were located outside of the opening paths in all subjects. In the posterior portion of working condylar movements, subjects A and B exhibited characteristic crossing of the tracings in almond and in hard and light rice crackers. The WC shifted laterally from the most posterior position and followed by anterior and markedly medial movements during the occlusal phase. In subject C, the WC moved directly anteriorly and medially from the most posterior position in chewing almond and hard and light rice crackers. Whereas in gum and apple, it was commonly observed that the WC moved anteriorly from the most posterior position in opening.

For the non-working condylar movements, in all subjects and foods, it was commonly observed that the major components of final closure were posterior movements.

Table 3 shows the average lateral components in posterior portions of chewing paths at WC.

The entire mandibular movements during the final closure

When consider the entire mandibular movements in the horizontal plane during the final closure, (from time 1 to 2 in Figure 3), the entire mandible translated to posterior and medial in every food for all subjects. In almond, hard and light crackers, it involved the rotation, which resulted the anterior and medial movements at the WC. In chewing gum and apple, the entire

Table 3. Range of Lateral Movements(mm) in the Working Condyle

Subject	almond			HRC			LRC			apple			chewing gum		
	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD	n	Mean	SD
A	25	0.6 *	0.1	26	0.6 *	0.1	19	0.5 *	0.1	24	0.3	0.1	29	0.3	0.02
B	19	1.5*†	0.5	28	1.3 *	0.4	25	1.1 *	0.3	23	0.7	0.2	52	0.9	0.2
C	33	0.8 ‡	0.3	39	0.7 ‡	0.2	27	0.7 ‡	0.3	20	0.7 ‡	0.09	40	0.5	0.2

(Test foods: almond, HRC, LRC, apple, chewing gum)

The range of the lateral components in working condyle at final closure for each test food.
HRC : Hard rice cracker; LRC : Light rice cracker
* $p<0.05$ relative to apple and gum; † $p<0.05$ relative to light rice cracker
‡ $p<0.05$ relative to gum
No symbol indicates the absence of a significant contrast

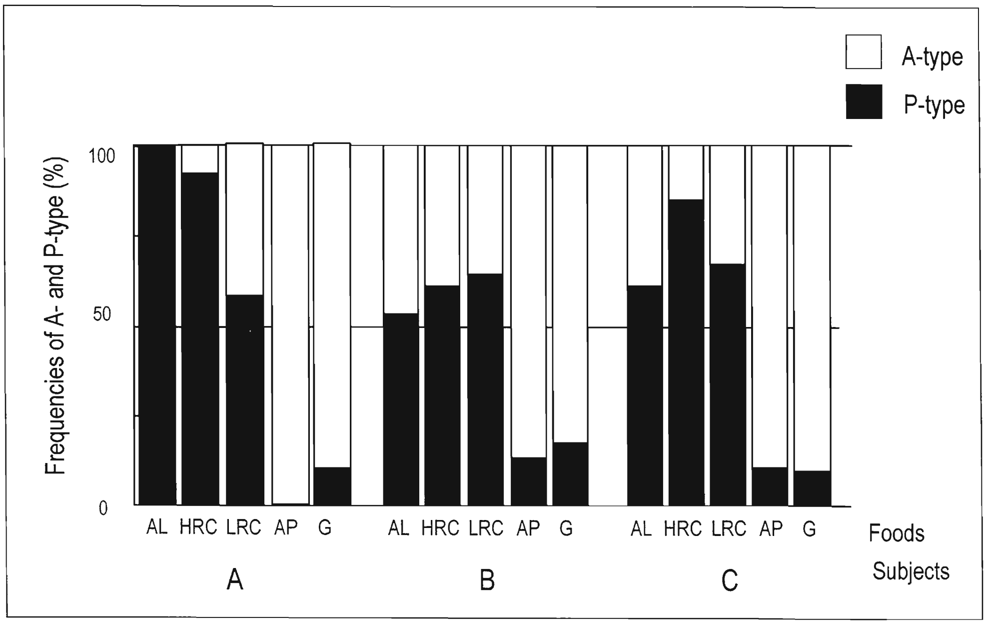


Fig. 4. The frequency of the anterior (A-type) and posterior (P-type) chewing paths during the final closure in relation to the lateral border paths in the horizontal plane. ($19 \leq n \leq 52$)
AL: almond; HRC: hard rice cracker; LRC: light rice cracker; AP: apple; G: chewing gum.

mandible showed the rotation towards the inner side near the WC, which caused the mandible the posterior and medial translation.

Discussion

In a study of food texture related to words, Yoshikawa and Nishimaru[3] reported that numerous onomatopoetic terms were found in the glossary of Japanese texture words, and that many of these terms refer primarily to a food's cohesiveness, secondary fracturability and gumminess as their mechanical textural attributes. The fracturability and gumminess are also related to the primary parameter of hardness, and the fractural materials, which possessing a substantial degree of hardness produce sound effects on mastication[14] and the materials, which possessing some degree of the gumminess have low degree of hardness[15]. This might suggest that minute differences in mechanical attributes could be distinguished by intra-oral sensory receptors individually, and were represented with different texture words. Therefore, in a study of the masticatory movements resulting from changes in food texture, it might be of interest to select test foods from the texture words in the glossary and the definition of their textural attributes.

Most of the studies on masticatory movements have analyzed the chewing strokes after elimination of the first several irregular strokes. However, it is indicated that the perception of food textures like hardness, crispness, and firmness is mainly made during the first bite.[16–18] On the other hand, it is considered that during the later part of the chewing series, the bolus, which is triturated and mixed with saliva, might not reflect the inherent food texture.[19] With the purpose of eliciting the texture differences, this study analyzed the first two-thirds of the masticatory sequences.

The chewing movements can be better understood when related to familiar border movement.[20] Previous studies that analyzed the IC paths have shown that food types changed the vertical and lateral extent of the chewing loop in the frontal view. Furthermore, this study indicated that minute textural differences among foods were also reflected in the paths in the horizontal plane. Despite the wide range of chewing movements, the characteristic masticatory movements with the changes in food texture could be observed at the final closure in all subjects.

In chewing soft foods, apple and chewing gum, the paths at the IC almost coincided with the lateral border paths that were approximately the same as the natural teeth guidance patterns. The entire mandible simply rotated towards the posterior and medial near the working condyle. In the soft foods, continuous control by the neuromuscular system seemed to be less necessary, since the teeth routinely glided the jaw to final closure[7]. When chewing apple, the opening paths of the IC turned towards the working side, while the paths of the chewing gum were toward the non-working side. The difference in the opening paths between these foods appeared to be associated with the stickiness of the foods. The texture word 'necha-necha', for gum, and means 'a sticky feeling', suggests a wider and more lateral mouth opening in response to the presence of sticky substances, while that of 'saku-saku' for apple means 'crispy' and suggests less trituration.

When chewing hard foods, the IC entered IP from rearward with lateral aspects. Furthermore, in the course of mandibular movements to posterior and medial, the WC translated laterally prior to final closure with chewing hard foods in subjects A and B. Though this lateral shift could not be observed in subject C, all subjects showed that the WC translated anteriorly and remarkably medially during final closure. Overall, it could be inferred that the working side of the mandible approached IP from rearward and laterally, during final closure when chewing harder foods. Moreover, the examinations of the articulations for each subject commonly appeared that the working side of the mandible almost followed the oblique ridge of the bucco-distal cusps of the upper molars in P-type paths. In his investigation of interocclusal clearance during lateral gliding, Watabe[21] indicated that the so-called Squeezing Room in the mesio-palatal section of the upper molar was considered to be a place for crushing and compressing food. During hard foods chewing, it can be assumed that particles of food are effectively triturated between the opposing dentition eliciting the Squeezing Room, as the lower working molars close along the oblique ridge of the bucco-distal cusps of the upper molars. In addition, the characteristic gliding contacts toward the non-working side in opening path was supposed to represent the twisting and triturating mandibular movements.

Between the rice crackers, the hard rice cracker exhibited larger lateral movements of the working condyle in subjects A and B. This result suggested that the harder one required more lateral movements to triturate food particles. The minute textural difference described in another Japanese onomatopoetic texture words, corresponding to 'bari-bari' for harder and thicker foods and 'pari-pari' for harder and thinner foods, might concern with the masticatory jaw movements in the horizontal plane.

This study implies that all mandibular movements at the occlusal phase, in the horizontal plane, exhibit peculiar closure paths according to food textural differences described by specific texture words, even though the overall paths of the mandibular movements and chewing patterns are individually different. It seems that the neuromuscular system harmoniously controls the jaw movements in response to minute textural differences. From the standpoint of the mandibular movements, the analysis at the occlusal phase in the horizontal plane might provide noteworthy factors that related to sensory evaluated food textures.

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