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Side switch frequency while masticating different chewing materials, and its relationship with other masticatory behaviors and sensory perceptions

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A R T I C L E I N F O

Keywords:
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A B S T R A C T

Objective: This cross-sectional study aimed to establish normative values for masticatory side switch (MSS) frequency in young Mexican adults and to assess the relationship between various indices and MSS frequency when masticating different chewing materials.

Design: We enrolled 101 dentate adults and performed four masticatory assays that involved masticating different chewing materials (i.e., two-colored chewing gum, sweet cracker, salty cracker, and bread). Participants were asked to eat and swallow these foods and to chew the gum for 40 cycles and the following indices were determined: MSS index (MSSI), unilateral chewing index, chewing cycle duration, and number of cycles before terminal swallowing. The participants then rated perceived flavor intensity, salivary flow, and muscle fatigue during each trial.

Results: The MSSI ranged from 0.03–0.06 (10th percentile) to 0.48–0.54 (90th percentile). A repeated-measures general linear model revealed a mean MSSI value of 0.28 (95 %CI, 0.25–0.30) adjusted by several factors. Male sex, soft food, and the last chewing period were associated with lower MSS frequency. Spearman's test showed a high correlation for the MSSI among the different foods. MSSI correlated negatively with the unilateral chewing index for each chewing material and with number of cycles for the sweet cracker. However, no significant correlation was detected between MSSI and sensory perception.

Conclusions: In healthy dentate individuals, the mean MSS relative frequency is 25–30 % with an 80-central percentile of 5–50 % of the maximum possible side changes. Lower MSS frequencies were detected in men, when chewing soft food, and during the final chewing period.

Abbreviations: MSS, masticatory side switch; MSSI, masticatory side switch index; OCA, occlusal contact area; UCI, unilateral chewing index; ICC, intraclass correlation coefficient.

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1. Introduction

The main role of mastication is to ingest food for its energy and nutritional value (Hollis, 2018). To achieve this, the masticatory system coordinates the movement of the jaw, tongue, and other structures to reduce food particle size and mix with saliva to form a bolus that can be swallowed safely.

Masticatory performance can be directly assessed using objective tests that evaluate the efficacy to comminute or mix food based on chewing for a fixed number of cycles and analyzing either the median particle size of a test food or the color mixture a two-colored chewing gum (Gonçalves et al., 2021; Khoury-Ribas et al., 2019; Speksnijder et al., 2009; van der Bilt et al., 2010). The number of chewing cycles needed at the end of chewing also provides an objective and direct assessment of masticatory function (Engelen et al., 2005; Fontijn-Tekamp et al., 2004; Gonçalves et al., 2021). Moreover, chewing rate (Khoury-Ribas et al., 2021; Po et al., 2011; van der Bilt & Abbink, 2017), jaw movement (Flores-Orozco et al., 2016b; Lepley et al., 2010), and masticatory laterality (Flores-Orozco et al., 2016a; Khoury-Ribas et al., 2020; Mizumori et al., 2003; Rovira-Lastra et al., 2016) may also be studied to determine how the goals of mastication are achieved. An important aspect of masticatory laterality is the masticatory side switch (MSS) frequency that measures side changes during the masticatory process. Although the normal MSS frequency has not yet been established, it seems to be between 5 % and 32 % of the maximum switches possible and to depend on the chewing material (Carvalho-da-Silva et al., 2011; Ignatova-Mishutina et al., 2022; Ignatova-Mishutina et al., 2022; Jemt et al., 1979; Khoury-Ribas et al., 2022; Mioche et al., 2002; Mizumori et al., 2006; Remijn et al., 2016). While masticating natural and artificial (e.g., chewing gum or silicone pieces) chewing materials, healthy participants have MSS frequencies of 8–32 % (Carvalho-da-Silva et al., 2011; Jemt et al., 1979; Mioche et al., 2002; Mizumori et al., 2006; Remijn et al., 2016) and 5–8 % (Ignatova-Mishutina et al., 2022, 2023; Khoury-Ribas et al., 2022), respectively. Little is known about whether individual characteristics (e.g., age, gender, or dental occlusion) and other masticatory behaviors affect MSS frequency.

It is clinically important to discriminate individuals with impaired masticatory function from those with normal mastication. Normative values for masticatory performance have been established with carrots and silicone impression material (Optosil, Kulzer) as chewing tests (Witter et al., 2013; Woda et al., 2010), including values by age and gender for the number cycles needed to chew a salty cracker until terminal swallowing (Frank et al., 2019; Huckabee et al., 2018). Furthermore, a significant reduction in the chewing rate (Bourdiol et al., 2017), low intra-individual stability in the chewing rate (Po et al., 2011; Woda et al., 2006), and masticatory laterality > 33 % (Khoury-Ribas et al., 2020; Rovira-Lastra et al., 2014; Rovira-Lastra et al., 2016) may suggest impaired mastication. To date, however, no study has proposed normative values for central tendency or extreme values for MSS frequency.

A secondary role of mastication is to experience pleasure through the visual appearance of food and its perceived taste, texture, and flavor (Chen, 2009). Taste and flavor mainly depend on the release of nonvolatile and volatile compounds from food that stimulate receptors in the oral cavity and nose (Salles et al., 2011). The presence of saliva is also essential for food consumption, not only providing lubrication but also enhancing taste and digestion (Chen, 2009; Engelen et al., 2005). Masticatory muscular fatigue refers to the perceptible decline in force when chewing is prolonged or requires high muscular effort (Al Sayegh et al., 2020; Ueda et al., 2002). It would be of interest to know whether different masticatory behaviors affect flavor intensity, saliva secretion, and minimum muscle fatigue, which in turn, could improve a person's enjoyment of mastication.

In this study, we aimed to establish normative values for MSS frequency in young Mexican adults with healthy dentitions. Our secondary aims were to assess the relationship between different factors and MSS frequency and to determine the correlation between various masticatory behaviors and sensory perceptions when chewing different foods.

2. Methods

2.1. Study design and population

This cross-sectional study included student volunteers recruited from the Autonomous University of Nayarit (Tepic, Mexico), provided they were aged 18–50 years and were in good health (without- chronic medical diagnoses). Additionally, we excluded those with severe malocclusion (negative overjet, negative overbite, more than 4 mm of midline deviation, or presence of scissor bite), large dental restorations, <24 natural teeth, tooth wear affecting the dentin, tooth mobility (Grade 2 or 3), orofacial pain or temporomandibular disorders that could affect the mandibular movement, and ongoing orthodontic treatment. Individuals with moderate malocclusion were not excluded because it is relatively frequent in general population and most of them have a normal masticatory function (Bernabé et al., 2008; Bourdiol et al., 2017; Lujan-Climent et al., 2008).

The local ethics committee approved the study protocol and informed consent form (Code UAO/CEI/010/2021, 8th December 2021). All participants gave informed signed consent and we carried out all procedures according to the principles of the Helsinki Declaration. This report has been completed in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology guidelines (von Elm et al., 2008).

2.2. Data collection

All participants answered a questionnaire interview, underwent clinical examination and interocclusal registration, and performed eight masticatory trials. The questionnaire included items for age, gender, and the inclusion/exclusion criteria. Clinical examination was performed to determine the number of teeth and occlusal characteristics in an intercuspal position to verify the inclusion criteria. Using a digital caliper, we measured the midline deviation, overjet, and overbite to determine the lateral, anteroposterior, and vertical relationships of the right central incisors.

The occlusal contact area (OCA) at the maximum intercuspation position was determined using bite registration. An addition silicone (Colorbite Rock, Zhermack) was applied to the occlusal surface of the mandibular teeth and participants were asked to close their mouth to the maximum intercuspation position as hard as they could for 1 min. The occlusal registration was removed, trimmed, and scanned using the Transparent Materials Adapter (HP Scanjet G4050, Hewlett Packard). The image of each occlusal registration was converted to grayscale and analyzed using ImageJ software (National Institute of Health, USA). Spatial calibration was performed using a known distance and the relationship between each of the 256 grays (Rovira-Lastra et al., 2023). The thickness of the occlusal registration was determined using a stepped wedge of Colorbite (Ayuso-Montero et al., 2020). Occlusal contact was considered present for an interocclusal distance of ≤ 200 μm (Lujan-Climent et al., 2008; Martinez-Gomis et al., 2009).

2.3. Masticatory assays

Each participant performed four different masticatory assays that comprised two trials of masticating freestyle a chewing material, without imposing any chewing rate or side. Each masticatory trial was video recorded using a smartphone (Samsung Galaxy S7 Edge). In the first masticatory assay, participants were instructed to chew a sugar-free two-colored chewing gum for 40 cycles (Ignatova-Mishutina et al., 2023). This chewing material was prepared from a spearmint flavor gum (Green, "Spearmint Rain," 5; Mars Wrigley) and a cool berry flavor gum

(Red, "Strawberry Flood," 5; Mars Wrigley). The 2-colored chewing gum (2.5 g; 3 ×20 ×37.5 mm) was created by sealing with a drop of distilled water a half of a strip of one flavor to another half of the other flavor. After completing the 40 cycles, the gum was retrieved from the mouth, dried, and placed into a transparent plastic bag and coded. The chewing gum was flattened to a thickness of 1.5 mm using two glass plates. Each side of the gum was then scanned (HP Scanjet G4050) at a resolution of 300 dpi and saved in JPG format for further image analysis. The color-histogram plugin in Image J determined the standard deviation of the blue color intensity from all pixels, which in turn reflected the degree of mixing between these two colors. Therefore, using the standard deviation of blue intensity as the mixing ability index, a high value indicated worse mixing capacity (and vice versa).

The three remaining masticatory assays consisted of two trials each of chewing a piece of sweet cracker (4.0 g; 52.5 mm diameter x 5.0 mm thickness) (Marías Gamesa®; Galletera Mexicana), a piece of salty cracker (4.0 g; 55.1 mm diameter x 4.3 mm thickness) (Habaneras Clásicas®, Galletera Mexicana), or a portion of bread (4.0 g; 45.1 mm diameter x 14.9 mm thickness) (Pan integral Bimbo®; Grupo Bimbo). These foods were chosen because they are among the most consumed in Mexico (Carbajal-Sánchez et al., 2021). Participants were asked to eat and swallow these foods, without imposing a specific style, and to raise a hand when all the food had been ingested. These six masticatory trials were performed in a random order. Immediately after each masticatory assay, we also asked participants to rate three sensory attributes experienced during the chewing test and swallowing. These included the perceived flavor intensity ("During this chewing test, what flavor intensity did you notice?"), the perceived salivary flow ("How much saliva do you think you produced?"), and the perceived muscular fatigue ("What fatigue intensity did you notice in the masticatory muscles?"). Each answer was marked as a short vertical line on a 100 mm visual analog scale from "not at all" (left) to "very much" (right) (Ignatova-Mishutina et al., 2023).

2.4. Data analysis

A single operator (I-M, T) watched the video recordings in slow-speed playback to assess the number of masticatory cycles before terminal swallowing, the chewing cycle duration, the unilateral chewing index (UCI), and the masticatory side switch index (MSSI) (Ignatova-Mishutina et al., 2022, 2023). The time needed to complete each masticatory assay was determined, divided by the number of cycles performed, and expressed as milliseconds per cycle (Flores-Orozco et al., 2020). For each chewing cycle in the masticatory assays, the same operator observed the chin and recorded the side where the jaw closed at the intercuspal position ("+1" if right, "−1" if left, and "0" if neither). The asymmetry index was determined as follows: [(number of right strokes) −(number of left strokes)] ÷ [(number of right strokes) +(number of left strokes)] (Flores-Orozco et al., 2016a; Mizumori et al., 2003). The UCI was established as the absolute asymmetry index and expressed the degree of unilateral mastication, regardless of side (Khoury-Ribas et al., 2020). Finally, to calculate the MSSI, the same operator revised the sides where the jaw closed during all cycles of each masticatory assay and scored as follows: 1 point per masticatory switch between right and left, 0.5 points per masticatory switch between either side and the center, and 0 points for no masticatory switch. The total number of points was divided by the maximum number of the possible switches (number of cycles minus 1) and recorded as the MSSI (Ignatova-Mishutina et al., 2022, 2023; Khoury-Ribas et al., 2022). For each masticatory assay, the MSSI was determined at each chewing period, considering the 1st, 2nd and 3rd thirds of chewing cycles the early, middle and late period, respectively.

A new variable called OCA asymmetry was calculated as the difference between right OCA and left OCA. Several quantitative variables were dichotomized to interpret this variable as a predictive factor. Therefore, we used the median as cutoff to dichotomize age (22 years), midline deviation (0.785 mm), overjet (3.15 mm), overbite (2.65 mm), OCA asymmetry (5 mm^2), and chewing mixing ability (9.14).

2.5. Statistical analysis

The sample size (n = 102) was determined to estimate a population MSSI mean with a 95 % confidence interval using the GRANMO online platform (https://www.imim.es/ofertadeserveis/software-public/granmo/). We established a precision of ± 0.01 units, an infinite population, a drop-out rate of 5 %, and a standard deviation of MSSI of 0.05 units (Ignatova-Mishutina et al., 2022).

The test-retest reliability of the main parameters was evaluated in 24 participants (17 women and 7 men, median age of 22.8 years old) chosen by convenience. They repeated the masticatory assays 2–4 weeks after the first session. Reliability, which relates the measurement error to the variability between participants, was assessed by the intraclass correlation coefficients (ICC) for average measurements using a 2-way random effects model and absolute agreement (Koo & Li, 2016).

The Kolmogorov–Smirnov test was used to assess the normality of the distribution of MSSI variables. MSS frequency percentiles (10th, 25th, 50th, 75th, and 90th) were calculated for each chewing material. A general linear model with repeated measures was used to assess the effects of three within-participant factors (chewing period, food type, masticatory assay) and seven between-individual factors (gender, age, midline deviation, overjet, overbite, OCA asymmetry, mixing ability) on MSSI variance as a dependent variable. We also estimated the mean MSSI adjusted for all within- and between-individual factors, plus the mean MSSI by gender, period, and food type. Gender differences, masticatory parameters, and sensory perception were analyzed using Mann–Whitney *U* tests. Friedman's test was used to assess the effect of food type on masticatory behavior and sensory perception. Spearman's correlation was used to assess the relationship between different foods by masticatory parameters and to determine the correlation between different masticatory behaviors and sensory perceptions when masticating different chewing materials. Bonferroni correction for multiple comparison was applied to P values, as appropriate. All analyses were performed using IBM SPSS, Version 29.0 (IBM Corp., Armonk, NY, USA) and $P < 0.05$ was considered significant.

3. Results

The video files of 2 of the 103 eligible participants were lost, leaving 101 participants (67 women and 34 men) for inclusion in the final analysis. Their median age was 22.1 years (IQR: 21.3–23.2; range 20.7–46.8) and their dental characteristics are summarized in Table 1. All participants had natural dental occlusions without severe malocclusion, but men had more teeth and a higher OCA compared with women ($P < 0.05$; Mann–Whitney U Test).

Table 2 shows the ICC values and indicates good to excellent reliability in masticatory and sensory parameters for all chewing materials. Among the masticatory parameters, the degree of unilateral chewing showed the highest intra-individual variance in relation to the inter-individual variance. Sensory perception while chewing nutritive foods showed higher reliability than chewing gum. Furthermore, the MSSI variables were normally distributed ($P > 0.05$; Kolmogorov–Smirnov). Table 3 shows the 5th, 10th, 25th, 50th, 75th, 90th, and 95th percentiles for MSSI by type of test food. Regardless of the type of nutritive food, MSSI values ranged from 0.03–0.06 for the 10th percentile to 0.48–0.54 for the 90th percentile.

The repeated-measures general linear model showed that the MSSI depended on the food type ($P < 0.001$) and the chewing period ($P = 0.004$) (Table 4). Participants changed side more frequently when chewing the sweet or salty cracker compared with bread. The MSS frequency was reduced in the last period compared with the middle. Between-individual factors significantly related to the MSSI were gender ($P = 0.006$), age ($P = 0.034$), midline deviation ($P = 0.035$), and lateral

Table 1
Characteristics of the participants.

	Women n = 67	Men n = 34	Total N = 101	Significance (p)*
Occlusion				
Number of teeth	29 (28–29)	29 (29–30)	29 (28–29)	0.017
Overjet (mm)	3.2 (2.9–3.5)	3.2 (2.7–3.7)	3.2 (2.9–3.4)	0.671
Overbite (mm)	2.7 (2.4–3.0)	2.9 (2.3–3.5)	2.8 (2.5–3.1)	0.963
Midline deviation (mm)	0.8 (0.6–1.0)	0.7 (0.4–1.0)	0.8 (0.6–0.9)	0.381
Occlusal contact area (mm^2)	57 (48–66)	75 (61–89)	63 (55–71)	0.021
Mixing Ability Index	9.1 (8.9–9.4)	9.1 (8.7–9.5)	9.1 (8.9–9.3)	0.946

Results are shown as mean (95 % confidence interval)
*Independent-Samples Mann–Whitney *U* Test

Table 2
Test-retest reliability of different masticatory aspects with different chewing materials (n = 24).

Variable	Chewing gum ICC (95 %CI)	Sweet cracker ICC (95 %CI)	Salty cracker ICC (95 % CI)	Bread ICC (95 % CI)
Masticatory side switch index	0.73 (0.37–0.88)	0.68 (0.29–0.86)	0.90 (0.77–0.96)	0.89 (0.74–0.95)
Unilateral chewing index	0.66 (0.21–0.86)	0.51 (−0.15 to 0.79)	0.82 (0.58–0.92)	0.58 (0–0.82)
Chewing cycle duration	0.90 (0.77–0.96)	0.87 (0.64–0.95)	0.95 (0.72–0.98)	0.93 (0.77–0.97)
Number of masticatory cycles*		0.87 (0.71–0.95)	0.85 (0.65–0.93)	0.81 (0.57–0.92)
Flavor intensity	0.58 (0–0.82)	0.93 (0.83–0.97)	0.84 (0.64–0.93)	0.90 (0.77–0.96)
Salivary flow	0.87 (0.69–0.94)	0.89 (0.74–0.95)	0.81 (0.56–0.92)	0.88 (0.72–0.95)
Muscle fatigue	0.55 (−0.05 to 0.81)	0.72 (0.38–0.88)	0.71 (0.36–0.88)	0.84 (0.64–0.93)

Abbreviations: CI, confidence interval; ICC, intraclass correlation coefficient.
* from incision to food swallowing ICC–2-way random, absolute agreement for average measurements

Table 3
Masticatory side switch index percentiles by type of chewing material.

Percentile	Masticatory side switch Index			
	Chewing gum	Sweet cracker	Salty cracker	Bread
5th	0	0.017	0.045	0.001
10th	0	0.057	0.070	0.033
25th	0.019	0.189	0.195	0.112
50th	0.038	0.281	0.286	0.207
75th	0.083	0.404	0.381	0.318
90th	0.141	0.543	0.530	0.484
95th	0.203	0.566	0.566	0.523

OCA asymmetry (P = 0.044): women, individuals with 23–46 years old, and individuals with higher midline deviation and OCA had higher MSS frequency than men, individuals with 20–22 years old, or those with little or no midline deviation or OCA asymmetry. The repeated-measures general linear model revealed a mean MSSI value of 0.28 (95 %CI, 0.25–0.30) adjusted by several factors.

Table 5 summarizes the other masticatory behaviors and sensory perceptions when masticating the different chewing materials. The chewing pattern of the participants were 11–15 % unilateral left, 69–72 % alternate/simultaneous bilateral, and 13–16 % unilateral right. Of note, men masticated faster than women for each chewing material (P < 0.001; Mann–Whitney U Test) and women perceived higher muscle fatigue than men when chewing gum (P = 0.044). Friedman's test revealed that participants chewed faster when eating bread compared with the salty cracker, while the slowest rhythm was present when eating the sweet cracker. The mean numbers of chewing cycles before terminal swallowing were 30 for the sweet cracker, 35.6 for the bread, and 50.9 for the salty cracker. Participants perceived greater flavor intensity and salivary flow, but less muscular fatigue, while chewing gum; by contrast, they felt greater muscular fatigue and less flavor intensity and salivary flow when chewing the salty cracker.

Table 4
Mean values of Masticatory Side Switch Index (adjusted by nutritive food, period, assay, gender, age, occlusal characteristics, and Mixing ability).

Variable	Categories	Mean (95 %CI)	Significance
Food			< 0.001
	Sweet cracker	0.298 (0.265–0.331)[b]	
	Salty cracker	0.299 (0.269–0.329)[b]	
	Bread	0.227 (0.193–0.261)[a]	
Chewing Period			0.004
	Early	0.273 (0.241–0.304)[ab]	
	Middle	0.295 (0.261–0.330)[b]	
	late	0.256 (0.225–0.287)[a]	
Chewing Assay			0.241
	First	0.270 (0.242–0.299)	
	Second	0.279 (0.247–0.311)	
Gender			0.006
	Women	0.308 (0.272–0.344)	
	Men	0.217 (0.167–0.267)	
Age			0.034
	19–22 years	0.241 (0.199–0.284)	
	23–48 years	0.305 (0.264–0.346)	
Midline Deviation			0.035
	<0.785 mm	0.245 (0.204–0.286)	
	>0.785 mm	0.309 (0.266–0.351)	
Overjet			0.692
	<0.315 mm	0.269 (0.228–0.310)	
	>0.315 mm	0.281 (0.239–0.323)	
Overbite			0.629
	<2.65 mm	0.281 (0.240–0.322)	
	>2.65 mm	0.267 (0.225–0.309)	
OCA asymmetry			0.044
	No/little asymmetry	0.246 (0.204–0.287)	
	OCA asymmetry	0.306 (0.264–0.348)	
Chewing mixing ability			0.158
	Low mixers	0.294 (0.253–0.335)	
	High mixers	0.252 (0.210–0.295)	
Mean		0.275 (0.245–0.304)	

Repeated-measures ANOVA (General lineal model). Different superscript letters means that the mean difference was significant (P < 0.05) adjusted for multiple comparisons (Bonferroni) Abbreviations: CI, confidence interval; OCA, occlusal contact area.

Among the different masticatory behaviors, chewing cycle duration showed the highest correlation between the natural foods, whereas the UCI showed the lowest correlation (Fig. 1). The correlation between the MSSI values for different foods was similar to that between the number of cycles before swallowing the foods. Finally, Tables S1 to S4 show the correlations between masticatory behavior and sensory perception when masticating each chewing material. Significant and negative correlations existed between the MSSI and UCI for each chewing material and between the MSSI and number of cycles before terminal swallowing only the sweet cracker. Significant and positive correlations existed

Table 5
Masticatory aspects during chewing different chewing materials by gender.

Variable		Chewing gum		Sweet cracker		Salty cracker		Bread	
		Mean (CI 95 %)	*P*-value	Mean (CI 95 %)	*P*-value	Mean (CI 95 %)	*P*-value	Mean (CI 95 %)	*P*-value
Unilateral chewing index	women	0.301 (0.22–0.38)	0.860	0.266 (0.21–0.32)	0.267	0.257 (0.20–0.31)	0.719	0.273 (0.21–0.33)	0.763
	men	0.325 (0.20–0.45)		0.329 (0.24–0.42)		0.273 (0.19–0.35)		0.311 (0.21–0.41)	
	Total	0.309 (0.25–0.37)^{a}		0.287 (0.24–0.33)^{a}		0.262 (0.22–0.31)^{a}		0.286 (0.24–0.37)^{a}	
Chewing cycle duration (msec)	women	883 (849–917)	<0.001	949 (905–992)	<0.001	900 (864–936)	<0.001	873 (839–907)	<0.001
	men	775 (733–816)		813 (761–864)		784 (736–832)		756 (712–800)	
	Total	847 (819–874)^{a,b}		903 (867–938)^{c}		861 (830–892)^{b}		834 (805–862)^{a}	
Number of masticatory cycles *	women			29.3 (27.5–31.2)	0.198	50.2 (46.6–53.8)	0.448	34.9 (31.4–38.5)	0.321
	men			31.4 (28.6–34.2)		52.1 (46.8–57.4)		36.8 (32.9–40.7)	
	Total			30.0 (28.5–31.6)^{a}		50.9 (47.9–53.8)^{c}		35.6 (32.9–38.2)^{b}	
Flavor intensity	women	79.9 (75.6–84.3)	0.622	60.9 (55.3–66.6)	0.857	39.6 (32.8–46.3)	0.336	48.5 (41.9–55.1)	0.838
	men	81.5 (75.6–87.4)		61.8 (54.6–68.9)		45.7 (35.5–56.0)		46.9 (38.4–55.5)	
	Total	80.5 (77.0–83.9)^{d}		61.2 (56.8–65.6)^{c}		41.6 (36.1–47.2)^{a}		48.0 (42.8–53.1)^{b}	
Salivary flow	women	60.6 (55.5–65.7)	0.846	28.7 (23.8–33.7)	0.903	19.7 (15.5–23.9)	0.345	30.7 (25.9–35.5)	0.377
	men	60.9 (53.4–68.4)		30.3 (22.0–38.5)		18.0 (11.1–24.8)		27.3 (21.1–33.5)	
	Total	60.7 (56.6–64.8)^{c}		29.3 (25.1–33.5)^{b}		19.1 (15.6–22.7)^{a}		29.5 (25.8–33.3)^{b}	
Muscular fatigue	women	19.1 (14.3–23.8)	0.044	19.4 (15.4–23.3)	0.989	33.0 (27.2–38.7)	0.411	19.3 (14.4–24.2)	0.917
	men	12.1 (6.9–17.4)		20.5 (13.9–27.2)		28.8 (20.6–36.9)		17.6 (12.0–23.3)	
	Total	16.7 (13.1–20.3)^{a}		19.8 (16.4–23.1)^{a}		31.6 (26.9–36.2)^{b}		18.7 (15.0–22.4)^{a}	

* from incision to food swallowing. Values with different superscript letters on a horizontal line are significantly different, where the letter "a" has the lowest value ($P < 0.05$; Friedman's test, pairwise comparisons adjusted by the Bonferroni correction for multiple tests). Gender differences analyzed by independent-Samples Mann–Whitney U test Abbreviations: CI, confidence interval.

between flavor intensity and saliva secretion for all chewing materials, except for the salty cracker.

4. Discussion

Among individuals with a healthy dentition, the average MSS relative frequency when chewing food was 25–30 %, but with a range of 5–50 % between the 10th and 90th percentiles. This could be considered the reference values for MSS frequency, with evidence that this was reduced in men, when chewing soft food, and during the late phase of chewing. Consequently, the accuracy of these reference values could be improved by adjustment for factors related to MSS frequency.

Nutritive foods require more side alternation (19–33 %) than artificial foods (5–8 %), consistent with the results of other studies that used natural (Carvalho-da-Silva et al., 2011; Remijn et al., 2016) and artificial (Ignatova-Mishutina et al., 2022, 2023; Khoury-Ribas et al., 2022) foods. However, this is the first study to have compared natural and artificial foods within individuals. When people chew nutritive foods, they aim to reduce the particle size and to lubricate the food with saliva so that they can form a bolus that can be safely swallowed. Frequent side alternances could benefit bolus formation in these cases. By contrast, there is no need to form a bolus while chewing a gum or silicon pieces placed in a latex bag, meaning that side alternations are less frequent. Among the nutritive foods, bread requires fewer side changes than crackers; however, whether the cracker was sweet or salty did not affect the MSSI. These results support previous studies that hard food requires more side changes than soft food (Remijn et al., 2016), with taste having no clear effect on the MSS frequency.

This is perhaps the first study to show that women tend to alternate chewing sides more often than men. Therefore, MSS frequency can be added to existing gender-specific masticatory behaviors, such as masticatory performance, muscular activities, vertical amplitude of mandibular movement, and chewing rate (Lujan-Climent et al., 2008; Sano & Shiga, 2021; Scudine et al., 2016; Woda et al., 2006). The masticatory behaviors directly related to muscular force, such as comminution, seems logical to attribute to the genetic and biological differences

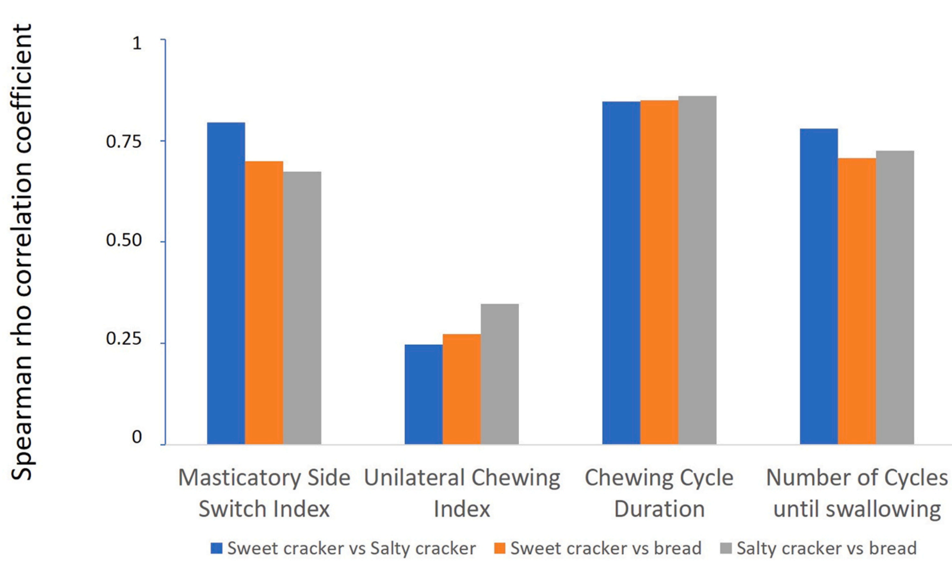

Fig. 1. Spearman rho correlations between nutritive foods for each masticatory behavior.

between sexes from adolescence (Sano & Shiga, 2021; Scudine et al., 2016). However, gender differences in chewing rate and MSS frequency could also be influenced by culture (Palinkas et al., 2010; Sella-Tunis et al., 2018). We also found gender differences in the perceived muscular fatigue when chewing gum, again consistent with other studies in which men have shown greater masseter endurance than women (Ueda et al., 2002).

MSS frequency was weakly related to midline deviation and OCA asymmetry, but not with mixing ability. Participants had at least 28 natural teeth, no severe malocclusion, and no functional disturbances, and any small differences in occlusion were clinically insufficient to affect MSS frequency. Peripheral factors may therefore influence MSS frequency little, with MSS frequency being relatively stable and only varying by the type of food. In the present study, the MSSI showed a high correlation between natural foods and an excellent test-retest reliability when chewing a salty cracker or bread, reflecting higher inter-individual variance than intra-individual variance of MSS frequency. Therefore, individuals could be considered frequent and infrequent switchers, similar to slow and fast swallowers (Engelen et al., 2005) or slow and fast chewers (Po et al., 2011; van der Bilt & Abbink, 2017). The present results suggest that the influence of the central pattern generator on masticatory function depends on masticatory behavior, being very high for chewing rate, high for MSS frequency and number of cycles before terminal swallowing, and moderate for UCI (Lund & Kolta, 2006).

People reportedly perceive increased flavor intensity and salivary flow when MSS frequency increases while chewing gum or custards (Aprea et al., 2006; Ignatova-Mishutina et al., 2023). However, this intra-individual relationship was not detected in the present study; that is, people who switch sides more often when chewing do not perceive greater flavor intensity or salivary secretion than those who switch side less often. The high inter-individual variability in these parameters makes it difficult to find the relationship significant. However, significant inter-individual relationship was detected between the perceived salivary flow and flavor intensity when masticating three of the four chewing materials, in line with the results of other studies (Ignatova-Mishutina et al., 2023). These results confirm not only the important contribution of saliva to taste perception and flavor intensity but also that flavor perception regulates salivary flow (Jia et al., 2021; Muñoz-González et al., 2018). Perceived muscular fatigue was low (13–23 %) when chewing gum, sweet crackers, or bread, but slightly higher when chewing salty crackers (27–36 %). This probably reflects the greater number of cycles needed before swallowing, which in turn, might be related to the low level of salivary secretion. Other studies have shown that adding fluids to the dry food reduces both the number of chewing cycles before terminal swallowing and the total muscle activity (Engelen et al., 2005; van der Bilt et al., 2007).

A strength of this study was that each participant masticated different chewing materials and that intra-individual differences in MSS frequency could be attributed to food types. However, this study has some limitations. First, our results only apply to populations with natural dentitions and no severe malocclusion. It is likely that individuals who have several missing teeth or who wear complete dentures have a reduced MSS frequency. Therefore, future studies could focus on establishing gender-specific reference values for MSS frequency by both the type of occlusion and the type of food. Second, the study participants were mostly dental students recruited as a convenience sample and might not be representative of the general population. In addition, we did not determine the mid-sequence swallows, i.e. swallow cycles occurring within the feeding sequence, which might have affected the chewing cycle duration (Hiiemae et al., 1996).

5. Conclusions

In individuals with healthy dentitions, the mean MSS relative frequency can be considered to be between 25 % and 30 %, whereas the normal range can be considered to be between 5 % and 50 % of the maximum possible side changes. Lower MSS frequencies were detected in men, when chewing soft food, and during the last period of the chewing process. Individuals who show a more symmetrical chewing pattern also show a high frequency of side changes. MSS frequency showed a higher inter-individual variance than intra-individual variance and did not correlate with sensory perception.

Ethics statement

All procedures were conducted in accordance with the Declaration of Helsinki and was approved by the local Ethics Committee (Code UAO/CEI/010/2021). Written informed consent was obtained from all participants.

CRediT authorship contribution statement

Elan Ignacio Flores-Orozco: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition, Project administration. **Tatiana Ignatova-Mishutina:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing. **Miranda Oryana Hernandez-Zamora; Cristina De-Haro-López; Mireya Guadalupe Osuna-Hernández; Ximena Paola Escobedo-Jiménez; Frida Livier Flores-Hernández; Lizbeth Rodríguez-Correa:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – review & editing, Visualization. **Bernat Rovira-Lastra:** Conceptualization, Methodology, Formal analysis, Writing – review & editing, Visualization, Supervision. **Jordi Martinez-Gomis:** Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.archoralbio.2023.105804.

References

Al Sayegh, S., Vasilatou, I., Kumar, A., Al Barwari, C., Fredriksson, L., Grigoriadis, A., & Christidis, N. (2020). Experimental pain and fatigue induced by excessive chewing. *BMC Oral Health, 20*(1), Article 179. https://doi.org/10.1186/s12903-020-01161-z

Aprea, E., Biasioli, F., Gasperi, F., Märk, T. D., & van Ruth, S. (2006). In vivo monitoring of strawberry flavour release from model custards: Effect of texture and oral processing. *Flavour and Fragrance Journal, 21*(1), 53–58. https://doi.org/10.1002/ffj.1702

Ayuso-Montero, R., Mariano-Hernandez, Y., Khoury-Ribas, L., Rovira-Lastra, B., Willaert, E., & Martinez-Gomis, J. (2020). Reliability and validity of t-scan and 3d intraoral scanning for measuring the occlusal contact area. *Journal of Prosthodontics, 29*(1), 19–25. https://doi.org/10.1111/jopr.13096

Bernabé, E., Sheiham, A., & de Oliveira, C. M. (2008). Condition-specific impacts on quality of life attributed to malocclusion by adolescents with normal occlusion and Class I, II and III malocclusion. *The Angle Orthodontist, 78*(6), 977–982. https://doi.org/10.2319/091707-444.1

Bourdiol, P., Soulier-peigue, D., Lachaze, P., Nicolas, E., Woda, A., & Hennequin, M. (2017). Only severe malocclusion correlates with mastication deficiency. *Archives of Oral Biology, 75*, 14–20. https://doi.org/10.1016/j.archoralbio.2016.12.002

Carbajal-Sánchez, J. A., Ramírez-Durán, N., Gamboa-Angulo, M., & Moreno-Pérez, P. A. (2021). Estado de la información del consumo en México de antioxidantes sintéticos en alimentos ultra-procesados, basados en los productos de la canasta básica. *Estudios Sociales. Revista de Alimentación Contemporánea y Desarrollo Regional, 31*(58), 1–20. https://doi.org/10.24836/es.v31i58.1143

Carvalho-da-Silva, A. M., Van Damme, I., Wolf, B., & Hort, J. (2011). Characterisation of chocolate eating behaviour. *Physiology and Behavior, 104*(5), 929–933. https://doi.org/10.1016/j.physbeh.2011.06.001

Chen, J. (2009). Food oral processing-A review. *Food Hydrocolloids, 23*(1), 1–25. https://doi.org/10.1016/j.foodhyd.2007.11.013

Engelen, L., Fontijn-Tekamp, A., & Van Der Bilt, A. (2005). The influence of product and oral characteristics on swallowing. *Archives of Oral Biology, 50*(8), 739–746. https://doi.org/10.1016/j.archoralbio.2005.01.004

Flores-Orozco, E. I., Pérez-Rodríguez, P. M., Flores-Mendoza, E. A., Flores-Ramos, J. M., Rovira-Lastra, B., & Martinez-Gomis, J. (2020). Nutritional status and masticatory function of the indigenous compared with non-indigenous people of Nayarit, Mexico. *Archives of Oral Biology, 115*, Article 104731. https://doi.org/10.1016/j.archoralbio.2020.104731

Flores-Orozco, E. I., Rovira-Lastra, B., Peraire, M., Salsench, J., & Martinez-Gomis, J. (2016a). Reliability of a visual analog scale for determining the preferred mastication side. *The Journal of Prosthetic Dentistry, 115*(2), 203–208. https://doi.org/10.1016/j.prosdent.2015.07.006

Flores-Orozco, E. I., Rovira-Lastra, B., Willaert, E., Peraire, M., & Martinez-Gomis, J. (2016b). Relationship between jaw movement and masticatory performance in adults with natural dentition. *Acta Odontologica Scandinavica, 74*(2), 103–107. https://doi.org/10.3109/00016357.2015.1048996

Fontijn-Tekamp, F. A., Van Der Bilt, A., Abbink, J. H., & Bosman, F. (2004). Swallowing threshold and masticatory performance in dentate adults. *Physiology and Behavior, 83* (3), 431–436. https://doi.org/10.1016/j.physbeh.2004.08.026

Frank, U., van den Engel-Hoek, L., Nogueira, D., Schindler, A., Adams, S., Curry, M., & Huckabee, M. L. (2019). International standardisation of the test of masticating and swallowing solids in children. *Journal of Oral Rehabilitation, 46*(2), 161–169. https://doi.org/10.1111/joor.12728

Gonçalves, T. M. S. V., Schimmel, M., van der Bilt, A., Chen, J., van der Glas, H. W., Kohyama, K., & José Pereira, L. (2021). Consensus on the terminologies and methodologies for masticatory assessment. *Journal of Oral Rehabilitation, 48*(6), 745–761. https://doi.org/10.1111/joor.13161

Hollis, J. H. (2018). The effect of mastication on food intake, satiety and body weight. *Physiology and Behavior, 193*(April), 242–245. https://doi.org/10.1016/j.physbeh.2018.04.027

Hiiemae, K., Heath, M. R., Heath, G., Kazazoglu, E., Murray, J., Sapper, D., & Hamblett, K. (1996). Natural bites, food consistency and feeding behaviour in man. *Archives of Oral Biology, 41*(2), 175–189. Https://10.1016/0003-9969(95)00112-3.

Huckabee, M. L., McIntosh, T., Fuller, L., Curry, M., Thomas, P., Walshe, M., & Sella-Weiss, O. (2018). The Test of Masticating and Swallowing Solids (TOMASS): Reliability, validity and international normative data. *International Journal of Language and Communication Disorders, 53*(1), 144–156. https://doi.org/10.1111/1460-6984.12332

Ignatova-Mishutina, T., Khoury-Ribas, L., Flores-Orozco, E. I., Rovira-Lastra, B., & Martinez-Gomis, J. (2023). Influence of masticatory side switch frequency on masticatory mixing ability and sensory perception in adults with healthy dentitions: A randomized crossover trial. *The Journal of Prosthetic Dentistry*. https://doi.org/10.1016/j.prosdent.2023.03.006. In Press.

Ignatova-Mishutina, T., Khoury-Ribas, L., Flores-Orozco, E. I., Rovira-Lastra, B., & Martinez-Gomis, J. (2022). Effect of side switch frequency on masticatory performance and rhythm in adults with natural dentition: A randomised crossover trial. *Journal of Oral Rehabilitation, 49*(4), 373–380. https://doi.org/10.1111/joor.13308

Jemt, T., Karlsson, S., & Hedegard, B. (1979). Mandibular movements of young adults recorded by intraorally placed light-emitting diodes. *The Journal of Prosthetic Dentistry, 42*(6), 669–673. https://doi.org/10.1016/0022-3913(79)90199-9

Jia, J., Zhang, Y., Xu, Z., Wang, X., Chen, J., & Van der Glas, H. W. (2021). The influence of flavor release from a solid test food, and its Time Intensity (TI) scoring, on chewing efficiency. *Food Quality and Preference, 93*(March). https://doi.org/10.1016/j.foodqual.2021.104247

Khoury-Ribas, L., Ayuso-Montero, R., Willaert, E., Peraire, M., & Martinez-Gomis, J. (2019). Do implant-supported fixed partial prostheses improve masticatory performance in patients with unilateral posterior missing teeth? *Clinical Oral Implants Research, 30*(5), 420–428. https://doi.org/10.1111/clr.13427

Khoury-Ribas, L., Ayuso-Montero, R., Willaert, E., Peraire, M., & Martinez-Gomis, J. (2020). Changes in masticatory laterality 3 months after treatment with unilateral implant-supported fixed partial prosthesis. *Journal of Oral Rehabilitation, 47*(1), 78–85. https://doi.org/10.1111/joor.12873

Khoury-Ribas, L., Ayuso-Montero, R., Willaert, E., Peraire, M., & Martinez-Gomis, J. (2021). Masticatory rhythm 3 months after treatment with unilateral implant-supported fixed partial prosthesis: A clinical study. *Journal of Prosthetic Dentistry, 126* (4), 553–559. https://doi.org/10.1016/j.prosdent.2020.06.001

Khoury-Ribas, L., Ignatova-mishutina, T., Rovira-Lastra, B., Ayuso-Montero, R., & Martinez-Gomis, J. (2022). Impact of treatment with unilateral implant-supported fixed partial prosthesis on the frequency of masticatory side switches in patients with unilateral posterior missing teeth. *The European Journal of Prosthodontics and Restorative Dentistry, 30*(4), 245–251. https://doi.org/10.1922/EJPRD_2336Khoury-Ribas07

Koo, T. K., & Li, M. Y. (2016). A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *Journal of Chiropractic Medicine, 15*(2), 155–163.

Lepley, C., Throckmorton, G., Parker, S., & Buschang, P. H. (2010). Masticatory performance and chewing cycle kinematics- Are they related? *Angle Orthodontist, 80* (2), 295–301. https://doi.org/10.2319/061109-333.1

Lujan-Climent, M., Martinez-Gomis, J., Palau, S., Ayuso-Montero, R., Salsench, J., & Peraire, M. (2008). Influence of static and dynamic occlusal characteristics and muscle force on masticatory performance in dentate adults. *European Journal of Oral Sciences, 116*(3), 229–236. https://doi.org/10.1111/j.1600-0722.2008.00530.x

Lund, J. P., & Kolta, A. (2006). Generation of the central masticatory pattern and its modification by sensory feedback. *Dysphagia, 21*(3), 167–174. https://doi.org/10.1007/s00455-006-9027-6

Martinez-Gomis, J., Lujan-Climent, M., Palau, S., Bizar, J., Salsench, J., & Peraire, M. (2009). Relationship between chewing side preference and handedness and lateral asymmetry of peripheral factors. *Archives of Oral Biology, 54*(2), 101–107. https://doi.org/10.1016/j.archoralbio.2008.09.006

Mioche, L., Hiiemae, K. M., & Palmer, J. B. (2002). A postero-anterior videofluorographic study of the intra-oral management of food in man. *Archives of Oral Biology, 47*(4), 267–280. https://doi.org/10.1016/S0003-9969(02)00007-9

Mizumori, T., Arai, K., Tsubakimoto, T., & Yatani, H. (2006). Chewing side continuity and masticatory performance. *Prosthodontic Research & Practice, 5*(1), 10–14.

Mizumori, T., Tsubakimoto, T., Iwasaki, M., & Nakamura, T. (2003). Masticatory laterality–evaluation and influence of food texture. *Journal of Oral Rehabilitation, 30* (10), 995–999. https://doi.org/10.1046/j.1365-2842.2003.01086.x

Muñoz-González, C., Feron, G., & Canon, F. (2018). Main effects of human saliva on flavour perception and the potential contribution to food consumption. *Proceedings of the Nutrition Society, 77*(4), 423–431. https://doi.org/10.1017/S0029665118000113

Palinkas, M., Nassar, M. S., Cecílio, F. A., Siéssere, S., Semprini, M., Machado-De-Sousa, J. P., & Regalo, S. C. (2010). Age and gender influence on maximal bite force and masticatory muscles thickness. *Archives of Oral Biology, 55*(10), 797–802. https://doi.org/10.1016/j.archoralbio.2010.06.016

Po, J. M. C., Kieser, J. A., Gallo, L. M., Tésenyi, A. J., Herbison, P., & Farella, M. (2011). Time-frequency analysis of chewing activity in the natural environment. *Journal of Dental Research, 90*(10), 1206–1210. https://doi.org/10.1177/0022034511416669

Remijn, L., Groen, B. E., Speyer, R., van Limbeek, J., & Nijhuis-van der Sanden, M. W. G. (2016). Reproducibility of 3D kinematics and surface electromyography measurements of mastication. *Physiology and Behavior, 155*, 112–121. https://doi.org/10.1016/j.physbeh.2015.11.018

Rovira-Lastra, B., Flores-Orozco, E. I., Ayuso-Montero, R., Peraire, M., & Martinez-Gomis, J. (2016). Peripheral, functional and postural asymmetries related to the preferred chewing side in adults with natural dentition. *Journal of Oral Rehabilitation, 43*(4), 279–285. https://doi.org/10.1111/joor.12369

Rovira-Lastra, B., Flores-Orozco, E. I., Salsench, J., Peraire, M., & Martinez-Gomis, J. (2014). Is the side with the best masticatory performance selected for chewing? *Archives of Oral Biology, 59*(12), 1316–1320. https://doi.org/10.1016/j.archoralbio.2014.08.005

Rovira-Lastra, B., Khoury-Ribas, L., Flores-Orozco, E. I., Ayuso-Montero, R., Chaurasia, A., & Martinez-Gomis, J. (2023). Accuracy of digital and conventional systems in locating occlusal contacts: A clinical study (in press) *Journal of Prosthetic Dentistry*. https://doi.org/10.1016/j.prosdent.2023.06.036.

Salles, C., Chagnon, M. C., Feron, G., Guichard, E., Laboure, H., Morzel, M., & Yven, C. (2011). In-mouth mechanisms leading to flavor release and perception. *Critical Reviews in Food Science and Nutrition, 51*(1), 67–90. https://doi.org/10.1080/10408390903044693

Sano, M., & Shiga, H. (2021). Gender differences in masticatory function in elderly adults with natural dentition. *Odontology, 109*(4), 973–978. https://doi.org/10.1007/s10266-021-00622-3

Scudine, K. G. O., Pedroni-Pereira, A., Araujo, D. S., Galvão, D., Prado, D. G. A., Rossi, A. C., & Castelo, P. M. (2016). Assessment of the differences in masticatory behavior between male and female adolescents. *Physiology & Behavior, 163*, 115–122. https://doi.org/10.1016/j.physbeh.2016.04.053

Sella-Tunis, T., Pokhojaev, A., Sarig, R., O'Higgins, P., & May, H. (2018). Human mandibular shape is associated with masticatory muscle force. *Scientific Reports, 8* (1), Article 6042. https://doi.org/10.1038/s41598-018-24293-3

Speksnijder, C. M., Abbink, J. H., Van Der Glas, H. W., Janssen, N. G., & Van Der Bilt, A. (2009). Mixing ability test compared with a comminution test in persons with normal and compromised masticatory performance. *European Journal of Oral Sciences, 117*(5), 580–586. https://doi.org/10.1111/j.1600-0722.2009.00675.x

Ueda, H. M., Kato, M., Saifuddin, M., Tabe, H., Yamaguchi, K., & Tanne, K. (2002). Differences in the fatigue of masticatory and neck muscles between male and female. *Journal of Oral Rehabilitation, 29*(6), 575–582. https://doi.org/10.1046/j.1365-2842.2002.00869.x

van der Bilt, A., & Abbink, J. H. (2017). The influence of food consistency on chewing rate and muscular work. *Archives of Oral Biology, 83*(July), 105–110. https://doi.org/10.1016/j.archoralbio.2017.07.011

van der Bilt, A., Mojet, J., Tekamp, F. A., & Abbink, J. H. (2010). Comparing masticatory performance and mixing ability. *Journal of Oral Rehabilitation, 37*(2), 79–84. https://doi.org/10.1111/j.1365-2842.2009.02040.x

van der Bilt, A., Engelen, L., Abbink, J. H., & Pereira, L. J. (2007). Effects of adding fluids to solid foods on muscle activity and number of chewing cycles. *European Journal of Oral Sciences, 115*(3), 198–205. https://doi.org/10.1111/j.1600-0722.2007.00448.x

von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2008). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: Guidelines for reporting observational studies. *Journal of Clinical Epidemiology, 61*(4), 344–349. https://doi.org/10.1016/j.jclinepi.2007.11.008

Witter, D. J., Woda, A., Bronkhorst, E. M., & Creugers, N. H. J. (2013). Clinical interpretation of a masticatory normative indicator analysis of masticatory function in subjects with different occlusal and prosthodontic status. *Journal of Dentistry, 41* (5), 443–448. https://doi.org/10.1016/j.jdent.2013.02.004

Woda, A., Foster, K., Mishellany, A., & Peyron, M. A. (2006). Adaptation of healthy mastication to factors pertaining to the individual or to the food. *Physiology and Behavior, 89*(1), 28–35. https://doi.org/10.1016/j.physbeh.2006.02.013

Woda, A., Nicolas, E., Mishellany-Dutour, A., Hennequin, M., Mazille, M. N., Veyrune, J. L., & Peyron, M. A. (2010). The masticatory normative indicator. *Journal of Dental Research, 89*(3), 281–285. https://doi.org/10.1177/0022034509357022