Archives of Oral Biology 174 (2025) 106245

Contents lists available at ScienceDirect

Archives of Oral Biology

journal homepage: www.elsevier.com/locate/archoralbio

Colorimetric and visual assessment of two-color chewing gum mixing ability test: Correlation and reference parameters in dentate subjects

Murali Srinivasan[a,1,*], Lisa Takeshita[a], Prachi Jain[a,b,c], Yasmin Milhomens Moreira[b], Martin Schimmel[c,2], Claudio R. Leles[a,b,c,3]

[a] Clinic of General-, Special Care, and Geriatric Dentistry, Center of Dental Medicine, University of Zurich, Zurich, Switzerland
[b] School of Dentistry, Federal University of Goias, Goiania, Brazil
[c] Department of Reconstructive Dentistry and Gerodontology, School of Dental Medicine, University of Bern, Bern, Switzerland

ARTICLE INFO

Keywords:
Masticatory performance
Two-color mixing-ability
Chewing gum

ABSTRACT

Objective: This study assessed the chewing performance of dentate subjects, using mixing ability tests with two-colored chewing gums, and aimed to correlate the visual and optoelectronic measurement methods to provide a correspondence scale for predicting the standard deviation of hue (SD-Hue) values based on visual parameters and the number of chewing strokes.

Design: Two chewing gums were used (Hue-Check Gum® and Vivident Fruitswing®), and tests were performed with 1, 5, 10, 15, 20, 25, and 30 chewing cycles. The analysis included optoelectronic analysis to measure the level of color mixture (ViewGum software) expressed as the SD-Hue, ranging from 0 to 1, where lower values correspond to a higher level of mixture, and subjective analysis (SA) on a 5-point ordinal scale. Data analysis included bivariate correlation, definition of double-sided 90 % reference ranges, and GEE regression.

Results: There were significant correlations between SD-Hue and the number of chewing cycles and SA scores ($p < 0.001$), and SA score was strongly correlated with the number of chewing cycles ($p < 0.001$). A downward logarithmic curve for SD-Hue and SA can be observed according to the number of chewing cycles. The mixture level progressively increased by approximately 50 % for each five chewing cycles.

Conclusion: It was possible to correlate visual and optoelectronic methods and to establish a scale prediction of SD-Hue values based on SA and the number of chewing cycles. The color mixing measured by optoelectronic and visual methods was proportional to the number of chewing cycles. For every five cycles, the level of color mixture was reduced by 50 %, expressed in a downward logarithmic curve, independently from the chewing gum type.

1. Introduction

Assessing masticatory function is pivotal in determining an individual's functional capacity and devising treatment strategies for oral rehabilitation (Fan et al., 2023; Schimmel et al., 2021). Masticatory function can be objectively assessed through clinical tests or subjectively via questionnaires. Traditionally, objective assessments have been conducted using comminution tests, often employing the sieve method (Elgestad Stjernfeldt et al., 2019; Gonçalves et al., 2021). While this method is considered the gold standard for clinical and experimental analyses, it's crucial to acknowledge that individuals with impaired oral function may not efficiently fragment the tested food (Imamura et al., 2023). Moreover, using various foods in tests is common without universal standardization. This lack of uniformity poses a frequent challenge in such assessments, making interpreting and comparing results more complex (Yoshida et al., 2007).

Recently, there has been a shift towards simpler methods for evaluating masticatory performance, using testing materials like chewing gum (Nrecaj et al., 2024), gummy jelly (Murakami et al., 2022), or paraffin wax (Khalid et al., 2020). The color mixing ability test using

* Correspondence to: Clinic of General-, Special Care, and Geriatric Dentistry, Center of Dental Medicine, University of Zurich, Plattenstrasse 11, Zurich 8032, Switzerland.

E-mail address: murali.srinivasan@zzm.uzh.ch (M. Srinivasan).

[1] https://orcid.org/ 0000-0003-3365-576X
[2] https://orcid.org/0000-0001-9700-5534
[3] https://orcid.org/0000-0002-6812-4849

https://doi.org/10.1016/j.archoralbio.2025.106245
Received 4 October 2024; Received in revised form 24 March 2025; Accepted 25 March 2025
Available online 27 March 2025

two-colored chewing gum is a straightforward method that has gained popularity. Chewing gum is easy to store, relatively inexpensive, and has familiar chewing properties, making it ideal for research, including studies involving children, due to its pleasant taste (Buser et al., 2018). This method involves chewing a two-layered or two-pieced gum with different colors for a predefined number of cycles and then grading the level of mixing of the chewed specimen based on an ordinal visual reference scale or quantifying the level of the mixture using optoelectronic methods (Schimmel et al., 2007). The masticatory performance, the state achieved after a certain number of chewing cycles, is evaluated by analyzing the achieved color mixing by an optoelectronic method. A measure of the level of mixture of the two colors is provided based on variance of hue (SD-Hue), ranging from 0 to 1, in which lower values represent better mixing ability and lower SD-Hue values. Additionally, a visual 5-point ordinal scale ranging from 1 to 5 is used as a reference for a subjective analysis of the mixing ability.

However, although the results obtained from colorimetric analysis provide a quantitative assessment of chewing function, there is limited information on the number of cycles required to achieve a specific chewing outcome. Consequently, there is a need for reference values on a numerical scale that correlates the quantitative masticatory performance (SD-Hue) in terms of the expected subjective analysis values and the number of chewing cycles to achieve a mixture level for each type of specimen. Therefore, this study aimed to correlate the visual and optoelectronic methods and provide a correspondence scale for predicting SD-Hue for specific gum based on visual parameters. Additionally, the full range of visual and quantitative values for dentate healthy individuals was developed.

2. Materials and methods

2.1. Study protocol

This study was designed as a cross-sectional assessment of the subject's masticatory performance based on an experiment using a mixing ability test with two-colored chewing gums. It was conducted at the Clinic of General, Special Care, and Geriatric Dentistry (ABS) of the Dental Medicine Center (ZZM) at the University of Zurich, Switzerland. The study received ethics approval from the relevant ethics committee from the state of Zurich in Switzerland (Kantonale Ethikkommission Zurich).

2.2. Participants

The participants were recruited from the team working at the Clinic of General Care - Special - and Geriatric Dentistry (ABS) of the Dental Medicine Center (ZZM) at the University of Zurich, Switzerland. Two researchers invited clinic team members to participate in an experimental study. The details and objectives of the study were briefly explained in the Swiss-German language, and written consent was obtained from all who agreed to participate.

Inclusion subjects should be older than 18 years, with complete, intact, or minimally restored dentition, good general health status, and no complaints about the dentition or oral condition. Exclusion criteria comprised subjects with missing teeth with edentulous gaps, with prosthetic rehabilitation (fixed or removable), under orthodontic treatment, with reduced salivary flow or xerostomia, experiencing any pain during the assessment period, or reporting existing or previous history of dental or temporomandibular disorders.

The minimum sample size for the study was calculated using the G*Power 3.1.9.4, based on a paired *t*-test to assess the difference in SD-Hue as affected by an increase in 10 chewing cycles, considering the following parameters: one-tail test, large effect size (0.50), 0.05 type I error, and 0.90 power. The estimated minimum number of participants was 36. No attrition rate was considered due to the cross-sectional design.

2.3. Masticatory performance test

Two two-colored chewing gums were used to assess masticatory function through color mixing capacity test: the Hue-Check Gum® (University of Bern, Switzerland), consisting of separate blue and pink elements, and the Vivident Fruitswing® "Karpuz/Asai Üzümü" (Vivident, Perfetti van Melle, Turkey), composed of two inseparable layers (violet and green) (Buser et al., 2018; Fankhauser et al., 2020). Both gums have been previously utilized in various studies analyzing masticatory performance and have been validated in dentate, partially edentulous, and edentulous individuals. This study followed the masticatory performance method described by Schimmel et al., utilizing a two-colored chewing gum (Silva et al., 2018).

The validated protocol recommends chewing the gum for 20 cycles (Buser et al., 2018; Schimmel et al., 2007; Schimmel et al., 2022); however, for experimental standardization in this study, seven masticatory cycles (1, 5, 10, 15, 20, 25, and 30) were employed. Therefore, each participant created seven samples of the test gum for 1, 5, 10, 15, 20, 25, and 30 chewing cycles. Each participant was instructed to chew gum #1 for the designated chewing cycles of 1, 5, 10, 15, 20, 25, and 30. Participants were asked to repeat the procedure for gum #2. Chewing cycles were counted by the operator, and participants were instructed to chew the sample with maximum rigor. Subsequently, the specimens were removed from the oral cavity, collected in a transparent cellophane package, and prepared for analysis.

Two independent evaluators conducted the subjective assessment: a researcher with a postdoctoral degree in dentistry (LT) and a first-year Master's student in dental medicine (PJ). Approximately five test samples were analyzed to calibrate the evaluators. When there was no consensus between the evaluators, the test was repeated until both were satisfied with the sample.

2.4. Optoelectronic assessment

The chewed gum was then flattened to form a 1 mm thick wafer. Images of each wafer, captured from both sides, are subsequently scanned using a conventional photographic scanner (Epson Perfection V800 Photo Scanner; Epson America, CA, USA) with a resolution of 500 dots per inch (dpi) to generate a single image file (.jpeg/.jpg). The two scans of the chewing gums were combined into a single image using a freely available software designed for optoelectronic evaluation (ViewGum software, dHAL Software, Kifissia, Greece) (Fankhauser et al., 2020; Halazonetis et al., 2013), and the program converts the sample images into the HSI color space (Hue, Saturation, Intensity) and calculates color mixing homogeneity as Standard Deviation of Hue (SD-Hue, range 0–1), allowing for the quantification of masticatory performance based on the color mixing achieved during participant chewing. Well-chewed samples with a high degree of color mixing exhibit low SD-Hue and vice versa.

2.5. Visual analysis

The Subjective Analysis (SA) was performed according to the method described by Schimmel et al., (2007). The two-sided 1 mm flattened and scanned specimens were assessed and classified subjectively on an ordinal scale ranging from SA1 to SA5, representing five categories: SA1 – chewing gum not mixed, impressions of cusps or folded once; SA2 – large parts of chewing gum unmixed; SA3 – slightly mixed, but bits of unmixed original color; SA4 – well mixed, but color not uniform; and SA5 – perfectly mixed with uniform color.

2.6. Data analysis

Descriptive statistics and distribution plots were presented to summarize the data. The Kolmogorov-Smirnov test was used to test the normality of the data. Bivariate correlation coefficients were calculated to measure the linear association between the sets of data, including the SD-Hue, SA, and number of chewing cycles.

Then, reference intervals (reference range) for the SD-Hue measurements were obtained, representing the interval in which the central values of the subjects lie, according to the number of chewing cycles and the SA ratings. A double-sided 90 % reference interval, where both low and high values are expected to occur, was calculated using the robust method, which is appropriate for a sample size of less than 120. The robust method involves an iterative process in which the initial central value is estimated by the median and the initial spread by the median absolute deviation about the median, and weighted estimators of variability and spread to calculate the reference limits using bootstrapping. Since data were positively skewed and non-normally distributed, a logarithmic transformation was required, and the back-transformed results were reported. During the analysis, multiple possible outliers were detected using the Tukey method, and these values were excluded from the analysis when applied.

Finally, a multivariate analysis was performed, using Generalized Estimating Equations (GEE) regression to model the effect of the number of chewing cycles and chewing gum on the level of mixture of the chewed gum. GEE was used due to the clustered effect of multiple observations within participants. Separate models were constructed for the SD-Hue and SA as dependent variables, specified as a non-normal distribution (gamma with log link model). Regression parameters in the final model were expressed as odds ratios (and their 95 % confidence intervals) and p-values. The significance of the model effects was tested using Wald chi-square statistics, and statistical significance was set at $p < 0.05$.

All data analyses were performed using the MedCalc® Version 22.023, and the IBM-SPSS 24.0 statistical software.

3. Results

The data were collected from 40 volunteers aged between 18 and 63 (mean=27.6; SD=8.66), with an equal gender distribution. All individuals had a complete dentition with 24–32 teeth (median=28).

Figure A.1 shows the variation in SD-Hue according to the number of chewing cycles and the SA score, revealing a marked and constant decrease in SD-Hue as the number of chewing cycles and level of mixture using SA increase. There was a significant correlation between SD-Hue values and the number of chewing cycles ($r_s = -0.87$; $p < 0.001$) and SA scores ($r_s = -0.90$; $p < 0.001$). Measurements using the HueCheck and FruitSwing gums were highly correlated when considering the SD-Hue values ($r = 0.90$; $p < 0.001$) and SA scores ($r_s = 0.93$; $p < 0.001$).

Similarly, the SA scores were strongly correlated with the number of chewing cycles ($r_s = 0.93$; $p < 0.001$). Although there was a consistent correspondence between the two measurements, the crosstabulation of chewing cycles and SA scores in Table A.1 reveals a lower definition for SA4, ranging from 15 to 25 chewing cycles, and for SA5, ranging from 25 to 30.

Table A.2 summarizes the SD-Hue values according to the number of chewing cycles and the SA score. There were wide ranges of SD-Hue values, especially with a lower number of chewing cycles and when classified as SA1 to SA3, and there were overlapping limits of values considering the 2-sided reference intervals for all the parameters tested. Then, the reference limits were represented in high-low charts that encompass the range of data within the reference limits displayed between two values and the geometric mean of the reference limits (Figure A.2). A downward logarithmic curve can be observed for both SD-Hue and SA scores, showing a quick reduction first and then changes slower.

The results of multiple regression are detailed in Table A.3. The chewing gum type and the number of chewing cycles influenced the SD-Hue and SA scores ($p < 0.001$). The odds of a higher SD-Hue value (lower mixture level) are increased by nearly 50 % for each 5 chewing cycles (from OR=8.8 after 1 cycle to 5.9 after 5 cycles, and successively until 30 cycles). Similarly, the odds of lower SA scores were reduced by nearly 80 % from 30 to 1 chewing cycles (OR=0.21; 95 %CI= 0.206 – 0.228), and a steady reduction by 50 % in OR values is observed for each decrease in 5 chewing cycles concerning the SA scores cycles (from OR=0.2168 after 1 cycle to 0.406 after 5 cycles, and successively until 30 cycles).

4. Discussion

This study aimed to develop a quantitative scale correlating visual and optoelectronic methods to predict mixing level based on visual parameters in individuals with healthy dentition. The results also reinforce findings from previous studies, indicating a significant correlation between SD-Hue values, the number of chewing cycles, and subjective analysis scores, revealing a marked and consistent decrease in SD-Hue as the number of chewing cycles and mixing levels increases. Additionally, the study showed that this method highlights the impact of the orofacial system on chewing function, exhibiting a logarithmic pattern of color degradation influenced by sample characteristics and masticatory system efficiency.

Furthermore, there was an increase in SD-Hue between initial chewing cycles, particularly in cycles 1, 5, and 10. This variation can be attributed to different chewing patterns among individuals, resulting in different gum areas appearing on the surface. As chewing progresses and gum samples mix more thoroughly, the color of the bolus becomes homogeneous, reducing this variation among individuals. Similarly, a

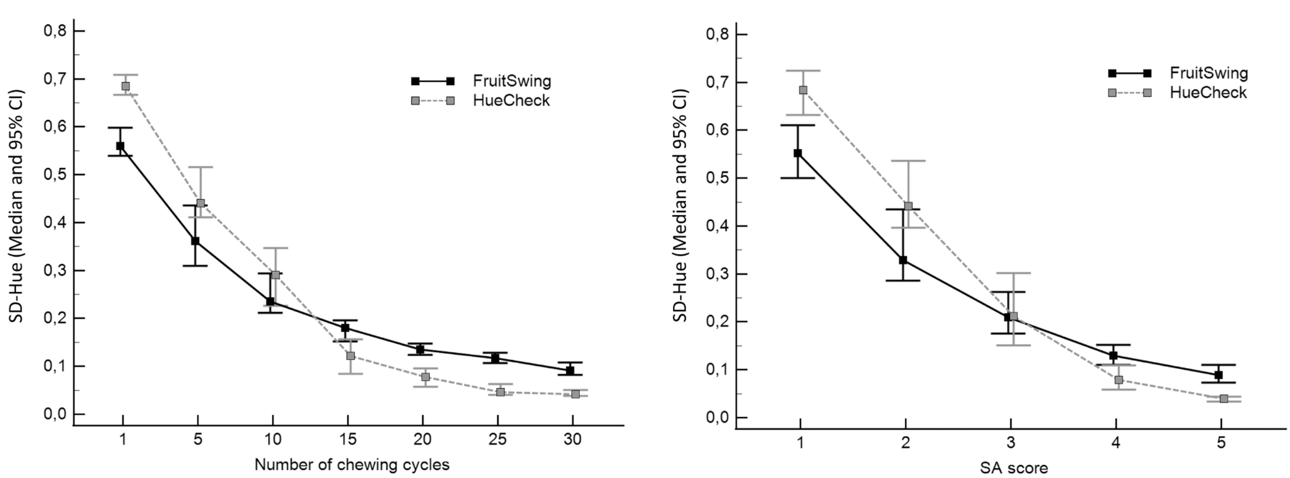

Fig. A.1. Distribution of SD-Hue data for the two-colored chewing gums (FruitSwing and HueCheck) according to the number of chewing cycles and SA scores.

Table A.1
Crosstabulation of the SA scores and the number of chewing cycles (percent in parenthesis).

SA score	Number of chewing cycles							Total
	1	5	10	15	20	25	30	
1	79 (87.8)	10 (11.1)	1 (1.1)					90 (100.0)
2		66 (85.7)	10 (13.0)	1 (1.3)				77 (100.0)
3	1 (0.8)	4 (3.2)	67 (53.2)	42 (33.3)	11 (8.7)	1 (0.8)		126 (100.0)
4			2 (1.2)	34 (19.8)	63 (36.6)	52 (30.2)	21 (12.2)	172 (100.0)
5				3 (3.2)	6 (6.3)	27 (28.4)	59 (62.1)	95 (100.0)

Table A.2
Summary values of SD-Hue according to the number of chewing cycles and the SA score.

		n	Min – Max	Range	Mean	2-sided 90 % reference interval (Upper – Lower limits)
Number of chewing cycles	1	77	0.412 – 0.784	0.372	0.625	0.826 – 0.507
	5	79	0.159 – 0.723	0.564	0.398	0.742 – 0.238
	10	79	0.095 – 0.644	0.549	0.261	0.528 – 0.143
	15	79	0.042 – 0.522	0.480	0.148	0.355 – 0.065
	20	80	0.038 – 0.236	0.198	0.105	0.268 – 0.050
	25	80	0.028 – 0.216	0.188	0.081	0.260 – 0.037
	30	80	0.023 – 0.152	0.129	0.065	0.158 – 0.029
Subjective Analysis (SA)	1	86	0.412 – 0.784	0.372	0.613	0.820 – 0.490
	2	77	0.203 – 0.705	0.502	0.396	0.676 – 0.245
	3	125	0.075 – 0.573	0.498	0.211	0.423 – 0.105
	4	172	0.038 – 0.284	0.246	0.105	0.232 – 0.055
	5	95	0.023 – 0.216	0.193	0.055	0.116 – 0.021

descending logarithmic pattern was observed for SD-Hue and SA scores, initially showing rapid reduction followed by slower changes attributed to advancing color mixing. This demonstrates that both gum type and number of chewing cycles influenced SD-Hue and SA scores.

When comparing the two chewing gums, Hue-Check gum had slightly higher SD-Hue values than FruitSwing. This difference can be attributed to the inherent characteristics of the gums. Hue-Check, being firmer, may offer greater resistance during chewing. Furthermore, this gum was specifically formulated to meet ideal colorimetric analysis requirements, resulting in a broader dispersion of hue values in the HIS color space (hue, saturation, and intensity) (Silva et al., 2018). In contrast, Vivident gum has a smoother consistency and was initially marketed as a lifestyle product(Nogueira et al., 2019). Despite these differences, numerous clinical studies have used both gums to evaluate chewing efficiency (Arakawa et al., 2020; Fankhauser et al., 2020). Notably, this discrepancy in SD-Hue is smaller in dentate individuals. However, as demonstrated by Schimmel et al., differences in SD-Hue values between the two gums are more pronounced in edentulous patients or those with weaker bite force, suggesting low agreement between the two gums in these cases (Schimmel et al., 2007; Schimmel et al., 2022).

The number of chewing cycles needed to achieve a certain level of miture is significantly influenced by the chewing gum used, which undergoes complex physical changes, including softening, throughout the chewing process (Gonçalves et al., 2021). During chewing, the gum may also undergo sweetener extraction and a reduction volume, factors that are relevant and can affect the appearance of the food bolus. Although these changes may introduce inaccuracies in the volumetric and qualitative assessment of the bolus, they do not appear to affect the proposed software, as the focus is on color variation rather than absolute volume (Halazonetis et al., 2013). Additionally, each gum base exhibits distinct behaviors, influenced by including flavors or essences during manufacturing (Schimmel et al., 2022). Therefore, it is crucial to determine the ideal number of chewing cycles for each type of gum.

Previous studies have demonstrated that after 20 chewing movements, tests display the best discriminatory characteristics among subjects or different oral conditions (Arakawa et al., 2020; Silva et al.,

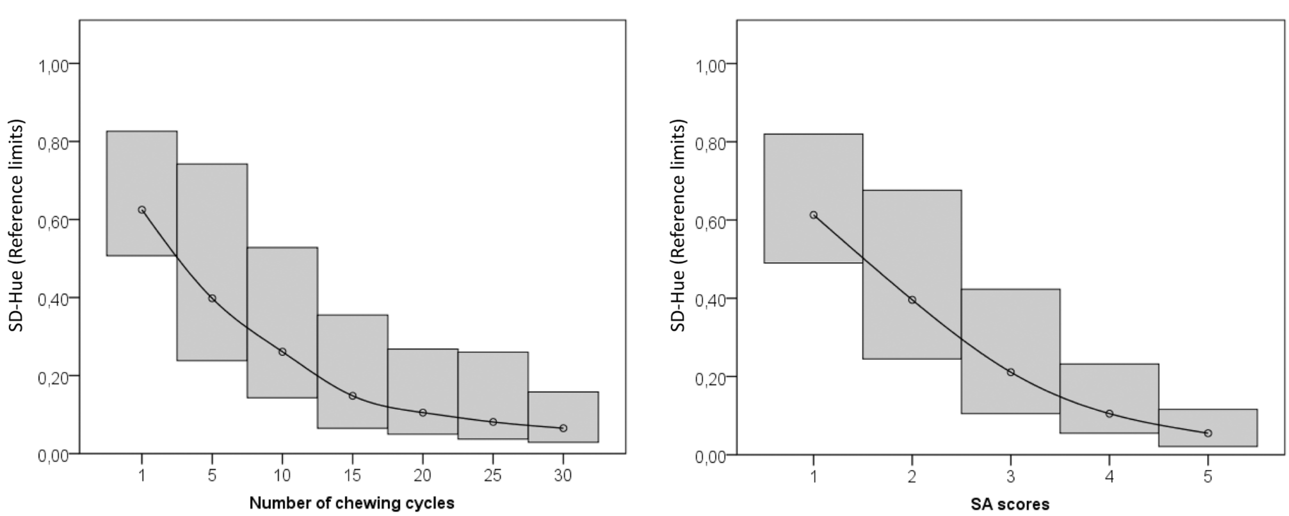

Fig. A.2. Reference limits (2-sided 90 % reference interval) of the SD-Hue values according to the number of chewing cycles and SA scores. Boxes represent the 90 % upper and lower limits, and dots are the geometric mean values. Data were back-transformed after logarithmic transformation.

Table A.3
Parameter estimates for the GEE regression with SD-Hue and SA score as dependent variables.

Independent variables	Categories	SD-Hue			SA score		
		B	95 % CI	p-value	B	95 % CI	p-value
(Intercept)		0.065	0.059 – 0.071	< 0.001	4.758	4.629 – 4.891	< 0.001
Chewing gum	FruitSwing	1.215	1.111 – 1.328	< 0.001	0.991	0.961 –1.022	0.578
	HueCheck	1			1		
Chewing cycles	1	8.806	8.130 – 9.538	< 0.001	0.216	0.206 – 0.228	< 0.001
	5	5.917	5.394 – 6.491	< 0.001	0.406	0.383 – 0.431	< 0.001
	10	3.965	3.570 – 4.403	< 0.001	0.607	0.583 – 0.632	< 0.001
	15	2.320	2.045 – 2.632	< 0.001	0.736	0.703 – 0.771	< 0.001
	20	1.615	1.424 – 1.832	< 0.001	0.831	0.800 – 0.863	< 0.001
	25	1.268	1.147 – 1.401	< 0.001	0.913	0.887 – 0.940	< 0.001
	30	1			1		

2018). Therefore, the chewing cycle categories (1, 5, 10, 15, 20, 25, and 30) adopted in this study cover a broad spectrum of chewing efficiencies, from severely compromised ones represented by 1 cycle to fully functional ones in individuals with complete dentition. Moreover, the narrow margin of improvement in SD-Hue for 25 and 30 chewing cycles, compared to 20 cycles, suggests that tests beyond 20 cycles may not be helpful to discriminate changes in masticatory performance in dentate subjects and may be restricted to subjects with impaired oral function, such as edentulous subjects using complete dentures, or those with neuromotor disorders. Previous studies considered masticatory tests with up to 50 chewing cycles successfully discriminating functional changes after implant interventions for subjects with conventional complete dentures (Hartmann et al., 2020; Leles et al., 2024; Silva et al., 2018).

Van der Bilt observed a lesser variation in the results of the mixing capacity test (mixing index) among younger individuals. All younger participants could effectively mix the two colors of chewing gum, suggesting that the task may have been overly simple for them, thereby complicating precise discrimination of masticatory performance (Van Der Bilt et al., 2010). In contrast, our study demonstrated that patients with normal chewing function can develop a scale to assess chewing deficiency compared to healthy individuals. This scale can be applied in both clinical settings and future research. Furthermore, Schimmel et al. validated and confirmed the reliability of the mixing test using colorimetric software and visual assessment, concluding that this technique can distinguish masticatory performance (MP) between adults with natural dentition and elderly individuals with dentures (Halazonetis et al., 2013; Schimmel et al., 2011). Moreover, the results showed no significant difference in mixing capacity between females and males. These findings suggest that mixing capacity tests primarily depend on the sensitivity, coordination, and strength of the oral muscles, such as the tongue, lips, and cheeks.

In a study conducted by Schimmel, electronic and visual methods for assessing mixing ability were compared (Schimmel et al., 2007). The visual assessment (SA) of the "food bolus" and the "wafer" proved less accurate, with intra-examiner agreement ranging from 70 % to 90 % for the food bolus and 80–100 % for the wafer. Additionally, inter-examiner agreement was limited, being slight to moderate for specimens chewed five or ten cycles and moderate to substantial for those chewed twenty or thirty cycles. In contrast, the electronic evaluation demonstrated a significant reduction in functional units (occluding teeth pairs) with an increasing number of chewing cycles, indicating a higher degree of color mixing. These findings align with the present study, which also observed a sharp and consistent decrease in SD-Hue as the number of chewing cycles increased and the mixing level, assessed by SA, improved.

Considering methods for assessing chewing, different types of foods were employed in tests, each presenting distinct advantages. Artificial materials, such as gummy jelly (Nrecaj et al., 2024), silicone cubes (Ignatova-Mishutina et al., 2022), and Optosil (Van Der Bilt et al., 2010), are standardized in terms of shape, size, hardness, flavor, and texture (Komagamine et al., 2011). However, some of these materials may be fragmentable, making them unsuitable for use in patients with dysphagia, stroke, or Amyotrophic Lateral Sclerosis due to the potential risk of particle aspiration (Schimmel et al., 2011; Schimmel et al., 2021; Shiga et al., 2023). On the other hand, natural foods are unpredictable regarding these parameters, as they are subject to quality and seasonal changes and are practically impossible to prepare in a standardized manner (Murakami et al., 2023).

Color mixing ability tests are quick and economical, requiring little time and effort, especially in large test sets (Endo et al., 2014). They have been recommended to evaluate chewing function in individuals with severely compromised masticatory performance, such as total prosthesis users or patients with dementia (Weijenberg et al., 2013). Chewing gum, in turn, has reproducible consistency, is widely available, easy to store, and relatively inexpensive. Its chewing properties are familiar to most people, and its pleasant taste makes it suitable for research with children. Visual assessment of the food bolus is quick, simple, and can be performed by nursing staff after minimal training (Buser et al., 2018).

Considering clinical application, the SD-Hue assessment developed for bicolor chewing gum mixing tests can be used in scenarios for quick and straightforward evaluation of chewing deficiencies in dental offices, hospitals, or large-scale epidemiological studies with extensive test batteries. However, despite its practicality, it is essential that clinicians receive adequate minimum training to ensure the accuracy of the results, preventing difficulties in identifying subtle variations in the chewing gum samples and ensuring the correct interpretation of the scores. Therefore, we conclude that the scale developed in this study adequately represents individuals with an efficient masticatory system, as the gums were chewed by healthy and fully dentate patients (Endo et al., 2014). Thus, the data obtained from our sample provide a valuable basis for both clinical assessment and objective evaluation of masticatory efficiency that can be extrapolated to subjects with impaired dentition or poor health status.

Limitations of this clinical investigation include the inability to establish a causal relationship due to the study cross-sectional design. Additionally, while chewing-related variables were considered, the role of other elements, such as the tongue or cheeks, was not analyzed (Morita et al., 2018). The investigation also did not account for differences in functional units on each side of the mouth, treating it as a whole entity. Furthermore, certain groups, such as patients with uncontrolled diabetes mellitus, autoimmune diseases, stroke, infections, denture wearers, and elderly individuals, among others, were not represented in this study (Kaya et al., 2017; Schimmel et al., 2011; Silva et al., 2018). These conditions can influence masticatory function and should be considered in future research. These parameters can be used to identify masticatory dysfunctions in patients compared to healthy dentate individuals. Additionally, the assessment of mixing capacity using bicolor chewing gum is reliable for measuring intra-individual differences in chewing ability. Another limitation of the study is that participant inclusion was conducted in medical centers, which may have influenced the participant profile, resulting in a less diverse sample with lower heterogeneity.

5. Conclusion

Within the limitations of this study, it was possible to correlate visual and optoelectronic methods to establish a scale predicting SD-Hue values based on visual parameters and the number of chewing cycles. Color mixing measured by optoelectronic and visual methods was proportional to the number of chewing cycles. For each five cycles, the level of color mixture was reduced by 50 %, expressed in a downward logarithmic curve, independently from the chewing gum type.

CRediT authorship contribution statement

Leles Cláudio Rodrigues: Writing – review & editing, Writing – original draft, Validation, Methodology, Formal analysis, Conceptualization. **Moreira Yasmin:** Writing – original draft, Validation, Investigation, Formal analysis, Data curation. **Schimmel Martin:** Writing – review & editing, Writing – original draft, Validation, Methodology, Conceptualization. **Jain Prachi:** Writing – original draft, Visualization, Validation, Supervision, Investigation, Data curation. **Srinivasan Murali:** Writing – review & editing, Writing – original draft, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Takeshita Lisa:** Writing – original draft, Validation, Project administration, Investigation.

Declaration of Competing Interest

The authors do not report any conflict of interest related to the present study.

Acknowledgments

The Hue Check gums were provided by the University of Bern, Switzerland.

References

Arakawa, I., Abou-Ayash, S., Genton, L., Tsuga, K., Leles, C. R., & Schimmel, M. (2020). Reliability and comparability of methods for assessing oral function: Chewing, tongue pressure and lip force. *Journal of Oral Rehabilitation, 47*(7), 862–871. https://doi.org/10.1111/JOOR.12976

Buser, R., Ziltener, V., Samietz, S., Fontolliet, M., Nef, T., & Schimmel, M. (2018). Validation of a purpose-built chewing gum and smartphone application to evaluate chewing efficiency. *Journal of Oral Rehabilitation, 45*(11), 845–853. https://doi.org/10.1111/joor.12696

Elgestad Stjernfeldt, P., Sjögren, P., Wårdh, I., & Boström, A. M. (2019). Systematic review of measurement properties of methods for objectively assessing masticatory performance. *Clinical and Experimental Dental Research, 5*(1), 76–104. https://doi.org/10.1002/CRE2.154

Endo, T., Komatsuzaki, A., Kurokawa, H., Tanaka, S., Kobayashi, Y., & Kojima, K. (2014). A two-colored chewing gum test for assessing masticatory performance: a preliminary study. *Odontology, 102*(1), 68–75. https://doi.org/10.1007/S10266-012-0089-7

Fan, Y., Shu, X., Leung, K. C. M., & Lo, E. C. M. (2023). Association between masticatory performance and oral conditions in adults: A systematic review and meta-analysis. *Journal of Dentistry, 129*. https://doi.org/10.1016/J.JDENT.2022.104395

Fankhauser, N., Kalberer, N., Müller, F., Leles, C. R., Schimmel, M., & Srinivasan, M. (2020). Comparison of smartphone-camera and conventional flatbed scanner images for analytical evaluation of chewing function. *Journal of Oral Rehabilitation, 47*(12), 1496–1502. https://doi.org/10.1111/JOOR.13094

Gonçalves, T. M. S. V., Schimmel, M., van der Bilt, A., Chen, J., van der Glas, H. W., Kohyama, K., Hennequin, M., Peyron, M. A., Woda, A., Leles, C. R., & 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

Halazonetis, D. J., Schimmel, M., Antonarakis, G. S., & Christou, P. (2013). Novel software for quantitative evaluation and graphical representation of masticatory efficiency. *Journal of Oral Rehabilitation, 40*(5), 329–335. https://doi.org/10.1111/JOOR.12043

Hartmann, R., Bandeira, A. C. F. de M., Araújo, S. C. de, Brägger, U., Schimmel, M., & Leles, C. R. (2020). A parallel 3-group randomised clinical trial comparing different implant treatment options for the edentulous mandible: 1-year effects on dental patient-reported outcomes and chewing function. *Journal of Oral Rehabilitation, 47*(10), 1264–1277. https://doi.org/10.1111/JOOR.13070

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

Imamura, Y., Chebib, N., Ohta, M., Mojon, P., Schulte-Eickhoff, R. M., Schimmel, M., Graf, C., Sato, Y., & Müller, F. (2023). Masticatory performance in oral function assessment: Alternative methods. *Journal of Oral Rehabilitation, 50*(5), 383–391. https://doi.org/10.1111/joor.13421

Kaya, M. S., Güçlü, B., Schimmel, M., & Akyüz, S. (2017). Two-colour chewing gum mixing ability test for evaluating masticatory performance in children with mixed dentition: validity and reliability study. *Journal of Oral Rehabilitation, 44*(11), 827–834. https://doi.org/10.1111/JOOR.12548

Khalid, T., Yunus, N., Ibrahim, N., Saleh, N. B. M., Goode, D., & Masood, M. (2020). Assessment of masticatory function of mandibular implant-supported overdenture wearers: A 3-year prospective study. *Journal of Prosthetic Dentistry, 124*(6), 674–681. https://doi.org/10.1016/j.prosdent.2019.08.005

Komagamine, Y., Kanazawa, M., Minakuchi, S., Uchida, T., & Sasaki, Y. (2011). Association between masticatory performance using a colour-changeable chewing gum and jaw movement. *Journal of Oral Rehabilitation, 38*(8), 555–563. https://doi.org/10.1111/J.1365-2842.2011.02204.X

Leles, C. R., Curado, T. F. F., Nascimento, L. N., Silva, J. R., de Paula, M. S., McKenna, G., & Schimmel, M. (2024). Changes in masticatory performance and bite force after treatment with mandibular overdentures retained by four titanium-zirconium mini implants: One-year randomised clinical trial. *Journal of Oral Rehabilitation*. https://doi.org/10.1111/JOOR.13722

Morita, K., Tsuka, H., Kato, K., Mori, T., Nishimura, R., Yoshida, M., & Tsuga, K. (2018). Factors related to masticatory performance in healthy elderly individuals. *Journal of Prosthodontic Research, 62*(4), 432–435. https://doi.org/10.1016/J.JPOR.2018.03.007

Murakami, K., Hori, K., Yoneda, H., Sato, N., Suwanarpa, K., Sta. Maria, M. T., Marito, P., Nokubi, T., & Ono, T. (2022). Compatibility of two types of gummy jelly tests for detecting decreased masticatory function. *Gerodontology, 39*(1), 10–16. https://doi.org/10.1111/GER.12601

Murakami, K., Yoshimoto, T., Hori, K., Sato, R., Sta. Maria, M. T., Marito, P., Takano, H., Khaing, A. M. M., Nokubi, T., & Ono, T. (2023). Masticatory Performance Test Using a Gummy Jelly for Older People with Low Masticatory Ability. *Journal of Clinical Medicine, 12*(2). https://doi.org/10.3390/JCM12020593

Nogueira, T. E., Schimmel, M., & Leles, C. R. (2019). Changes in masticatory performance of edentulous patients treated with single-implant mandibular overdentures and conventional complete dentures. *Journal of Oral Rehabilitation, 46*(3), 268–273. https://doi.org/10.1111/JOOR.12744

Nrecaj, A., Takeshita, L., Moreira, Y. M., Schimmel, M., Leles, C. R., & Srinivasan, M. (2024). Reliability between the two-colour chewing gum and the gummy-jelly tests used for the assessment of masticatory performance. *Journal of Oral Rehabilitation, 51*(6), 954–961. https://doi.org/10.1111/JOOR.13665

Schimmel, M., Aarab, G., Baad-Hansen, L., Lobbezoo, F., & Svensson, P. (2021). A conceptual model of oro-facial health with an emphasis on function. *Journal of Oral Rehabilitation, 48*(11), 1283–1294. https://doi.org/10.1111/joor.13250

Schimmel, M., Christou, P., Herrmann, F., & Müller, F. (2007). A two-colour chewing gum test for masticatory efficiency: Development of different assessment methods. *Journal of Oral Rehabilitation, 34*(9), 671–678. https://doi.org/10.1111/j.1365-2842.2007.01773.x

Schimmel, M., Leemann, B., Herrmann, F. R., Kiliaridis, S., Schnider, A., & Müller, F. (2011). Masticatory function and bite force in stroke patients. *Journal of Dental Research, 90*(2), 230–234. https://doi.org/10.1177/0022034510383860

Schimmel, M., Rachais, E., Al-Haj Husain, N., Müller, F., Srinivasan, M., & Abou-Ayash, S. (2022). Assessing masticatory performance with a colour-mixing ability test using smartphone camera images. *Journal of Oral Rehabilitation, 49*(10), 961–969. https://doi.org/10.1111/JOOR.13352

Shiga, H., Nakajima, K., Yokoyama, M., Komino, M., Uesugi, H., Sano, M., Arakawa, I., & Oh, T. (2023). Masticatory path pattern and masticatory performance while chewing gummy jelly. *Odontology, 111*(3), 728–733. https://doi.org/10.1007/S10266-022-00777-7

Silva, L. C., Nogueira, T. E., Rios, L. F., Schimmel, M., & Leles, C. R. (2018). Reliability of a two-colour chewing gum test to assess masticatory performance in complete denture wearers. *Journal of Oral Rehabilitation, 45*(4), 301–307. https://doi.org/10.1111/joor.12609

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

Weijenberg, R. A. F., Scherder, E. J. A., Visscher, C. M., Gorissen, T., Yoshida, E., & Lobbezoo, F. (2013). Two-colour chewing gum mixing ability: digitalisation and spatial heterogeneity analysis. *Journal of Oral Rehabilitation, 40*(10), 737–743. https://doi.org/10.1111/JOOR.12090

Yoshida, E., Fueki, K., & Igarashi, Y. (2007). Association between food mixing ability and mandibular movements during chewing of a wax cube. *Journal of Oral Rehabilitation, 34*(11), 791–799. https://doi.org/10.1111/J.1365-2842.2007.01743.X