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CLINICAL RESEARCH

# Chewing Performance Calculator: An interactive clinical method for quantifying masticatory performance

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## ABSTRACT

**Statement of problem**. There is a need to quantitatively differentiate between impaired and normal mastication using straightforward and reliable methods because currently available methods are expensive, complex, and time-consuming.

**Purpose.** The purpose of this clinical study was to assess the reliability, validity, and clinical utility of new web-based software designed to calculate masticatory performance, the Chewing Performance Calculator (CPC) measuring masticatory performance (MP), by analyzing the area of mixed bicolored chewing gum.

**Material and methods**. One hundred and ten participants were consecutively recruited from the School of Dentistry of the University of Salamanca. MP was determined using 2-colored chewing gum (Kiss 3 white & blue; Smint) that was masticated for a total of 20 strokes. The masticated gum was then flattened between 2 transparent glass tiles, generating a 1-mm-thick specimen that was scanned to calculate the percentage of the area where the 2 colors were mixed. The area was calculated using photo editing software as described by Schimmel et al (Gold-Standard-Method=GSM). In addition, all of the images were analyzed with the CPC web application, which took as input the image of the masticated bolus enclosed in a customized plastic platen that allowed 3 parts of the image to be selected interactively: the platen, the bolus background, and the mixed color fraction of the bolus. The application then computed MP as a percentage. Additionally, an oral examination was carried out to record the number of occlusal units. These data were used to assess the validity of CPC using the Pearson correlation coefficient. Construct validity was assessed using ANOVA by comparing the MP scores obtained for masticated gums, classified upon inspection as being poorly, moderately, or highly mixed. The time spent evaluating the specimens with GSM and CPC methods was also recorded and used to indicate the usefulness of the procedure.

**Results.** The MP was found to range between 5.2% and 100% (95%-CI: 80.8–88.8) with the GSM and between 9.2% and 96.4% (95%-CI: 60.0–67.6) with the CPC. The time needed to calculate MP using the GSM was significantly higher (235.2 versus 260.5 seconds) than with the CPC (42.3 to 48.6 seconds). Both methods were significantly intercorrelated (r=0.65; $P<.001$) and correlated with the number of occlusal units (r=0.54 for CPC and r=0.40 for GSM). The correlation coefficient of MP calculated using CPC (r=0.54; $P<.001$) was greater than that calculated using GSM (r=0.40; $P<.001$). Moreover, both methods showed adequate construct validity, since the values calculated for MP significantly increased as the mixing of the masticated gums also increased, subjectively classified as poor, moderate, and high.

**Conclusions.** The CPC software allowed MP to be determined in a valid and easy-to-use manner by using 2-colored chewing gum.

## CLINICAL IMPLICATIONS

A straightforward and reliable method is introduced for objectively assessing masticatory performance to evaluate the effects of dental treatment on mastication.

## INTRODUCTION

The Glossary of Prosthodontics Terms[1] defines mastication as the process of preparing food for swallowing and digestion. It is the first step in the process of digestion and is essential for good health. When mastication deteriorates, the choice of food and nutritional intake are consequently affected.[2] Masticatory function is reduced in people who have lost posterior teeth[3] and in those with removable dentures.[4] However, when teeth are replaced by fixed prostheses, masticatory function significantly improves.[5]

Masticatory function can be described in terms of the objective capacity of a person to fragment solid food, usually called masticatory performance (MP) or masticatory efficiency (ME), which is the subjective response of a person to questions concerning their ability to masticate food (masticatory ability).[6] Although an individual's self-assessment of their MP is important, many individuals with a compromised dentition or poor fitting dentures judge their masticatory function as 'good.'[3,6] However, the results of comminution tests indicate that MP values are much lower for these patients than for normal dentate individuals.[6] The self-assessment of masticatory function is generally overoptimistic when compared with the results of objective tests.[6]

A wide variety of methods have been used to determine masticatory performance, classified into 3 groups: comminution tests, optochemical tests, and mixing ability tests. Comminution tests, traditionally considered as the gold standard, measure an individual's ability to pulverize a test food (natural or artificial), which is subsequently sieved after a fixed number of masticatory cycles.[7-10] The optochemical methods are used to quantify the loss of a particular food component such as the loss of sugar from chewing gum[11] or the release of dye when masticating raw carrots.[12] Mixing ability tests (MATs) are designed to measure the true ability of mixing by assessing changes in the color of a 2-colored material, usually gum or paraffin wax, either subjectively[13,14] or digitally using a computer.[15,16] The outcomes of comminution tests and MATs are significantly correlated (r=0.66). However, MATs seem to identify those patients with compromised mastication better than traditional comminution tests. Moreover, MATs are more suitable in clinical settings,[17] being more rapid, less costly, and cleaner than a comminution test. These methods have not become common practice in clinical situations because extremely precise quantitative methods often require complex and time-consuming tasks performed by skilled clinicians. Sophisticated equipment is used, making the routine use of such methods in clinical settings difficult. In addition, more straightforward methods tend to be quantitatively imprecise.[6] As a result, a rapid, straightforward, and reliable test is needed for quantifying masticatory performance in clinical situations. The purpose of the study was to assess the reliability, validity, and clinical utility of the Chewing Performance Calculator (CPC) software, a recently introduced interactive application for measuring masticatory performance by analyzing the mixing ability of 2-colored chewing gum. The research hypothesis was that the Chewing Performance Calculator is as useful and clinically valid a method for evaluating masticatory performance as is the gold standard method of the mixing ability tests.

## MATERIAL AND METHODS

This study was carried out on 110 treated patients who had been consecutively recruited at the School of Dentistry of the University of Salamanca during 2015 to 2017. No special screening process was applied for patient recruitment, so the sample represented the relatively healthy patients attending this University Clinic for dental treatment. All treatments received by the patients were carried out by dental students under the supervision of faculty members. The Bioethics Committee of the University of Salamanca approved the study design (EXPTE:PI081020), and informed written consent was provided by all participants after being informed of the objectives and procedures. No sample size calculation was made, but a 5-fold greater sample size was recruited than for the study of Schimmel et al,[16] and the sample size was comparable with that used in studies with similar purposes.[17-22]

Masticatory performance (MP) was determined using 2-colored chewing gum (Kiss 3 white & blue; Smint) masticated for 20 strokes. The masticated gum was then collected and flattened between 2 transparent glass tiles, generating a 1-mm-thick specimen that was subsequently analyzed using 2 MATs: the gold standard method proposed by Schimmel et al[16] and the experimental method using the new CPC software.

The Schimmel method has been described in detail elsewhere.[16] Briefly, the 1-mm-thick specimens were scanned on both sides at a resolution of 500 dots per inch. The image generated was resized to a fixed size of 1175×925 pixels and saved as an Adobe Photoshop document (PSD) file. A piece of unmixed gum was scanned and used as the color reference.

The "magic wand" tool was used, with a tolerance of 20, to select the unmixed blue parts of the image, and the number of selected pixels was recorded from the histogram for calculating the ratio of unmixed pixels from the total number of pixels. This ratio was transformed into a percentage estimate of the mixing ability whereby a higher percentage indicated a greater masticatory ability.

All the masticated boluses were also analyzed using the CPC, which is a web application that inputs the image of the masticated bolus enclosed in customized plastic platens. The practitioner can then select any of the 3 parts of the input image: the platen, the background, and the mixed color fraction. The procedure is described as follows (Fig. 1): a photograph of the flattened bolus is made with a mobile phone (without using flash, at 30 cm from the bolus) and uploaded as an image file (≤8MB) at the website https://studio.chewing.app/; the shape of the customized platen is selected by clicking and dragging (click-and-drag) the computer mouse; upon releasing the computer mouse, an overlay automatically appears on top of the platen, thus calibrating the size of the masticated bolus; the background color of the enclosed bolus is selected by click-and-drag, thus delimiting the total area of the masticated bolus; finally, the mixed area is selected, also by click-and-drag, after which the area of the mixed color divided by the total area is automatically computed. The CPC software recorded the mixing ability, represented as a percentage. Any of these steps can be repeated at any time. Additional information on the software is provided in Supplementary Material.

Convergent validity was evaluated by comparing the Pearson linear correlation between the MP, calculated using both methods. MP was always expressed in percentage format, proportional to the ability to mix colors. For criterion validity, a straightforward oral examination was conducted, at which time oral health status and the number of occlusal units (natural or fixed artificial teeth in contact when the arches were in maximal intercuspal position) was recorded. This value was correlated with MP using the Pearson correlation coefficient. For construct validity, the flattened bolus was inspected and classified as being poorly, moderately, or highly mixed. The ANOVA test was used to analyze the variance of the MP calculated with both methods for each of these 3 groups. The predictive validity was analyzed by performing linear correlations between the MP score and the self-reported mastication difficulties rated using a 0 to 100 visual analog scale (VAS).

The clinical utility of each method was assessed by recording the amount of time spent to carry out each evaluation (after the masticated gum was flattened) and compared them using paired *t* tests. In addition, 15% of the participants (n=17) were reevaluated (Test-Retest) 1 week later to determine the reliability of both methods by using the interclass correlation coefficient (ICC) for a 2-way mixed effects model. The statistical analyses were done with statistical software (IBM SPSS Statistics, v21; IBM Corp) ($\alpha$=.05).

## RESULTS

Table 1 shows the sociodemographic, behavioral, and clinical description of the study sample

(N=110). The sample consisted of 37 women and 73 men between the ages of 26 and 90 years (mean ±standard deviation, 67.1±13.0 years). The participants socio-occupational status was mainly low to medium (90%), as most were retired or unemployed. Most of the participants (69.1%) reported brushing their teeth daily and that they regularly visited the dentist (78.2%). The sample had a mean ±standard deviation of 14.3 ±10.3 teeth that included 6.6 ±6.5 occlusal units. Although the average number of missing teeth was 16.1 ±10.8, the prosthetic space required for replacement was 8.0 ±7.3. The sample had a mean ±standard deviation of 5.3 ±7.8 teeth replaced by removable dentures, although half of the total sample had no dental prostheses.

Table 2 shows that both the CPC and the Schimmel methods had excellent intra-examiner reliability (ICC ≥0.8), being slightly higher with the CPC method (*P*<.001). The 95% CI of MP was 60.0 to 67.6 according to the CPC method and 80.8 to 88.8 according to Schimmel method. The MP values obtained using both methods were significantly and coherently intercorrelated (r=0.65; *P*<.001). None of the methods were highly correlated with the ability to predict self-reported mastication difficulties with a 0 to 100 VAS, although the CPC method was found to be more strongly correlated (r=-0.33; *P*=.001) than the Schimmel method (r=-0.21; *P*=.03). A similar trend was found for the criterion validity, in which case the CPC method was more strongly correlated to both occlusal units and healthy teeth than the Schimmel method. Both methods were found to have adequate construct validity, as their MP values were significantly different (*P*<.001) among the groups of masticated gum classified subjectively as being poorly, moderately, and highly mixed. The Schimmel method was 5 times more time-consuming (247.9 ±62.4 seconds) than the CPC method (45.4 ±16.0 seconds). In a clinical context, a clinician evaluating 10 patients a day could save more than half an hour with CPC.

According to the scatter plots (Figs. 2 and 3) in which the MP calculated using both methods were plotted with the number of occlusal units, there were large individual differences in the MP of edentulous patients (no occlusal units). Figure 4 depicts the scatter plot of the MP obtained with both methods and shows that, in general, both methods were coherently correlated, although some strong individual discrepancies were observed. The Schimmel method exhibited a certain ceiling effect (some participants scored 100); therefore, the effect of increasing the number of occlusal units could not be detected with this test, and moreover these participants were indistinguishable from each other. This ceiling effect could explain some of the discrepancies observed between the 2 methods (patients above 60 on the CPC appeared to do quite well on the Schimmel method).

## DISCUSSION

A new method for assessing the MP on a diverse sample population by using the mixing ability test was compared with the well-established method of Schimmel et al.[16] The results support the research hypothesis that the CPC software provides a valid and reliable method for assessing MP and is useful in the clinical setting because of its speed and easy of use. The validity and reliability of new measurement methods for use in clinical practice must be determined. Validity is more important than reliability because, if a method does not measure what is intended, then reliability becomes irrelevant. In the present study different types of validities were evaluated. The convergent or concurrent validity was determined by comparing the linear correlation with the scores obtained using an equivalent method such as the Schimmel method.[16]

The convergent validity (r=0.65) found in this study is similar to that reported by Sato et al[14] and Speksnijder et al,[17] who compared the mixing ability test with comminution tests (r=0.66). Furthermore, the predictive validity was compared to assess the ability of the test to predict the presence and severity of mastication difficulties reported by participants. The low values of predictive validity of both methods (coefficients ranging between -0.21 to -0.33) can be explained by the weak correlations between the laboratory tests and patient self-assessment, as previously reported.[5,18]

Future efforts should be directed toward assessing the predictive validity of this method against other laboratory tests for determining masticatory impairment. In this study the criterion validity was based on the correlation of the tests with both the number of occlusal units (natural or fixed prostheses) and the number of healthy teeth, because both variables have been reported to be major factors in masticatory function in partially edentulous individuals.[19]

This linear correlation coefficient between occlusal units and MP would be greatly increased if participants with no occlusal units had not been included in the analysis, given the high variability of the mixing ability of these individuals (Fig. 2). The underlying factors of this high variability may be related to prosthesis fit, denture wearing experience, occlusal force, and occlusal design.[6,7] Construct validity was tested as to whether the MP scores obtained from both methods were coherently distributed according to the amount of color mixing, where the masticated gums were visually assessed and classified into 3 different groups (poorly, moderately, and highly mixed gum). This type of subjective evaluation can be as accurate as computer-assisted assessments, although they are not quantitative but ordinal variables.[13]

The new CPC method was significantly faster than the Schimmel method,[16] and could be easily applied in clinical practice. Moreover, as shown in Figure 2, the new CPC method does not seem to suffer from either floor or ceiling effects (none of the patients scored 0 or 100), which would have hampered its ability to discriminate the MP of patients.

Since reliability and validity may change when the method is used in different populations, the CPC is freely available for every researcher at https://studio.chewing.app/. In addition, the click-and-drag interaction technique featured in CPC makes the software versatile and easy to use. The CPC can be used with different types of materials and different colors, as long as the mixed area can be properly discriminated by the human eye. The use of easily distinguishable color combinations, such as black and white, are highly recommended.

Limitations of the present study included that the intra-examiner concordance was only assessed with Test-Retest, since this was the most straightforward way to evaluate reliability and consistency. However, the inter-examiner consistency should have been measured, and future studies should address this issue. Furthermore, in order to reduce variability each action was performed by only 1 trained operator; a dentist calculated the MP according to Schimmel et al[16] (RBR) and a postgraduate student (IMQ) used the CPC to calculate the MP using the same specimens. The gold standard method chosen for the comparative analysis (Schimmel)[16] may represent a limitation since comminution tests (sieving method) are often considered the gold standard for validating objective methods for assessing MP.[15,20] Nevertheless, mixing ability tests are better at discriminating than comminution tests,[17] and the Schimmel method has been a well-accepted method that has been reported to be both valid and reliable.[16,21,22] Since considerable variation existed in the dentition or prosthetic status of the study sample, the validation results observed here should be taken with caution because such variation could have influenced the findings of the present study.

## CONCLUSIONS

Based on the findings of this clinical study, the following conclusions were drawn:

1. The new CPC software was a rapid, valid, and easy-to-use method for assessing the

masticatory performance using a 2-colored chewing gum.

2. Future research will include further testing of the evaluative validity of CPC in clinical trials using before-after assessments.

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## TABLES

Table 1. Description of sociodemographic, behavioral, and clinical variables of participants (N=110)

| **SOCIODEMOGRAPHIC VARIABLES** | Mean ±standard deviation |
|---|---|
| **Average age in years** | 67.1 ± 13.0 |
| **Age Interval** | N (%) |
| ≤50 years | 14 (12.7) |
| 51 to 64 years | 37 (33.6) |
| ≥65 years | 59 (53.6) |
| **Sex** | |
| Women | 37 (33.6) |
| Men | 73 (66.4) |
| **Socio-occupational status** | |
| High | 10 (9.9) |
| Medium | 34 (30.1) |
| Low | 66 (60.0) |
| **BEHAVIORAL VARIABLES** | |
| **Frequency of brushing** (self-reported) | |
| 2 to 3 times/day | 30 (27.3) |
| 1 time/day | 46 (41.8) |
| Once a week | 20 (18.2) |
| Less than once a week | 14 (12.7) |
| **Pattern of visits to the dentist** | |
| Regularly | 86 (78.2) |
| Problem-based | 24 (21.8) |
| **CLINICAL VARIABLES** | Mean ±standard deviation |
| Natural standing teeth | 14.3 ±10.3 |
| Healthy teeth | 13.6 ±10.5 |
| Missing teeth | 16.1 ±10.8 |
| Occlusal Units | 6.6 ±6.5 |
| Teeth prosthetically replaced by removable dentures | 5.3 ±7.8 |
| Teeth prosthetically replaced by fixed prosthesis | 0.6 ±1.8 |
| Teeth prosthetically replaceable | 8.0 ±7.3 |
| **Prosthodontic status** | N (%) |
| Without prosthesis | 57 (51.8) |
| Fixed Prosthesis | 10 (9.1) |
| Removable Partial Denture | 15 (13.6) |
| Complete dentures | 28 (25.5) |

Table 2. Reliability and validity of CPC and Schimmel methods

| | CPC method | | Schimmel method | |
|---|---|---|---|---|
| Test-Retest reliability | Intraclass Correlation Coefficient (95%-CI) | *P* | Intraclass Correlation Coefficient (95%-CI) | *P* |
| | 0.92 (0.91 - 0.93) | <.001 | 0.89 (0.88 - 0.90) | <.001 |
| Convergent Validity: Masticatory Performance | Mean ±SD | 95% CI | Mean ±SD | 95% CI |
| | 63.8 ±19.1 | 60.0 to 67.6 | 84.8 ±20.1 | 80.8 to 88.8 |
| Pearson Coefficient r =0.65; *P*<.001 | | | | |
| Predictive Validity: Self-reported chewing difficulties (VAS=0-100) | 95% CI | Correlation with MP (*P*) | Mean ±SD | Correlation with MP (*P*) |
| | 12.3-19.2 | -.33 (.001) | 15.7 ±18.2 | -.21 (.03) |
| Criterion Validity: | Pearson Coefficient | *P* | Pearson Coefficient | *P* |
| Occlusal Units | 0.54 | <.001 | 0.40 | <.001 |
| Healthy Teeth | 0.51 | <.001 | 0.36 | <.001 |
| Construct Validity: | 95%-CI | F ANOVA (*P*) | 95%-CI | F ANOVA (*P*) |
| Poorly mixed | 40.7 to 51.7 | 74.5(<.001) | 62.9 to 77.1 | 32.6(<.001) |
| Moderately Mixed | 64.5 to 71.2 | | 85.1 to 94.1 | |
| Highly Mixed | 79.3 to 83.9 | | 98.0 to 99.0 | |
| Clinical Utility: | 95% CI | Paired *t* test (*P*) | 95% CI | Paired *t* test (*P*) |
| Time spent since flattening (s) | 42.3 to 48.6 | 39.5 (<.001) | 235.2 to 260.5 | 39.5 (<.001) |