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# Reliability of mandibular range of motion measurements in healthy children

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## Abstract

**Background:** Mandibular range of motion (MROM) variables are widely used to evaluate oral function.

**Objective:** The aim of this study was to establish the reliability of MROM variables in healthy children.

**Methods:** In this cross-sectional study, healthy children were examined 2 weeks apart. The following MROM variables were established: active maximum interincisal opening (AMIO), passive maximum interincisal opening (PMIO), protrusion and left and right laterotrusion. The reliability of the MROM measurements was determined by analysing the intra-class correlation coefficient (ICC), standard error of measurement (SEM), smallest detectable change (SDC) and limits of agreement (LoA).

**Results:** A total of 167 healthy children were examined. The ICC indicated good reliability for AMIO (0.885); excellent reliability for PMIO (0.925); and moderate reliability for protrusion (0.578), laterotrusion left (0.601) and laterotrusion right (0.634). The SDC was 0.9 mm for AMIO, 0.4 mm for PMIO, 2.2 mm for protrusion, 1.6 mm for laterotrusion left and 1.4 mm for laterotrusion right. The LoA was −5.67 to 5.82 for AMIO, −3.90 to 3.57 for PMIO, −3.89 to 3.55 for protrusion, −2.99 to 2.77 for laterotrusion left, and − 2.71 to 2.77 for laterotrusion right.

**Conclusions:** AMIO and PMIO measurements are both highly reliable in healthy children. The low SDC indicate that AMIO and PMIO are promising longitudinal measurements. Protrusion and laterotrusion measurements had moderate reliability. These results support our clinical recommendation to measure AMIO rather than PMIO, as PMIO is more difficult and more time-consuming to perform than AMIO.

KEYWORDS
children, mouth opening, range of motion, reliability, reproducibility, temporomandibular joint

## 1 | INTRODUCTION

Mandibular range of motion (MROM) variables such as the mouth opening, protrusion and laterotrusion are widely used in the clinical examination of the masticatory system in order to appraise oral function. The active maximum interincisal opening (AMIO) is one of the most used clinical variables: it is a quick and easy-to-perform measurement tool for health care providers without expertise in the orofacial area. Articular and muscular conditions may affect the MROM variables. In chronic conditions such as spinal muscular atrophy (SMA) and juvenile idiopathic arthritis (JIA), as well as in non-specific temporomandibular conditions, knowledge regarding follow-up measurement is key for the evaluation of oral function. In growing individuals the MROM values are affected by age and length.[1,2] Growth curves of MROM values in healthy children show a wide spread in the same age groups. For this reason, when taking longitudinal measurements it is advised to compare the child's MROM value with a previous individual measurement.[1,2] Knowledge regarding the test–retest reliability and the smallest detectable change (SDC) of MROM variables is important in monitoring oral function. The SDC differentiates biological fluctuations from clinically relevant changes. There have been no studies on the SDC of the MROM measurements in healthy children. In healthy adults, MROM values, AMIO in particular, are highly reliable; however, information in healthy children is scare.[3–5] Therefore, the aim of this study was to assess the reliability of several MROM in healthy children: AMIO, passive maximum interincisal opening (PMIO), protrusion and laterotrusion.

## 2 | MATERIALS AND METHODS

In this cross-sectional study, children were recruited from and measured at primary schools in Utrecht and a high school in Tilburg, the Netherlands, between February 2018 and April 2019. Two measurements, with 2 weeks between each measurement, were carried out in all recruited children by experienced examiners (MS, DV, WdS). The inclusion criterion for these children was an age between 6 and 18 years. The exclusion criteria were: (1) a history of mandibular trauma; (2) previous temporomandibular joint (TMJ) treatment, such as physical therapy, application of an occlusal splint, intra-articular injections, or maxillofacial surgery; (3) incisal dental restoration or non-erupted incisors; (4) an additional orofacial condition (e.g. dental pain or a pre-existing jaw or temporomandibular disorder [TMD]); and (5) a score of at least two on the TMJ screening protocol.[6]

The study was carried out in accordance with the Code of Ethics of the World Medical Association. The study protocol, with study ID NL.METC-17-528/C, was approved by the Ethics Committee of the University Medical Center (UMC) Utrecht. All participants and their parents and/or guardians received written information and provided oral and signed informed consent. Data were collected by using the good-clinical-practice-compliant Electronic Data Capture system Research Online. The proprietary Electronic Data Capture system is owned by the Julius Center at the UMC Utrecht.

### 2.1 | MROM

The MROM—AMIO, PMIO, protrusion, and left and right laterotrusion—were assessed. The overbite was not included in the AMIO and PMIO, as it is more time-consuming and difficult to perform for healthcare providers without experience in the dental field. The MROM were measured with a metal ruler to the nearest millimetre. While measuring AMIO and PMIO, the participants were asked to open their mouth as wide as possible. During the PMIO measurement, the examiner applied a gentle stretch with the index finger and thumb on the incisal edges of the incisors to increase the mouth opening. Protrusion was assessed by requesting the participant protrude the mandible as far anterior as possible. The overjet was measured by the horizontal overlap of the front teeth and was included in the protrusion measurement. The dental midlines were used as reference points when measuring left and right laterotrusion. In the case of a midline shift in occlusion, a correction was made for the size of this shift.

### 2.2 | Statistical analysis

The characteristics of the children are presented as numbers and percentages or as means and standard deviations (*SD*). For the analyses of demographic and clinical data, the unpaired sample *t*-test was used for continuous data and the chi-squared test was used for dichotomous or ordered categorical outcomes. The data were graphically evaluated to determine whether they showed a normal distribution.

The test–retest reliability was checked for the two measurements and is presented as $AMIO_{1\text{-}2}$. It was calculated by using the two-way random, absolute agreement, single measurement intraclass correlation coefficient ($ICC_{2,1}$) and the associated 95% confidence interval (CI). The ICC was calculated as $\frac{MS_R - MS_E}{MS_R + (k-1)MS_E + \frac{k}{n}(MS_C - MS_E)}$, in which $MS_R$ is the mean square of the rows, $MS_E$ is the mean square of the error, k is the number of measurements, and n is the number of subjects. The ICC explains the consistency of the measurements; the cut-off points were set as poor (<0.50), moderate (0.50–0.75), good (0.75–0.90), and excellent (>0.90).[7,8] In addition the ICC was corrected for age, as it can substantially overestimate the reliability.[9] The standard error of measurement (SEM) was calculated as $SEM = SD \times [\sqrt{(1 - ICC)}]$, with SD defined as the difference between the two AMIO measurements. The SEM explains how much the values of the measurements of the test and retest differ from each other. The SEM per cent change was calculated as $SEM\% = [(SEM / \overline{X}) \times 100]$, in which $\overline{X}$ the mean of all test and retest measurements. The SDC was calculated as $SDC = 1.96 \times [\sqrt{(2 \times SEM)}]$.[10] The SDC is the smallest statistically significant change in AMIO that can be detected in individuals. The SDC per cent change was calculated as

SDC% = [SDC / ($\overline{X}$ × 100)], in which $\overline{X}$ is the mean of all test and retest measurements.

To check for proportional bias, variability, and agreement, Bland–Altman plots were constructed by plotting the test–retest difference versus the mean value of the test and retest.[11] Agreement between the test and retest was summarised by using the mean difference and SD of the difference, and the 95% limits of agreement (LoA) were calculated as LoA = Mean ± (1.96 × *SD*).[11] The LoA estimated the interval of the difference between the test and retest. Statistical analyses were performed by using SPSS Statistics for Windows Version 25 (IBM Corp., Armonk, NY, USA).

## 3 | RESULTS

A total of 179 children were examined in this study. Twelve children were excluded for this study due to a TMJ screening protocol score of 2. Five children were not able to execute smooth mandibular lateral movements. Therefore, we analysed AMIO, PMIO, and protrusion in 167 children and laterotrusion in 162 children. Of the 167 children, the mean age was 11.5 years old (*SD* 3.5) and 88 children were male (52.1%; Table 1). The MROM values for measurements 1 and 2 are presented in Table 1.

The ICC was good for AMIO (ICC = 0.885); excellent for PMIO (ICC = 0.925); and moderate for protrusion (ICC = 0.578), laterotrusion left (ICC = 0.601) and laterotrusion right (ICC = 0.634; Table 2). The ICC corrected for age ranged from moderate to excellent for AMIO (ICC = 0.642–0.987) and PMIO (ICC = 0.716–0.990), and from poor to good for protrusion (ICC = 0.182–0.834), laterotrusion left (ICC = 0.014–0.818) and laterotrusion right (ICC = 0.041–0.880; Table 3).

The SEM was 0.3 mm for AMIO (SEM% = 0.7%), 0.1 mm for PMIO (SEM% = 0.3%), 0.8 mm for protrusion (SEM% = 9.3%), 0.6 mm for laterotrusion left (SEM% = 6.0), and 0.5 mm for laterotrusion right (SEM% = 5.3%). The SDC was 0.9 mm for AMIO (SDC% = 1.9), 0.4 mm for PMIO (SDC% = 0.8), 2.2 mm for protrusion (SDC% = 25.8%), 1.6 mm for laterotrusion left (SDC% = 16.7%), and 1.4 mm for laterotrusion right (SDC% = 14.6). The LoA was between −5.67 and 5.82 for AMIO, between −3.90 and 3.57 for PMIO, between −3.89 and 3.55 for protrusion, between −2.99 and 2.77 for laterotrusion left, and between −2.71 and 2.77 for laterotrusion right (Table 2; Figure 1–5).

**TABLE 1** Clinical characteristics of the healthy children.

| | ***n* = 167** |
|---|---|
| Gender, *n* (%) | |
| Male | 88 (52.1) |
| Female | 81 (47.9) |
| Mean age, years (mean, *SD*) | 11.5 (3.5) |
| Mean weight, kg (mean, *SD*) | 46.9 (17.3) |
| Mean height, cm (mean, *SD*) | 153.0 (20.9) |
| $AMIO_1$, mm (mean, *SD*) | 49.0 (6.1) |
| $AMIO_2$, mm (mean, *SD*) | 48.8 (6.1) |
| $PMIO_1$, mm (mean, *SD*) | 50.4 (6.1) |
| $PMIO_2$, mm (mean, *SD*) | 50.6 (6.3) |
| $Protrusion_1$, mm (mean, *SD*) | 8.5 (2.1) |
| $Protrusion_2$, mm (mean, *SD*) | 8.7 (2.0) |
| $Laterotrusion\ left_1$, mm (mean, *SD*) | 9.7 (1.6) |
| $Laterotrusion\ left_2$, mm (mean, *SD*) | 9.8 (1.7) |
| $Laterotrusion\ right_1$, mm (mean, *SD*) | 9.7 (1.6) |
| $Laterotrusion\ right_2$, mm (mean, *SD*) | 9.7 (1.6) |

Abbreviations: AMIO, active maximum interincisal mouth opening; PMIO, passive maximum interincisal opening; SD, standard deviation.

## 4 | DISCUSSION

We found that AMIO and PMIO are highly reliable measurements in healthy children based on their good to excellent ICC values. The ICC corrected for age were moderate to excellent for AMIO, with the lowest ICC in the youngest children (6 years old; ICC = 0.701). The ICC corrected for age were good to excellent for PMIO, with the exception of the moderate ICC of the 18-year-old group. This may be due to the low numbers of 18-year-old subjects in this study (*n* = 3). The low SDC for AMIO (SDC = 0.93) and PMIO (SDC = 0.39) indicate that it could be promising to include these parameters in longitudinal measurements. Protrusion and laterotrusion had moderate reliability. Because PMIO is more difficult to execute and more time consuming than AMIO, a health care provider without experience in the examination of the oral function is advised to screen and document AMIO.

### 4.1 | Comparison with the existing literature

In this study we focused on the reliability of MROM values in healthy children. There have been several well-known reliability studies in healthy adults.[5,9,12] A study in healthy adults showed excellent reliability for mouth opening (ICC = 0.97), protrusion (ICC = 0.95), laterotrusion right (ICC = 0.90), and laterotrusion left (ICC = 0.92).[12] The authors measured the range of motion variables with a vernier calliper with 7 days between the sessions. Another study showed similar results in healthy adults with excellent reliability for active (unassisted) maximum mouth opening (ICC = 0.98), passive (assisted) maximum mouth opening (ICC = 0.98) and protrusion (ICC = 0.90), and good reliability for laterotrusion (ICC = 0.77).[9] The reliability of MROM measurements in children can potentially differ from the reliability in adults due to factors such as growth, age, and differences in physical dexterity. In the literature, there are fewer studies regarding the reliability of MROM values in children. In one study, the reliability of the mouth opening was assessed in 41 Swiss school children.[1] The intra-observer reliability was determined based on two mouth opening measurements separated by 30 minutes. The authors found a mean difference of 0.8 mm (standard error [*SE*]

**TABLE 2** Reliability of the mandibular range of motion measurements for healthy children.

| | $AMIO_{1\text{-}2}$ ($n=167$) | $PMIO_{1\text{-}2}$ ($n=167$) | $Protrusion_{1\text{-}2}$ ($n=167$) | $Laterotrusion\ left_{1\text{-}2}$ ($n=162$) | $Laterotrusion\ right_{1\text{-}2}$ ($n=162$) |
|---|---|---|---|---|---|
| Mean difference between test and retest (SD) | 0.08 (2.93) | −0.16 (1.90) | −0.17 (1.90) | −0.11 (1.47) | 0.03 (1.40) |
| ICC | 0.885 | 0.925 | 0.578 | 0.601 | 0.634 |
| 95% CI | 0.847–0.914 | 0.900–0.945 | 0.467–0.671 | 0.492–0.691 | 0.532–0.719 |
| SEM | 0.34 | 0.14 | 0.80 | 0.59 | 0.51 |
| SEM% | 0.70% | 0.28% | 9.30% | 6.04% | 5.25% |
| SDC | 0.93 | 0.39 | 2.22 | 1.63 | 1.42 |
| SDC% | 1.90% | 0.77% | 25.80% | 16.69% | 14.61% |
| 95% LoA | −5.67 to .82 | −3.90 to 3.57 | −3.89 to 3.55 | −2.99 to 2.77 | −2.71 to 2.77 |

Abbreviations: AMIO, anterior maximum interincisal mouth opening; CI, confidence interval; ICC, intra-class correlation coefficient; LoA, limits of agreement; PMIO, passive maximum interincisal opening; SD, standard deviation; SDC, smallest detectable change; SDC%, SDC / mean of all test and retest measurements; SEM, standard error of measurement; SEM%, SEM / mean of all test and retest measurements.

**TABLE 3** Intra-class correlation corrected for age of the mandibular range of motion measurements in healthy children.

| Age, years | AMIO | PMIO | Protrusion | Laterotrusion left | Laterotrusion right |
|---|---|---|---|---|---|
| 6 ($n=9$) | 0.701 | 0.869 | 0.732 | 0.216 | 0.463 |
| 7 ($n=24$) | 0.845 | 0.911 | 0.275 | 0.617 | 0.692 |
| 8 ($n=7$) | 0.844 | 0.850 | 0.492 | 0.093 | 0.735 |
| 9 (n=21) | 0.907 | 0.901 | 0.475 | 0.523 | 0.503 |
| 10 ($n=16$) | 0.729 | 0.910 | 0.182 | 0.661 | 0.612 |
| 11 ($n=10$) | 0.922 | 0.924 | 0.482 | 0.014 | 0.041 |
| 12 ($n=10$) | 0.781 | 0.871 | 0.717 | 0.328 | – |
| 13 ($n=10$) | 0.984 | 0.973 | 0.654 | 0.698 | 0.880 |
| 14 ($n=20$) | 0.915 | 0.923 | 0.537 | 0.717 | 0.481 |
| 15 ($n=15$) | 0.775 | 0.842 | 0.571 | 0.818 | 0.669 |
| 16 ($n=10$) | 0.987 | 0.990 | 0.834 | 0.703 | 0.714 |
| 17 ($n=12$) | 0.642 | 0.828 | 0.727 | 0.431 | 0.790 |
| 18 ($n=3$) | 0.856 | 0.716 | – | – | – |

*Note*: In some age classes, the number of participants was too low to determine the ICC. This was the case in the 12-year-old group for laterotrusion right, and the 18-year-old group for protrusion, laterotrusion left and laterotrusion right.

Abbreviations: AMIO, active maximum interincisal opening; PMIO, passive maximum interincisal opening.

0.30 mm). The authors stated that mouth opening was measured after the subject opened their mouth once, but mobilising the mouth opening three times and taking the highest value may improve reliability. In the context of our study, we asked the children to open their mouth a few times in order to document the dental status and to inspect the oral cavity. Moreover, we encouraged the children to open their mouth as wide as possible. This may explain the higher reliability as shown by the lower mean differences of the test–retest (0.08, SD 2.93) in our study.

We used the ICC to assess the reliability of the MROM values; Hirsch et al.[13] also used this approach. In children aged 10–17 years, they reported an excellent ICC for mouth opening (ICC = 0.92), and fair-to-good reliability for protrusion (ICC = 0.75) and laterotrusion (ICC = 0.44). Our results are similar for mouth opening, but we obtained lower ICC values for protrusion (ICC = 0.58).

The mouth opening SDC, which is a less frequently used method to appraise clinical changes in follow-up measurements, varied between 3 and 5 mm in healthy adults.[10,14,15] In adults with non-specific TMD, the SDC were higher: values between 5.0 and 9.1 mm have been reported.[16,17] Kropmans et al.[16] explained that these higher SDC values are due to variation regarding pain and mouth opening values, which can differ each day.[14] No studies regarding SDC values of the MROM measurements have been done before in healthy children. One study involving children with JIA (age range 3.8–18.0 years old) reported SDC values of 4.9 mm for mouth opening, 2.8 mm for protrusion and 2.4 mm for laterotrusion.[18] We found

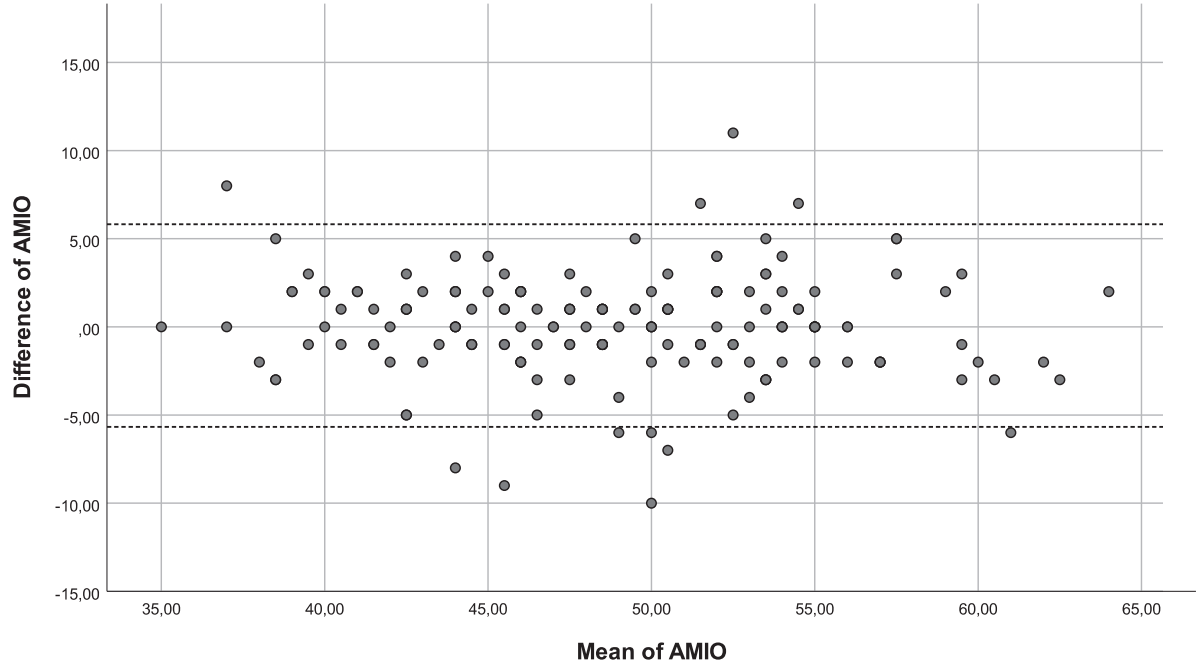


FIGURE 1 Bland–Altman plot for the difference between test and retest (test 1–2) of the active maximum interincisal mouth opening (AMIO) for healthy children. The dashed line represents the mean difference between test and retest, and the striped lines represent the 95% limits of agreement.

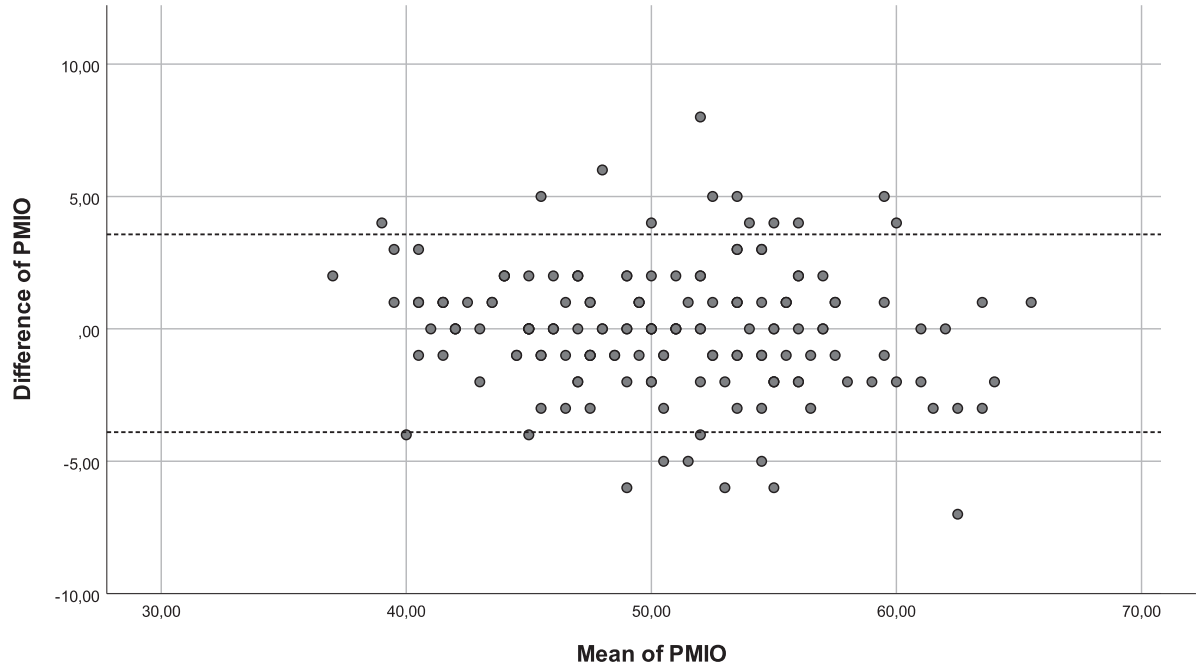


FIGURE 2 Bland–Altman plot for the difference between test and retest (test 1–2) of the passive maximum interincisal mouth opening (PMIO) for healthy children. The dashed line represents the mean difference between test and retest, and the striped lines represent the 95% limits of agreement.

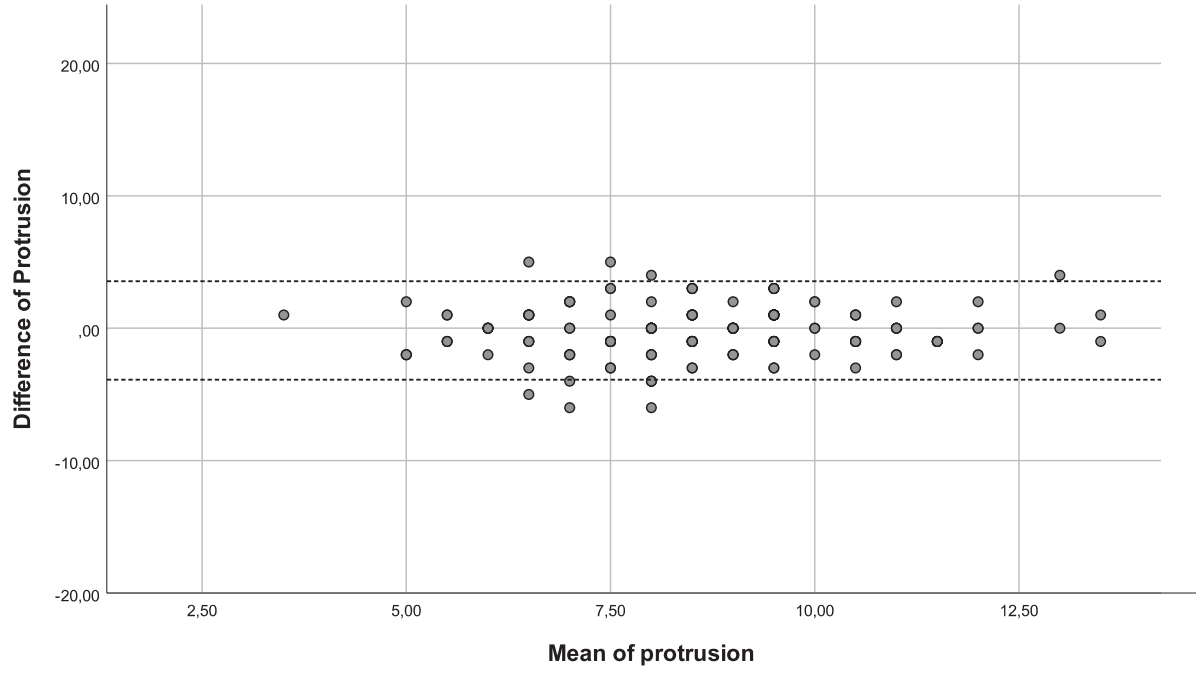


FIGURE 3 Bland–Altman plot for the difference between test and retest (test 1–2) of protrusion for healthy children. The dashed line represents the mean difference between test and retest, and the striped lines represent the 95% limits of agreement.

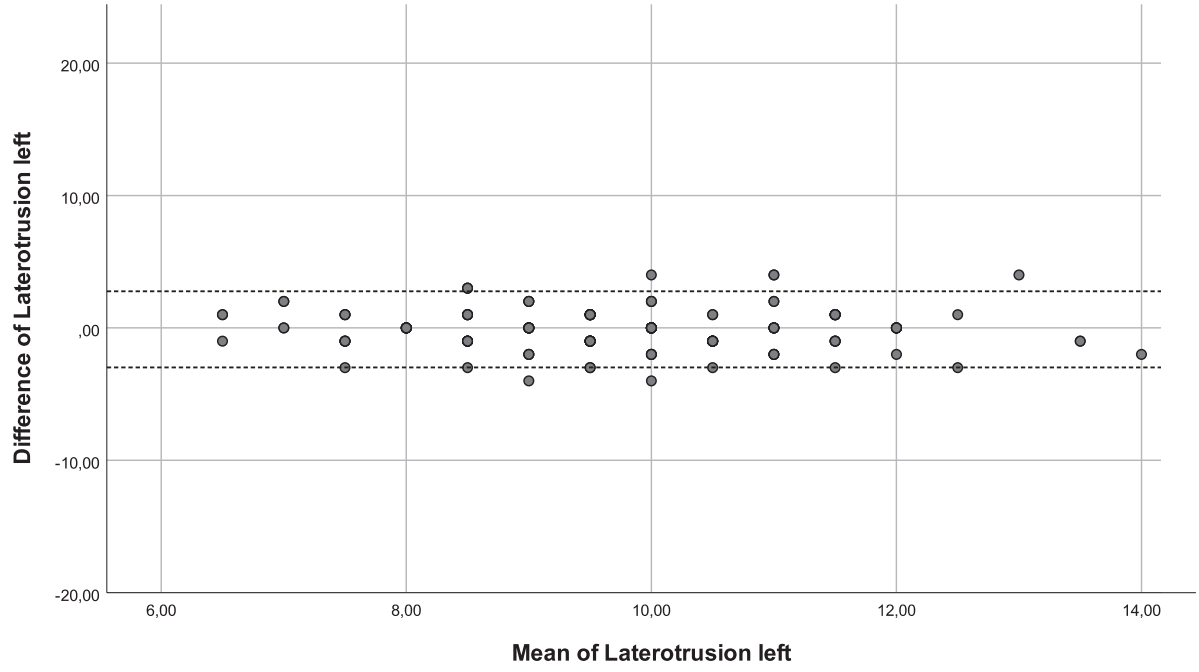


FIGURE 4 Bland–Altman plot for the difference between test and retest (test 1–2) of laterotrusion left for healthy children. The dashed line represents the mean difference between test and retest, and the striped lines represent the 95% limits of agreement.

lower SDC values for AMIO in healthy children compared with children with JIA. This means that small differences in AMIO between two measurements can be detected more precisely in healthy children than in children with JIA.

## 4.2 | Clinical implications

We found that the AMIO and PMIO measurements were highly reliable based on the ICC and SDC. The SDC of <1 mm indicate that a

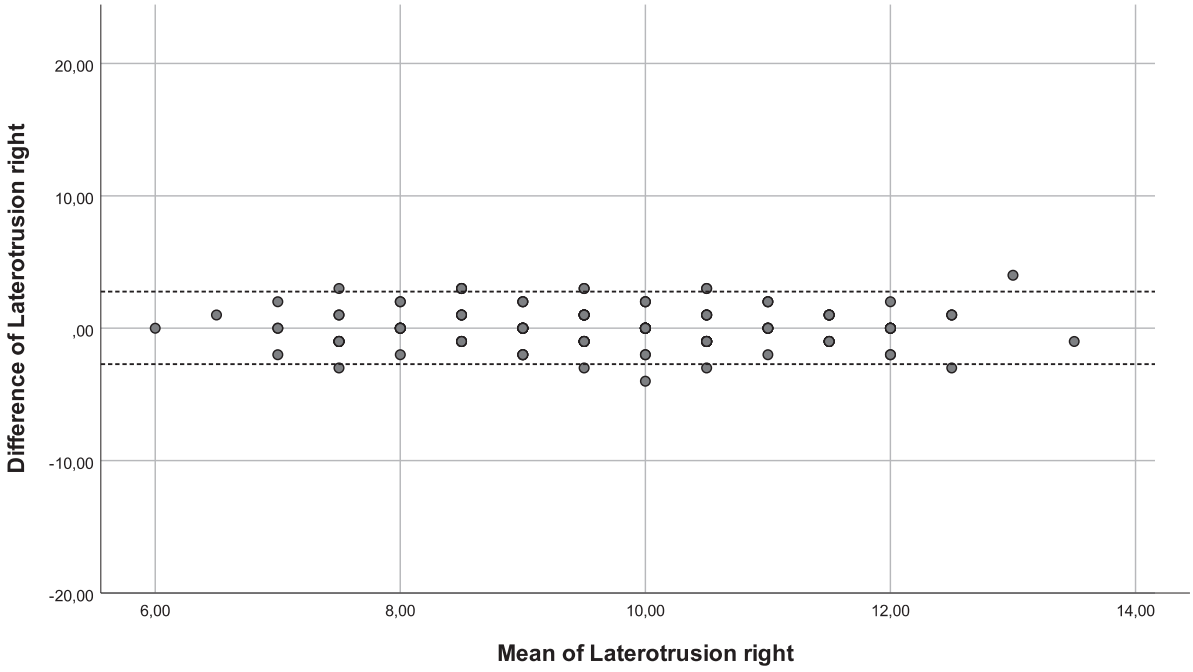


**FIGURE 5** Bland–Altman plot for the difference between test and retest (test 1–2) of laterotrusion right for healthy children. The dashed line represents the mean difference between test and retest, and the striped lines represent the 95% limits of agreement.

difference of 1 mm in AMIO or PMIO measurements is a true clinical relevant difference and not a measurement error or biological fluctuation. This finding support the use of both AMIO and PMIO in longitudinal measurements to follow up the mandibular function. Measuring AMIO and PMIO is used to differentiate between an articular or muscular temporomandibular origin. When PMIO is ≥3 mm higher than AMIO, the condition may indicate a muscular rather than an articular origin.[19,20] AMIO is one of the most used indicators to appraise oral function. We recommend measuring AMIO because it is a quicker, easier to perform and more known measurement among health care providers.

We demonstrated lower reliability for laterotrusion and protrusion compared with AMIO and PMIO. A possible explanation may be the difficulties in getting children to perform these movements. This is reflected in our study by the missing values of lateral movements for five children. The five children who were unable to execute smooth mandibular lateral movement were all under 7 years old. These children did not understand the instructions for the lateral movement. However, they were able to perform both AMIO and PMIO. In addition, in the case of a midline shift the laterotrusion measurements for non-dental clinicians are more difficult to perform and can influence the reliability of the measurements. In a study with healthy adults, the authors explained the lower reliability of laterotrusion by citing possible small deviations during the movement.[12] Moreover, the authors stated that patients have difficulties to reach the end position, because the ruler does not have contact with the teeth. In addition the angle of the mouth opening may influence laterotrusion.

Our data suggest that follow-up measurements with AMIO and PMIO are highly reliable based on the ICC and SDC. The SDC of AMIO (0.93 mm) indicates that a ≥ 1 mm difference between two measurements is a true difference and not a measurement error. The ruler that we used measures the mouth opening with 1-mm steps; hence, a value below 1 mm would hardly be measurable with a ruler. In contrast, laterotrusion and protrusion showed higher SDC (1.42–2.22); therefore, they are less reliable in follow-up measurements. Based on this study, both AMIO and PMIO are highly reliable. Given that PMIO is more difficult to execute and more time consuming than AMIO, we advise that a health care provider without experience in examining oral function screen and document AMIO.

## 4.3 | Strengths and limitations

The strengths of this study are the large group of participants, the prospective study design, and the methodology to assess the reliability of the MROM values. The limitation of this study is the lack of measurements in specific patients groups, as we focused on healthy children. Caution is necessary to extend our findings to children with a specific condition such as SMA and JIA. However, knowing these values in heathy children provides the clinician with the best outcomes that can be expected regarding MROM reliability not influenced by pathological conditions. Changes beyond the values reported here can be clinically relevant for appraising either improvement or deterioration of oral function in terms of MROM.

## 5 | CONCLUSION

AMIO and PMIO are both highly reliable measurements in healthy children. The low SDC values indicate that it could be promising to include AMIO and PMIO in longitudinal measurements. Protrusion and laterotrusion had moderate reliability, and their utility is lower than AMIO and PMIO. These results support our clinical recommendation to measure AMIO rather than PMIO, as PMIO is more difficult and more time-consuming to perform than AMIO.


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### CONFLICT OF INTEREST STATEMENT

The authors report no financial conflicts of interest.

### DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.


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