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Mandibular movements in children with deciduous and mixed dentition, and in young adults with permanent dentition – the association between movements and occlusal traits

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Summary

Background: Cross-sectional studies of mandibular movements provide data on developmental trends of dentition, and support planning of public health services.

Objective: The aim of this study was to measure mandibular movement capacities in children with deciduous and mixed dentition, and in young adults with permanent dentition. The influence of age and gender on mandibular movements, and the association between mandibular movements and occlusal traits were analysed.

Method: The sample consisted of 1,172 Estonians. Group 1: children with deciduous dentition; Group 2: children with mixed dentition; and Group 3: young adults with permanent dentition. Maximum opening, mandibular laterotrusion, and protrusion were registered.

Results: Age was correlated with mandibular movements. Young adults had statistically significantly larger mandibular movements compared to children with deciduous and mixed dentition, and children with mixed dentition had larger mandibular movements as compared to children with deciduous dentition. Young adult males had larger mandibular movements than females of the same age. Associations were found between mandibular movement capacities and some occlusal traits. Mandibular movement capacities were smaller in children with crossbite and open bite as compared to children without corresponding occlusal traits. Mandibular movement capacities were larger in children with deep bite and increased overjet as compared to those without corresponding occlusal traits.

Conclusion: Mandibular movement capacities are age and gender dependent. Maximum mouth opening, mandibular laterotrusion, and protrusion are related, and mandibular movement and some occlusal traits are associated.

Keywords: mandibular movements, TMJ, deciduous dentition, mixed dentition, permanent dentition, occlusal traits

Introduction

Health of the masticatory organ is a good indicator of the overall well-being of an individual (1, 2). In addition to treatment of biofilm diseases, oral care ought to achieve an optimal functional balance between TMJ and occlusion. Integration of occlusal development with facial structures, and the head and neck region is complex, especially during childhood and mixed dentition stage (3). During normal growth, the mandibular condyle has been found to undergo significant changes in size and shape as part of occlusal development and maturation of the masticatory organ (4). Therefore, it is understandable that also a range of mandibular movements change during growth, as indicated in the literature (5–7). In an optimal situation, TMJ adapts, even in adulthood, to various occlusal traits because of the adaptive nature of condylar secondary cartilage (8, 9).

Various factors may affect the stomatognathic system (10) and reduce the movement capacity of the mandible. In TMJ, internal derangement or, in active TMJ, inflammation-reduced mandibular movements are common findings (11). Limited mandibular movements may be associated with pain, discomfort, disruption of daily activities—ability to eat and phonate, maintain oral hygiene, and perform dental treatment, if needed (1).

Free and relaxed mandibular movements are an essential part of a healthy masticatory organ (12), and the examination of mandibular movement capacity is an essential part of a thorough clinical examination of the masticatory organ. To the best of our knowledge, the literature on mandibular movement capacities in relation to occlusal traits is lacking.

The aims of this study were to:

- measure mandibular movement values in children with deciduous and mixed dentition, and in young adults with permanent dentition
- analyse the influence of age and gender on mandibular movements
- analyse the association between mandibular movements and occlusal traits

The working hypotheses of the study were that:

- mandibular movements increase with age, and are larger in boys than in girls
- associations can be found between mandibular movements and occlusal traits in children with deciduous and mixed dentition, and in young adults with permanent dentition

Subjects and methods

This study complements earlier studies on the prevalence of occlusal traits in Estonian children and young adults (13–15) with measurements of mandibular movements. A 95.0% confidence interval around an estimate (±2.5% of the estimate) was specified for sample size calculation. In the sampling, a stratified cluster design was implemented (16). The list of all kindergartens and elementary/high schools from the three biggest cities located in different geographic areas of Estonia was acquired from the local government (n = 61 elementary/high schools and n = 191 kindergartens). The randomly selected school/kindergarten was contacted and asked to participate in the study. Of the contacted schools and kindergartens 20.0% declined to participate, mainly because they didn't have a doctor's office. The recruitment took place in eleven kindergartens and four elementary/high schools, and the number of invited subjects was 1,512. From invited subjects 340 were excluded for different reasons: 1) previous or current orthodontic treatment (n = 169), 2) parents did not agree to let their child participate in the clinical study (n = 64), 3) children were too afraid to participate in the clinical study (n = 62), 4) children were not in kindergarten on the examination day (n = 41), 5) three children had cleft lip and palate, and one had hemifacial microsomia. The final sample consisted of 1,172 Estonians in three groups. Group 1: 4–5-year-old children with deciduous dentition (n = 390, 190 girls, 200 boys, mean age 4.7 ± 0.9 years). Group 2: 7–10-year-old children with mixed dentition (n = 392, 198 girls, 194 boys, mean age 9.0 ± 0.8 years). Group 3: 17–21-year-old young adults with permanent dentition (n = 390; 219 females, 171 males, mean age 18.5 ± 0.9 years). The sampling procedure is illustrated in Figure 1.

All participants and their parents/guardians signed an informed consent form, indicating that their participation in the study was voluntary.
The study protocol was approved by the Ethics Review Committee on Human Research of the University of Tartu (Protocol No. 186T-24).
Registration of the occlusal traits was based on international standards (17–19). Detailed criteria of registration have been published previously (13). 'Flush terminal plane' denotes a condition in which the distal surface of the mandibular and maxillary second deciduous molars end in the same vertical plane, and 'mesial/distal terminal plane' is used when the distal surface of the mandibular second deciduous molar is mesial/distal to the corresponding surface in the maxillary second deciduous molar.

For the present study, maximum mouth opening (MMO), lateral movement of the mandible to right and left (LMMr, LMMl), and protrusive movement of the mandible (PMM) were registered on the basis of international standards and recommendations (20).

MMO, LMMr, and LMMl were measurable in all the participants. PMM was measurable in all of Group 2 and 3, and in 106 children (27.2%) in Group 1.

All clinical examinations of all participants were performed by the same orthodontist. The examination of the 4–5-year-old children was carried out in the kindergarten's medical office, the examination of the 7–10-year-old children and the 17–21-year-old young adults was carried out at the school's dental office using a dental mirror, probe, pencil (0.3 mm), and millimetre ruler (Dentaurum 042-751 Münchner Modell).

Registration criteria

The registration of mandibular movement was started with centric occlusion. To obtain centric occlusion, the orthodontist gently verified that the mandible was relaxed, and then the participant was asked to bite together lightly.

To obtain MMO, participants were asked to open their mouth slowly, as wide as possible, without specifying "end feel". The distance between the incisal edge (close to midline) of the upper and lower central incisors was measured. Overbite was considered in recording MMO.

The midline between maxillary central incisors was marked with a pencil on the labial surface of the mandibular incisor in centric occlusion. The participant was asked to move the mandible slowly to maximum excursion to the right (LMMr), and to maximum excursion to the left (LMMl). The distance between pencil marks was recorded.

The subject was asked to move the mandible slowly to maximum protrusion (PMM). The distance between the incisal edges of the upper and lower central incisors was recorded parallel to the occlusal plane. Overjet was considered in recording PMM.

The maximum opening, and the lateral and protrusive movements of the mandible were repeated, and the mean of two measurements was used in the study.

Reliability and statistical analyses

Before the study, twenty-two 4–5-year-olds and twenty-two 7–10-year-old children, and twenty-two 17–21-year-old young adults were examined clinically and re-examined after a one-week interval by the orthodontist who performed all clinical examinations for the study. The reliability was good ($r > 0.95$). A detailed description of the reliability of clinical examinations of occlusal traits has been presented previously (13–15).

The data was checked for normality, and appropriate analysis methods were selected. Reference range for MMO, PMM, LMM was calculated. Reference range contains the central 95.0% of the population. For age-group differences, ANOVA with the Bonferroni post-hoc test was applied. In addition, the odds for higher values of MMO, LMMr, LMMl, and PMM in boys and girls were evaluated with logistic regression. Differences in LMMr and LMMl were calculated with a paired *t*-test. To examine the correlation between MMO, LMMr, LMMl, and PMM, Pearson's correlation was used. Differences in MMO, LMMr, LMMl, and PMM between genders and occlusal traits (mesial, distal, and flush terminal plane; molar and canine Class I, II, III, and end-to-end; open (overjet < 0 mm) and deep bite (overbite ≥ 3.5 mm); crossbite and scissor bite) were calculated with an independent *t*-test and Welch *t*-test (in case of unequal sample size). *P*-values of less than

0.05 were considered statistically significant. The analyses were carried out with IBM SPSS Statistics (version 20.0; IBM Armonk, New York, USA).

Results

Mandibular movements

Deciduous dentition (Group 1)

The mean ± standard deviation of MMO was 43.6 ± 4.6 mm, range 32.0, and mode 45.0 mm (6.7%). The mean of LMMr and LMMl was 9.5 ± 2.6 mm and 9.4 ± 2.7 mm, respectively. There was no statistically significant difference between LMMr and LMMl ($P = 0.348$). The range of LMMr and LMMl was 15.0 and mode 10.0 mm (29.2% and 26.4%, respectively). The mean of PMM was 2.6 ± 1.9 mm, range 8.5, and mode 1.5 mm (4.9%).

Mixed dentition (Group 2)

The mean ± standard deviation of MMO was 49.2 ± 5.0 mm, range 31.0, and mode 46.0 mm (6.6%). The mean of LMMr and LMMl was 11.3 ± 2.3 mm and 10.8 ± 2.2 mm, respectively; the difference was statistically significant ($P < 0.001$). The range of LMMr and LMMl was 15.0 and 17.0, respectively, and mode 12.0 mm (24.0% and 24.7%, respectively). The mean of PMM was 7.5 ± 2.3 mm, range 13.0, and mode 9.0 mm (15.6%).

Permanent dentition (Group 3)

The mean ± standard deviation of MMO was 54.3 ± 7.5 mm, range 46.0, and mode 49.0 mm (3.6%). The mean of LMMr and LMMl was 11.6 ± 2.5 mm and 11.6 ± 2.4 mm, respectively. There was no statistically significant difference between LMMr and LMMl ($P = 0.842$). The range was 18.0 and 17.0 respectively, and mode 12.0 mm (23.1% and 24.1%, respectively). The mean of PMM was 8.6 ± 2.5 mm, range 15.5, and mode 9.0 mm (11.0%).

The distribution of the findings of mandibular movements in deciduous, mixed, and permanent dentition are presented in Figure 2.

Age was moderately correlated with MMO ($r = 0.610$, $P < 0.001$), LMMr ($r = 0.355$, $P < 0.001$), LMMl ($r = 0.369$, $P < 0.001$), and PMM ($r = 0.442$, $P < 0.001$). The correlations of MMO, LMMr, LMMl, and PMM are presented in Figure 3.

MMO was statistically significantly different between Groups 1 and 2 (5.4 mm), between Groups 1 and 3 (10.7 mm), and between Groups 2 and 3 (5.3 mm) ($P < 0.001$). Lateral movement to the right was different between Groups 1 and 2 (1.7 mm), and between Groups 1 and 3 (2.0 mm) ($P < 0.001$), but no statistically significant difference between Groups 2 and 3 ($P = 0.278$) was present. Lateral movement to the left was statistically significantly different between Groups 1 and 2 (1.4 mm), between Groups 1 and 3 (2.1 mm), and between Groups 2 and 3 (0.7 mm) ($P < 0.001$). Protrusion movement was statistically significantly different between Groups 1 and 2 (4.9 mm), Groups 1 and 3 (5.9 mm), and Groups 2 and 3 (1.1 mm) ($P < 0.001$) (Figure 4). Young adult males' permanent dentition had statistically significantly larger mandibular movements in MMO, LMMr, LMMl, and PMM as compared to females, and in PMM, the difference existed already in mixed dentition (Table 1).

Association between mandibular movements and occlusal traits (Table 2)

Deciduous dentition (Group 1)

Maximum opening was smaller in children with lateral crossbite, open bite, and anterior crossbite as compared to children without corresponding occlusal traits ($P = 0.002$, $P < 0.001$, and $P < 0.001$, respectively). Laterotrusions (LMMr and LMMl) were smaller in children with lateral crossbite ($P = 0.021$ and $P = 0.003$, in LMMr and LMMl, respectively), and in children with anterior crossbite as compared to those without corresponding occlusal traits ($P < 0.001$ and $P < 0.001$, respectively). Maximum opening was larger in children with deep bite and increased overjet as compared to those without corresponding occlusal traits ($P < 0.001$ and $P = 0.002$, respectively).

Mixed dentition (Group 2)

Maximum opening was larger in children with deep bite ($P < 0.001$) as compared to those without a corresponding occlusal trait, and smaller in children with open bite or crossbite ($P = 0.016$, $P < 0.002$, respectively) as compared to those without a corresponding occlusal trait.

Permanent dentition (Group 3)

Mandibular protrusion was larger in young adults with increased overjet or overbite ($P < 0.001$, $P < 0.002$, respectively) as compared to those without a corresponding occlusal trait.

Discussion

The present cross-sectional, population-based study provides values for mandibular movements in 4–5-year-old children with deciduous dentition, 7–10-year-old children with mixed dentition, and 17–21-year-old young adults with permanent dentition. In addition, the study points out associations between mandibular movement capacities and occlusal traits during those stages in dental development.

The difficulty of taking exact measurements in young children has been pointed out previously (6). Our experience confirmed that patience and time are needed when examining young children. Still, despite talking to the children, visualising, and practicing, protrusive mandibular movement could not be registered in all 4–5-year-old children.

The mean for mandibular movement capacities in 7–10-year-old Estonian children was found to be similar as in previous studies of 10–13-year-olds (5), and 8–10-year-olds (21). The mean for mandibular movement capacities in 17–21-year-olds was in line with that of 14–17-year-olds (5). However, in our study, the means for maximum mouth opening and lateral movements in 4–5-year-olds were clearly larger than in a Brazilian sample of 4.6–years, where those with TMJ dysfunction had been excluded from analyses (6), and clearly larger in 7–10-year-olds than in an Argentinian sample of 6–12 years (22).

Statistically significant difference was found between right and left lateral mandibular movement capacities in mixed dentition, but not in deciduous or permanent dentition. Earlier studies have also found the difference (5, 23), while others have not reported it (24). Theoretically, right and left lateral movements should not differ. Further studies are needed to find out reasons behind the difference. The finding may be clinically important if the difference exists constantly.

To the best of our knowledge, this study is the first to examine correlations between various mandibular movements. In all age groups, the relationship between maximum mouth opening, and lateral and protrusive movements was clear. Future studies should assess to what extent the finding of moderate/strong correlation applies/exists throughout the aging process/through development (i.e., childhood/adolescent development).

In line with other studies (5–7), age and dental stage is associated with mandibular movement capacities. Maximum mouth opening was 5.3 mm larger in 17–21-year-olds with permanent dentition as compared to 7–11-year-olds with mixed dentition, and 10.7 mm larger as compared to 4–5-year-olds with deciduous dentition. Lateral and protrusive mandibular movements were also larger in young adults than in children with mixed and deciduous dentition.

It seems that the mean of maximum mouth opening capacity increases to the level of 54.3 mm by age 17–21, and remains at that level until about age 30–40, after which it seems to decrease. Two studies report 43.0 mm for mean maximum mouth opening at age 61–70 (25, 26). The value is the same as in early childhood, at the age of 4–5 years (43.0 mm) in the present study.

Hirsch *et al*. (2006) reported a gender difference in maximum mouth opening in young adults with permanent dentition. Likewise, in the present study young adult boys had 1.1 times higher odds of having larger maximum mouth opening values compared to girls of the same age. Young adult boys had also larger lateral and protrusive values compared to girls. For protrusion, the gender difference was present already in mixed dentition; boys had higher values compared to girls of the same age. Gender differences in mandibular movement capacities were not present in 4–5-year-old children, which is in line with Argentinian 3–11-year-olds (6). In the present study, the gender difference appeared at the age of 17–21 years, and has been shown to persist until age 61–70 (25).

Age, developmental stage of dentition, and gender should be taken into account in evaluating mandibular movement capacities, and in defining possible restricted mandibular movement capacity. Proposed reference ranges are based on our cross-sectional study. Developing frames of reference or normative values, such as threshold values, for any biological measurement would require future studies conducted with much larger material sets than ours, and in several ethnic populations.

The exclusion of subjects with any history of conditions that may decrease or increase mandibular movement capacity would reduce the number of participants with restricted or hypermobile mandibular movement capacities. In this study, this exclusion was not done.

Mandibular movement capacity is related to the anatomic form of mandibular condyle, glenoid fossa, and is dependent on the relationship between occlusion and condylar position (4). Based on the present study, various occlusal traits seem to be associated with changes in mandibular movement capacity. A limitation of the present study is that, in the subgroup analyses, sample sizes have been unbalanced, which must be kept in mind when interpreting the findings.

Individuals with certain occlusal traits had a different maximum mouth opening, and lateral and protrusive movement capacities compared to the sample mean of these movements – in spite of the fact that the sample mean also included individuals with occlusal traits associated with mandibular movement capacities. This finding is very important clinically.

Children with crossbite and open bite have shown to have lower muscular activation and specific chewing pattern (27–29). Based on the findings of the present study, mandibular movement capacity is smaller in children with crossbite and open bite as compared to children without corresponding occlusal traits.
Mandibular movement capacity may be a sign of a functional disturbance in dentofacial development. The finding highlights the necessity to evaluate mandibular movement capacities carefully as part of each clinical examination.

Conclusions and hypothesis

1. The present study confirmed earlier findings and supports our hypothesis that mandibular movement capacities increase with age, and that young adult males have larger mandibular movements as compared to females of the same age.

2. This study adds new information and confirms our second hypothesis. There is a relationship between maximum mouth opening, and lateral and protrusive movements of the mandible. Associations exist between mandibular movement capacities and crossbite, open bite, deep bite and increased overjet. Mandibular movement capacities are smaller in children with crossbite and open bite as compared to children without corresponding occlusal traits. Mandibular movement capacities are larger in children with deep bite and increased overjet as compared to those without corresponding occlusal traits.

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Conflicts of interest

The authors declare that they have no conflicts of interest.

References

1. Bennadi, D., Reddy, C.V. (2013) Oral health related quality of life. *Journal of International Society of Preventive and Community Dentistry,* 3, 1–6.
2. Klineberg, I., Palla, S., Trulsson, M. (2014) Contemporary relevance of occlusion and mastication. *International Journal of Prosthodontics*, 27, 411–412.
3. Thilander, B., Rönning, O. (1985) *Introduction to Orthodontics.* Tandläkarförlaget, Stockholm, 5th edn, pp. 63–84.
4. Karlo, C.A., Stolzmann, P., Habernig, S., Müller, L., Saurenmann, T., Kellenberger, C.J. (2010) Size, shape and age-related changes of the mandibular condyle during childhood. *European Radiology*, 20, 2512–2517.
5. Hirsch, C., John, M.T., Lautenschläger, C., List, T. (2006) Mandibular jaw movement capacity in 10-17-yr-old children and adolescents: normative values and the influence of gender, age, and temporomandibular disorders. *European Journal of Oral Sciences*, 114, 465–470.
6. Cortese, S.G., Oliver, L.M., Biondi, A.M. (2007) Determination of range of mandibular movements in children without temporomandibular disorders. *Cranio: The Journal of Craniomandibular & Sleep Practice,* 25, 200–205.
7. Müller, L., van Waes, H., Langerweger, C., Molinari, L., Saurenmann, R.K. (2013) Maximal mouth opening capacity: percentiles for healthy children 4-17 years of age. *Pediatric Rheumatology Online Journal*, 22, 11:17.
8. Luder, H.U. (1998) Age changes in the articular tissue of human mandibular condyles from adolescence to old age: a semiquantitative light microscopic study. *The Anatomical Record,* 251, 439–447.
9. Caruso, S., Storti, E., Nota, A., Ehsani, S., Gatto, R. (2017) Temporomandibular Joint Anatomy Assessed by CBCT Images. *BioMed Research International*, doi:10.1155/2017/2916953.
10. Franco, A.L., de Andrade, M.F., Segalla, J.C., Gonçalves, D.A., Camparis, C.M. (2012) New approaches to dental occlusion: a literature update. *Cranio: The Journal of Craniomandibular Practice,* 30, 136–143.
11. Stoustrup, P., Twilt, M., Spiegel, L., et al. (2017) Clinical Orofacial Examination in Juvenile Idiopathic Arthritis: International Consensus-based Recommendations for Monitoring Patients in Clinical Practice and Research Studies. *Journal of Rheumatology*, 44, 326–333.
12. Okeson, J.P. (2008) *Management of Temporomandibular Disorders and Occlusion*. Mosby, Saint Louis, Missouri, United States of America, 6th edn, pp. 22–23.
13. Sepp, H., Saag, M., Svedström-Oristo, A.L., Peltomäki, T., Vinkka-Puhakka, H. (2017) Occlusal traits and orthodontic treatment need in 7- to 10-year-olds in Estonia. *Clinical and Experimental Dental Research,* 26, 93–99.

14. Sepp, H., Saag, M., Peltomäki, T., Vinkka-Puhakka, H., Svedström-Oristo, A.L. (2018) Occlusal traits, orthodontic treatment need and treatment complexity among untreated 17-21-year-olds in Estonia. *Acta Odontologica Scandinavica,* 7, 1–5.
15. Sepp, H., Saag, M., Vinkka-Puhakka, H., Svedström-Oristo, A.L., Peltomäki, T. (2019) Occlusal traits of 4-5-year-old Estonians. Parents' perception of orthodontic treatment need and satisfaction with dental appearance. *Clinical and Experimental Dental Research,* 31, 199–204.
16. Rothman, K.J., Greenland, S., Lash, T.L. (2008) *Modern Epidemiology*. Lippincott Williams & Wilkins, Philadelphia, United States of America, 3rd ed., p. 150.
17. Moorrees, C.F.A. (1959) *The Dentition of the Growing Child*. Harvard University Press, Cambridge, Massachusetts, pp. 192–193.
18. Horowitz, S.L., Hixon, E.H. (1966) *The nature of orthodontic diagnosis.* Mosby, Saint Louis, pp. 166–168.
19. Brunelle, J.A., Bhat, M., Lipton, J.A. (1996) Prevalence and distribution of selected occlusal characteristics in the US population, 1988–1991. *Journal of Dental Research,* 75, 706–713.
20. Okeson, J.P. (2008) *Management of Temporomandibular Disorders and Occlusion.* Mosby, Saint Louis, Missouri, United States of America, 6th edn, pp. 236–239.
21. Steinmassl, O., Steinmassl, P.A., Schwarz, A., Crismani, A. (2017) Dental age is more appropriate than chronological age for evaluating the mandibular movement range in children. *Journal of Cranio-Maxillo-Facial Surgery,* 45, 1201–1204.
22. Machado, B.C., Medeiros, A.P., Felício, C.M. (2009) Mandibular movement range in children. *Pró-Fono Revista de Atualização Científica,* 21, 89–94.
23. Türp, J.C., Alpaslan, C., Gerds, T. (2005) Is there a greater mandibular movement capacity towards the left? Verification of an observation from 1921. *Journal of Oral Rehabilitation,* 32, 242–247.
24. Benevides, S.D., Araujo, R.P., Ribeiro, C.O., Mello, S.M.F. (2016) Determining the mandibular range of motions in children from Bahia state. *Speech, Language, Hearing Sciences and Education Journal,*18, 95–103.
25. Khare, N., Patil, S.B., Kale, S.M., Sumeet, J., Sonali, I., Sumeet, B. (2012) Normal mouth opening in an adult Indian population. *Journal of Maxillofacial and Oral Surgery,* 11, 309–313.
26. Gallagher, C., Gallagher, V., Whelton, H., Cronin, M. (2004) The normal range of mouth opening in an Irish population. *Journal of Oral Rehabilitation,* 31, 110–116.
27. Piancino, M.G., Talpone, F., Dalmasso, P., Debernardi, C., Lewin, A., Bracco, P. (2006) Reverse-sequencing chewing patterns before and after treatment of children with a unilateral posterior crossbite. *European Journal of Orthodontics*, 28, 480–484.
28. Sever, E., Marion, L., Ovsenik, M. (2011) Relationship between masticatory cycle morphology and unilateral crossbite in the primary dentition. *European Journal of Orthodontics*, 33, 620–627.

29. Piancino, M.G., Isola, G., Merlo, A., Dalessandri, D., Debernardi, C., Bracco, P. (2012) Chewing pattern and muscular activation in open bite patients. *Journal of Electromyography and Kinesiology*, 22, 273–279.

Figure and Table Legends

Figure 1. Selection of the final study sample.

Figure 2. Box plots of maximum mouth opening (MMO), lateral (LMMr and LMMl) and protrusive (PMM) movements in deciduous (Group 1, n = 372), mixed (Group 2, n = 392), and permanent dentition (Group 3, n = 390).

Figure 3. Correlations of maximum mouth opening (MMO), lateral (LMMr and LMMl) and protrusive (PMM) movements in deciduous (Group 1, n = 372), mixed (Group 2, n = 392), and permanent dentition (Group 3, n = 390). * – statistically significant correlations between mandibular movements ($P < 0.05$). Black – LMMr vs LMMl, red – MMO vs PMM, blue – MMO vs LMMl, green – MMO vs LMMr, grey – PMM vs LMMr, yellow – PMM vs LMMl.

Figure 4. Maximum mouth opening (MMO), lateral (LMMr and LMMl) and protrusive (PMM) movements in deciduous (Group 1, n = 372), mixed (Group 2, n = 392), and permanent dentition (Group 3, n = 390). Mean and 95.0% confidence intervals. # – statistically significant difference between Groups 1 and 2 ($P < 0.05$); ¤ – statistically significant difference between Groups 1 and 3 ($P < 0.05$); * – statistically significant difference between Groups 2 and 3 ($P < 0.05$).

Table 1. Gender differences of mandibular movements in deciduous (Group 1, n = 372), mixed (Group 2, n = 390), and permanent dentition (Group 3, n = 390). The mean ± standard deviation and odds ratios (OR) with 95.0% confidence interval and reference range for maximum mouth opening (MMO), lateral (LMMr, LMMl), and protrusive (PMM) movements in boys and girls. Ref: females.

Table 2. Occlusal traits and the mean ± standard deviation for mandibular movements (MMO, LMMr, LMMl, PMM) in deciduous (n = 372), mixed (n = 390), and permanent dentition (n = 390).

	MMO (mm)		LMMr (mm)		LMMl (mm)		PMM (mm)	
	Yes	No	Yes	No	Yes	No	Yes	No
Group 1								
Mesial terminal plane			10.1 ± 2.0	9.2 ± 2.8*				
(n = 131)			(n = 130, 33.4%)	(n = 259, 66.6%)				
Flush terminal plane			9.1 ± 2.5	9.7 ± 2.7*				
(N = 167)			(n = 167, 42.9%)	(n = 222, 57.1%)				
Distal terminal plane	43.1 ± 4.8	44.1 ± 4.4*						
(n = 187)	(n = 187, 47.9%)	(n = 203, 52.1%)						
Canine Class III	38.6 ± 7.4	43.9 ± 4.4*						
(n = 15)	(n = 15, 3.8%)	(n = 375, 96.1%)						
Canine end to end	44.4 ± 4.3	43.1 ± 4.8*						
(n = 164)	(n = 164, 42.1%)	(n = 226, 57.9%)						
Posterior crossbite	42.1 ± 5.2	44.0 ± 4.4*			8.5 ± 3.6	9.6 ± 2.4*	1.6 ± 1.5	2.8 ± 1.9*
(n = 68)	(n = 68, 17.4%)	(n = 322, 82.6%)			(n = 68, 17.4%)	(n = 322, 82.6%)	(n = 16, 15.1%)	(n = 90, 84.9%)
Anterior crossbite	40.0 ± 6.8	44.0 ± 4.2*	7.6 ± 4.1	9.6 ± 2.4*	7.6 ± 4.2	9.6 ± 2.4*		
(n = 33)	(n = 33, 8.5%)	(n = 357, 91.5%)	(n = 33, 8.5%)	(n = 356, 91.3%)	(n = 33, 8.5%)	(n = 357, 91.5%)		
Negative overbite	38.0 ± 6.5	43.8 ± 4.4*						
(n = 12)	(n = 12, 3.1%)	(n = 378, 96.9%)						
Overjet ≥ 3.5 mm	45.3 ± 4.2	43.3 ± 4.6*					5.2 ± 1.7	2.2 ± 1.6*
(n = 61)	(n = 61, 15.6%)	(n = 329, 84.4%)					(n = 16, 15.1%)	(n = 90, 84.9%)
Overbite ≥ 3.5 mm	45.1 ± 4.1	42.8 ± 4.7*	10.1 ± 2.1	9.1 ± 2.8*	9.9 ± 2.1	9.1 ± 2.9*		
(n = 151)	(n = 151, 38.7%)	(n = 239, 61.3%)	(n = 151, 38.7%)	(n = 238, 61.0%)	(n = 151, 38.7%)	(n = 238, 61.0%)		
Crossbite or open bite	42.6 ± 5.0	44.1 ± 4.4*			8.9 ± 3.3	9.6 ± 2.2*		
(n = 123)	(n = 123, 31.5%)	(n = 267, 68.5%)			(n = 123, 31.5%)	(n = 267, 68.5%)		
OJ ≥ 3.5 or OB ≥ 3.5	44.9 ± 4.0	41.5 ± 4.8*	9.0 ± 2.3	9.1 ± 2.8*	9.7 ± 2.3	9.1 ± 2.9*	3.5 ± 2.1	1.9 ± 1.5*
(n = 188)	(n = 188, 48.2%)	(n = 202, 51.8%)	(n = 188, 48.3%)	(n = 201, 51.7%)	(n = 188. 48.2%)	(n = 202, 51.8%)	(n = 47, 44.3%)	(n = 59, 55.7%)
Group 2								
Molar Class I							7.1 ± 2.4	8.0 ± 2.2*
(n = 225)							(n = 225, 57.8%)	(n = 164, 42.2%)
Molar Class II							8.6 ± 2.2	7.2 ± 2.3*

(n = 86)							(n = 85, 21.9%)	(n = 304, 78.1%)
Canine Class I							7.2 ± 2.3	8.4 ± 2.1
(n = 289)							(n = 286, 73.5%)	(n = 103, 26.5%)
Canine Class II							9.4 ± 1.4	7.4 ± 2.3*
(n = 14)							(n = 14, 3.6%)	(n = 375, 96.4%)
Canine Class III							5.8 ± 1.6	7.5 ± 2.3*
(n = 9)							(n = 9, 2.3%)	(n = 382, 97.7%)
Canine end to end							7.8 ± 2.4	7.3 ± 2.3*
(n = 163)							(n = 162, 41.6%)	(n = 227, 58.4%)
Open bite	48.1 ± 4.6	49.4 ± 5.0*						
(n = 84)	(n = 82, 20.9%)	(n = 308, 78.6%)						
Anterior crossbite	39.3 ± 4.9	45.1 ± 5.5*						
(n = 9)	(n = 9, 2.3%)	(n = 382, 97.4%)						
Negative overbite	44.3 ± 2.6	49.2 ± 4.9*						
(n = 6)	(n = 6, 1.5%)	(n = 385, 98.2%)						
Overjet ≥ 3.5 mm							8.7 ± 2.1	6.8 ± 2.2*
(n = 147)							(n = 144, 37.0%)	(n = 245, 63.0%)
Overbite ≥ 3.5 mm	49.8 ± 5.0	48.5 ± 4.8*					7.8 ± 2.3*	7.2 ± 2.3*
(n = 203)	(n = 203, 51.8%)	(n = 188, 48.0%)					(n = 202, 51.5%)	(n = 187, 47.7%)
Scissor bite	56.5 ± 6.8	49.0 ± 4.8*						
(n = 6)	(n = 6, 1.5%)	(n = 385, 98.2%)						
Crossbite or open bite	48.4 ± 4.7	49.5 ± 5.0						
(n = 123)	(n = 122, 31.1%)	(n = 269, 68.6%)						
OJ ≥ 3.5 or OB ≥ 3.5	49.6 ± 5.0	48.4 ± 4.7*					7.9 ± 2.3	6.9 ± 2.2*
(n = 243)	(n = 242, 61.9%)	(n = 149, 38.1%)					(n = 240, 61.7%)	(n = 149, 38.3%)
Group 3								
Molar Class II	52.8 ± 7.6	54.8 ± 7.4*					9.1 ± 2.6	8.4 ± 2.4*
(n = 92)	(n = 88, 23.7%)	(n = 283, 76.3%)					(n = 88, 23.7%)	(n = 284, 76.3%)
Molar Class III							7.5 ± 2.7	8.7 ± 2.4*
(n = 51)							(n = 50, 13.4%)	(n = 322, 86.6%)
Molar end to end					12.0 ± 2.3	11.4 ± 2.5		
(n = 114)					(n = 110, 40.3%)	(n = 262, 59.7%)		
Canine Class III							6.9 ± 2.8	8.7 ± 2.4*
(n = 26)							(n = 26, 7.0%)	(n = 346, 93.0%)

Canine end to end (n = 183)	11.9 ± 2.3 (n = 176, 47.3%)	11.3 ± 2.6* (n = 196, 52.7%)	11.8 ± 2.4 (n = 176, 47.3%)	11.3 ± 2.5* (n = 196, 52.7%)		
Overjet ≥ 3.5 mm (n = 183)					9.5 ± 2.2 (n = 176, 47.3%)	7.7 ± 2.4* (n = 196, 52.7%)
Anterior crossbite (n = 24)					6.8 ± 2.4 (n = 24, 6.2%)	8.7 ± 2.4* (n = 348. 89.2%)
Scissor bite (n = 41)					9.6 ± 2.7 (n = 40, 10.3%)	8.5 ± 2.4* (n = 332, 85.1%)
OJ ≥ 3.5 or OB ≥ 3.5 (n = 263)					8.9 ± 2.4 (n = 250, 67.2%)	7.9 ± 2.4* (n = 122, 32.8%)

* - statistically significant difference between children with certain occlusal trait as compared with those without corresponding occlusal trait ($P < 0.05$).

	Group 1		Group 2		Group 3	
	Girls	Boys	Girls	Boys	Girls	Boys
MMO (N)	190	200	198	193	214	157
Mean ± SD (mm)	43.0 ± 4.6	43.6 ± 4.6	49.3 ± 4.7	49.0 ± 5.2	52.1 ± 6.5	**57.3 ± 7.8**#
95% CI	43.0…44.3	43.0…44.3	48.6…49.9	48.3…49.8	51.2…53.0	56.1…58.6
OR (95%CI)	1.00 (0.96…1.04)		0.99 (0.95…1.03)		**1.11 (1.07…1.15)** #	
Reference range	33…54		38…60		38…71	
LMMr (N)	190	199	198	194	214	158
Mean ± SD (mm)	9.5 ± 2.7	9.5 ± 2.6	11.2 ± 2.3	11.3 ± 2.4	11.3 ± 2.3	**11.9 ± 2.7**#
95% CI	9.1…9.9	9.1…9.8	10.9…11.5	11.0…11.7	11.0…11.6	11.5…12.4
OR (95%CI)	1.00 (0.92…1.08)		1.03 (0.94…1.12)		**1.11 (1.02…1.21)** #	
Reference range	4…15		6…16		6…17	
LMMl (N)	190	200	198	194	214	158
Mean ± SD (mm)	9.4 ± 2.7	9.4 ± 2.6	10.8 ± 2.0	10.8 ± 2.3	11.2 ± 2.4	**12.1 ± 2.4**#
95% CI	9.0…9.8	9.0…9.8	10.5…11.1	10.5…11.2	10.8…11.5	11.7…12.5
OR (95%CI)	1.00 (0.93…1.08)		1.01 (0.92…1.10)		**1.19 (1.08…1.31)** #	
Reference range	3…15		6…16		6…17	
PMM (N)	50	56	197	192	214	158
Mean ± SD (mm)	2.7 ± 1.8	2.6 ± 2.0	7.1 ± 2.3	**7.9 ± 2.2**#	8.2 ± 2.3	**9.0 ± 2.7**#
95% CI	2.2…3.2	2.0…3.1	6.8…7.5	7.6…8.2	7.9…8.5	8.6…9.5
OR (95%CI)	0.97 (0.79…1.18)		**1.15 (1.06…1.26)** #		**1.15 (1.05…1.25)** #	
Reference range	0…7		2…13		3…14	

– statistically significant difference between gender ($P < 0.05$)

Sagittal plane

The sagittal relationship of the first permanent molars was registered between perpendicular projections, on the occlusal plane, from the tip of the triangular ridge of the mesiobuccal cusp of the maxillary first permanent molar and the buccal groove of the mandibular first permanent molar.

Molar Class I: the triangular ridge articulated in the buccal groove of the mandibular first permanent molar.

Molar Class II: the triangular ridge articulated anterior to the mesial groove of the mandibular first permanent molar.

Molar Class III: the triangular ridge articulated posterior to the mesial groove of the mandibular first permanent molar.

End-to-end: the triangular ridge of the mesiobuccal cusp of the maxillary first permanent molar articulated to the triangular ridge of the mesiobuccal cusp of the mandibular first permanent molar.

Molar Class II and Class III were registered in the accuracy of $\geq 1/2$ cusp width. In cases of obvious tooth migration, no attempt was made to endeavour the original intercuspation. Registration was not done when the first molar was missing.

The sagittal relationship of the canines was measured between perpendicular projections, on the occlusal plane, from the tip of the maxillary canine and the contact point of the mandibular canine and the first deciduous molar/the first premolar.

Canine Class I: the tip of the maxillary canine occluded to the distal surface of the mandibular canine.

Canine end-to-end: the tip of the maxillary canine articulated to the tip of mandibular canines. A deviation of 1 mm or more to the mesial or distal was classified as *canine Class II* or Class I, respectively.

Canine Class III: the tip of the maxillary deciduous canine occluded more than 1mm posterior to the distal surface of the mandibular canine

In the case of missing canine, the registration was not recorded. No attempt was made to compensate for drift of teeth due to premature extraction or any other reasons.

The sagittal relationship of the second deciduous molars was registered between perpendicular projections, on the occlusal plane, from the distal surface of the mandibular second deciduous molar and the distal surface of the maxillary second deciduous molar.

Distal terminal plane: the distal surface of the mandibular second deciduous molar is distal to the corresponding surface in the maxillary second deciduous molar

Mesial terminal plane: the distal surface of the mandibular second deciduous molar is mesial to the corresponding surface in the maxillary second deciduous molar

Flush terminal plane: the distal surface of the mandibular and maxillary second deciduous molar end in the same vertical plane

A negative overjet was measured in 0.5 mm intervals as the horizontal distance, parallel to the occlusal plane from the most labial surface of the upper central incisor to the most labial point of the incisal edge of the corresponding lower central incisors.

The anterior crossbite was registered in the incisor area when the incisal edge of the maxillary tooth occluded lingually to the mandibular antagonists (at least one pair of teeth).

Vertical plane

The overbite (positive) was measured in 0.5 mm intervals as the distance between the projection of the edge of the most overlapped central incisor on the labial surface of the lower incisors (in centric occlusion) and the incisal edge of the lower incisor.

A negative overbite was recorded when there existed a vertical space between the upper and lower incisal edges in the centric occlusion. The negative overbite was measured in 0.5 mm intervals from the incisal edge of the lower incisors to the incisal edge of the upper corresponding incisors.

Sagittal and vertical plane

Open bite was registered when there existed no contacts between the upper and lower incisal edges in the centric occlusion.

Transversal plane

The posterior crossbite was registered in the canine, premolar and molar area when the buccal cusp of the maxillary tooth occluded lingual to the buccal cusp of the mandibular antagonists (at least one pair of teeth). Teeth in an end-to-end position were registered as crossbite.

A scissor bite was recorded in the premolar and molar area when lingual cusps of maxillary teeth occluded buccally of the buccal surfaces of corresponding mandibular teeth.

Crowding

Crowding of the teeth was estimated as total space deficiency (in millimetres) of the anterior teeth (incisors only). The amount of crowding was recorded in the maxillary and mandibular arch as the difference between the total mesio-distal tooth diameter and the arch circumference. The possible influence of growth in arch width was not estimated.

Midline diastema

Midline diastema between the central incisors in the upper and lower arch was measured in 0.5 mm intervals between the mesial margin of the right and left incisors on the middle-height of the tooth crown.