Effects of rapid palate expansion on body posture and motor functions in children with monolateral posterior crossbite are test and task-related

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Abstract

Stomatognathic apparatus and the postural system interact through biomechanical chains, whose neuromuscular properties influence both gross and fine motor coordination. To evaluate changes in body posture and motor functions in children with malocclusion who are treated with palatal expanders, 8 right-handed children (6-12 years) with unilateral posterior crossbite were enrolled in this non-randomized pragmatic longitudinal study. Fine motor skills tests, handgrip strength, 3D body posture analysis, electromyography, thermography and stabilometry were performed before and after the treatment with a Rapid Palatal Expander (RPE) at T0pre (before using RPE), t0Post (immediately after using RPE), T1 (after 21 days of RPE use) and T3 (after 6 months). The positive effect on malocclusion, as demonstrated by reduced mandibular offset, did not result in changes in motor symmetries across time. Velocity variance of stabilometry was reduced during the treatment. The immediate wearing of device only slightly affected the results. The beneficial results at the occlusal level through RPE were not accompanied by changes at the neuromuscular and postural level. Clinicians and practitioners should consider that orthodontics treatments and devices which are adapted due to neuromuscular and posturometric tests may be task and test-related.

Key Words: malocclusion; handwriting; motor asymmetries; thermography; stabilometry; electromyography.

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There are two approaches to treating skeletal malocclusions: the European method starts with interceptive therapy[1] and surgical intervention if necessary; the American approach avoids double therapy, recommending surgery only after reaching adulthood. But there have been drawbacks. Over time, the misalignment gets worse, leading to aesthetic and psychological problems. The surgery itself gets more complicated and can lead to another relapse.

Interceptive orthodontics treats malocclusion problems in children by diagnosing and treating any changes to the jaw bones as soon as they occur to avoid worsening in adulthood. Children often respond better to orthodontic treatment and achieve better results than adults, due to greater bone formation. Interceptive orthodontics affect orofacial muscles and uses two types of devices: orthopaedic ones that act on the bone of the upper or lower jaw, and functional ones that act on the soft tissues to stimulate the bone. Dickers and colleagues demonstrated the beneficial effects of orthopaedic-functional therapy on neuromuscular and functional status in a sample of 33 subjects aged 10-12 years with dental and skeletal malocclusions treated with an Andresen activator.[2]

A crossbite is defined as an inadequate transverse relationship between the upper and lower jaws in which the buccal cusps of the upper teeth are in contact with the central fossa of the lower molars. The posterior crossbite is the malocclusion that is most associated with asymmetric masticatory problems due to neuromuscular imbalance, asymmetric growth of the maxilla and midline deviation. Some studies suggest that its prevalence is between 8 and 22 per cent, making it one of the most common malocclusions in the primary and mixed dentition.[3] The unilateral posterior crossbite is a complicated malocclusion where the muscles are unevenly stronger on one side. This asymmetry can lead to facial unevenness if not treated during development. Early treatment is key to preventing facial asymmetry in adulthood, even in primary teeth. Surgical treatment is the best option to correct structural asymmetries,[4] but it can be put off for social, economic or personal reasons.

There are few studies on the treatment of unilateral crossbites, so there is little scientific evidence to choose the most appropriate treatment. One way to widen the arches is to expand the upper arch by opening the medial palatal suture. This operation can have significant advantages, such as restoring the correct relationship between the maxillary bases in the transverse plane, reducing crowding, improving smile aesthetics and reducing air resistance at the level of the nasal cavity.[5] It can also avoid the need for extractions in cases of crowding due to the increased length of the upper arch. Rapid palatal expansion can induce significant changes in muscle tone at the end of the active expansion phase because the musculature has to adapt to a new state and re-establish satisfactory occlusal relationships.[5] Normally, the electromyographic activity of the muscles at rest should be minimal, but if any factor intervenes to alter this balance, muscle tension is generated.

Temporomandibular features have been identified as contributing factors to body posture.[6] Previous studies have demonstrated that nerve stimulation from the periodontium and the temporomandibular joint converges towards the trigeminal nuclei, which regulate the body's posture.[7,8] The first paper focused on potential correlation between stomatognathic apparatus and body posture was released by Rocabado and colleagues in 1982.[9] However, the relationship between dental occlusion and body posture, as well as with balance, motor function and symmetries, has yet to be fully demonstrated for being translated into evidence-based clinical practices.[10–12]

Although the study of the links of odonto-stomatognathic inputs to neuromuscular patterns has attracted interest,[13] to our knowledge, a single study was found regarding how the systems of the jaw and neck are functionally related can influence the fine motor skills.[14] That study focused on handwriting, which represents a key outcome of graphomotor performances. In the aforementioned study, all parameters of handwriting were observed to vary between the resting, opening and clenching positions of the jaw on both solid and unstable surfaces. This demonstrated that a change in the jaw motor system had the potential to influence fine motor skills. However, no investigation was made into the patient's temporomandibular joint and occlusion, a key factor in assessing how the head/neck system may affect fine motor skills.

The normal function of the jaw is contingent upon a harmonious relationship between the various components of the masticatory system.[15] In children exhibiting malocclusion, the harmonious relationship may be subject to disruption, potentially impacting the conventional progression of jaw development and functionality.[16] In fact, it has been previously reported how dental malocclusion can affect the orofacial aesthetic perception, oral functions and psychological well-being,[17,18] thus influencing individuals' oral health-related quality of life. Within this background, it emerges the importance of identifying whether dental malocclusion can affect skills such as writing, which involves both high-level and low-level processes.

In Plamondon's kinematic model for handwriting production, each stroke results from a coordinated activity of the muscular system and is defined by a velocity vector.[19,20] Only the orientation and amplitude of each velocity vector would be encoded by the central nervous system.[21] In skilled adults, the main network is composed of five specialized regions for handwriting,[22] and the functional network of typical 8- to 11-year-old children is composed of the same five regions. A substantial body of research has previously been dedicated to the exploration of various geometric and kinematic aspects of writing, including the length of the trace and the execution speed of the movement,[23,24] while less attention has been devoted to the dynamic component. This body of research has shown that handwriting is done automatically and ballistically by the third grade of primary school.[23,25] Writing is not merely a series of discrete actions; rather, it is a methodical, hierarchical process in which the temporal and spatial parameters of each motor unit are contextually interdependent within a broader unit,[26] and various studies indicated that handwriting skills can be due to many different variables including ergonomic factors such as body posture.[27,28]

Aim of the study

The present work aims to provide pilot evidence of the effectiveness of interventions in real-life routine practice conditions from a set of skeletal, neuromuscular, stabilometric, and motor function features, after the application of a rapid palatal expander in developing-age participant with crossbite. A secondary objective was to evaluate the overarching associations between fine motor skills, dental malocclusion and posture in developmental age, presupposing that fine motor capabilities are indispensable to the writing process. In this context, the specific aim of this study was to examine the hypothesis that there is a direct correlation between fine motor control/handwriting and the resolution of dental malocclusions, such as unilateral cross bite in children.

Materials and Methods

Participants and design of the study

This study came with a non-randomized longitudinal design. A total of 8 participants were involved in this study, of which 5 males and 3 females, 10.9±1.9 years old, all right-handed; none of them were affected by developmental coordination disorders nor neuromotor dysfunctions nor swallowing dysfunction. They were selected from a population of 116 participants diagnosed with a Unilateral Posterior Crossbite (UPXB), independently from the side, in the local Unit of Orthodontics between January 2021 and December 2022, based to the abovementioned inclusion criteria and to the logistic availability to underwent additional analyses, accounting for real-life routine practice conditions. The presence of cross-bite accounts for the possibility to evaluate the side-to-side symmetry in motor functions due to the biomechanical alterations on the frontal plane. The study was approved by the local Ethics Committee, and informed consent was signed by the parents of the children. The study conformed to the Declaration of Helsinki.

The inclusion criteria were as follows: i) systemically healthy; ii) no history of medications that may affect periodontal status in the previous 6 months; iii) An UPXB diagnosed.

Children with an UPXB were treated with the application of a RPE (rapid palatar expander).

Functional tests were performed on all participants at: T_{0pre}, before the application of the RPE; T_{0post}, immediately after the first activation of the RPE; T_1, after 21 days which correspond to the mean activation period of the RPE; T_{2pre}, after the 6 months retention period; T_{2post}, immediately after the removal of the RPE

Treatment

The treatment entailed the cementation of a device, the maxillary expander type Hyrax, anchored to the first premolars and permanent molars, or deciduous molars (Figure 1). In particular, permanent molars were used where possible by using the molar band; in two participants the expander was anchored to deciduous molars (by using a wire extension to involve the permanent molars), in two participants to first molars and first premolars, and in four participants to first molars only. The activation protocol involved the concurrent performance of four screw turns with the cementing of the device, followed by one screw turn per day (corresponding to 0.25 mm). The participant was instructed in the correct method for turning the screw, and a slight overcorrection was achieved with the upper palatal cusps in contact with the lower vestibular cusps, a situation that was accomplished within approximately 21 days. Concurrently with the cementing of the device, the following were made with cement: photohardening glass ionomer cement (Ultra Band-Lok Blue, Reliance Orthodontic, Itasca, IL) of the flat elevations (plateaus) on the occlusal surface of the posterior teeth (Figure 1).

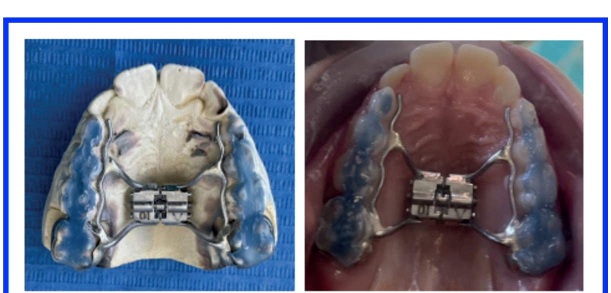

Figure 1. *Rapid palatal expander.*

Following the completion of the maxillary expansion, the expander was clamped in its middle, corresponding to the activation screw, with composite. The opening of the upper incisive diastema confirmed completion, with the palatal cusps of the upper molars coming to rest against the vestibular cusps of the lower molars, assessed by moving the jaw to align its frenulum with the maxillary frenulum. The expander and plateau were maintained on the teeth as restraints for approximately six months. At the conclusion of this period, the device was disassembled.

Testing procedures

Orthodontics

The value obtained, in mm, from the distance between the midline of the face and the line joining the glabella and the center of the chin was analyzed to assess the resolution of the mandibular shift due to the presence of unilateral crossbite. This was set as structural outcome, and the following as functional outcomes.

Motor functions

Two different tests (Figure 2) were used to assess the dynamics of handwriting of the dominant hand, taking into account that several imposed spatio-temporal constraints affect young children's handwriting performances.[29]

Alphabet Writing Task-cursive mode

Children were instructed to write the alphabet in lower case cursive letters from memory in order as quickly as they could as shown in Figure 2, but so that others could identify the letters out of word context; the score was the number of correct letters in 15 seconds (legible and in correct order) in writing the alphabet from memory, already used in children and adolescents.[30]

M-task

Children were instructed to continue as quickly as possible a zigzag sequence without pen lifts to the end of the lines shown on the screen[31] as shown in Figure 2.

Both tasks were conducted with a digital pen on a tablet pc screen, and pressure, speed, and number of strokes[32,33] will be registered through a home-made software (ScriptAN) implemented into the tablet pc (Microsoft Surface 6 pro); the analysis was focused on pressure.

Two other tests (Figure 2) were used to assess strength and fine motor skills for both hands.

Handgrip strength test

Rather than in standing position with arms extended laterally alongside the trunk, as in other protocols, children remained seated and performed their maximal grip strength keeping the arm leaning to the chair's armrest;[34,35] the procedure comprised one familiarisation trial and two effective trials for each hand, with the most successful trials being registered.

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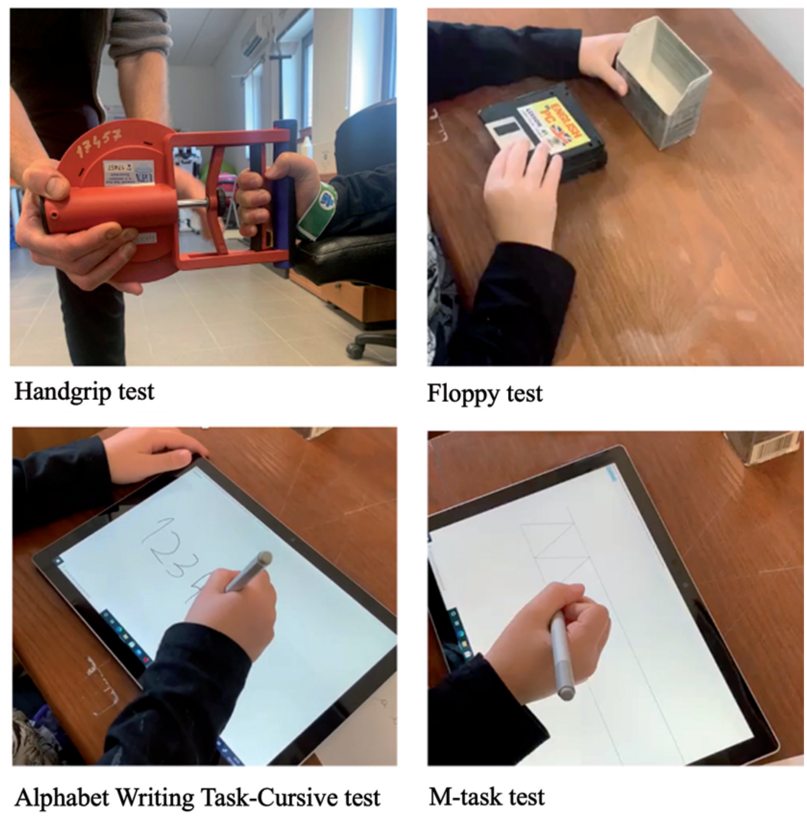

Figure 2. *Tests of motor functions.*

Floppy test

A transitive (tool-related) test measuring dexterity, which required participants to insert fourteen floppy disks one at a time in the proper case with one hand, as fast as possible, while the other hand controlled the case;[36] the procedure comprised one familiarisation trial and two effective trials for each hand, with the most successful trials being registered.

Postural analysis

A subset of participants (4 out of the 10) performed postural examinations using the GOALS-E.G.G. (Bioengineering & Biomedicine Company Srl-Pescara, Italy) methodology designed by D'Amico and colleagues [37]. This procedure integrates an optoelectronic stereophotogrammetric system, a baropodometric treadmill and a telemetric surface electromyographic device. The multifactorial analysis of posture and movement included full 3D synchronized skeletal kinematics, baropodometric assessments and electromyographic data. To describe trunk and global unbalancing, spinal offset, and global offset (*i.e.*, displacements of each spine markers with respect to the vertical line passing through the S3 vertebra and with respect to the vertical line passing through the middle point between the heels, respectively) are used. Both global and spinal offset values are finally averaged to obtain descriptive data that summarize these parameters. The Anterior Superior Iliac Spine (ASIS) and Posterior Superior Iliac Spine (PSIS) positions provide the basis for the assessment of hip joint center positions and of pelvis width.

Stabilometry

Postural-stabilometric assessment was performed by following a previous protocol.[38] A vertical force platform (Lizard; Lemax s.r.l., Como, Italy) and its software (Lizard v 3.0; Lemax s.r.l., Como, Italy) were used. Each participant was placed on the platform and was asked to maintain the most stable and relaxed body posture with their arm resting along the body. Natural head position was reached asking the participant to gaze a reference point painted on the wall 90 cm away and corresponding with the central axis of the platform. An operator guided participant's feet direction on the platform by using the guidance lines plot on the platform and a custom-made tool for the exact projection of the lateral malleolus center on the platform

The assessment was firstly performed in basal conditions: i) rest position/open eyes: slightly separated teeth and masticatory muscles in a relaxed non-contracted condition; ii) rest position/closed eyes: slightly separated teeth and masticatory muscles in a relaxed non-contracted condition; iii) maximum intercuspidation/open eyes: reaching the maximum intercuspidation between the teeth; iv) maximum intercuspidation/closed eyes: reaching the maximum intercuspidation between the teeth.

The following parameters were considered to assess the postural arrangement changes: i) Weight Distribution (WD, norm values <5%): the difference between the values expressed in kg of the projection to the ground of the postural loads divided between the two feet; ii) the Bar Torsion Angle (BTA): the angle formed by the line that joins the barycenter of the participant with the origin of the Cartesian X axis provided by the platform; ideally should have a value of 0; iii) opposite angle ascissa: the complementary of the previous; iv) the barycenter (Xmm; norm values –5mm ≤ X ≤ 5mm): the mean value (X-mean) of the lateral displacement of the center of gravity. It is obtained by calculating the mean of the X values obtained during the examination and it expresses the symmetry of the postural tone; v) oscillation area (A mmq; norm values $250mm^2 \leq X \leq 400mm^2$) the surface of the oscillation in square mm; vi) shape ratio: the ratio between the length and width of the ellipse, and ideally should have a value of 0.5: the smaller the ratio, the greater the width; the higher the value of the ratio, the longer the length; vii) Velocity variance (V mm/s): the harmony of the receptors of the postural system; a high variance indicates tension in the system, therefore greater energy expenditure, while a low variance indicates harmony in the system.

Electromyography

Surface electromyography (sEMG) acquisition was performed by following a previous protocol[39] by two blinded expert operators. The participant seated on a comfortable chair without a headrest, with their feet resting on the floor and their arms resting on their lap and was asked to look straight ahead towards a mirror adjusted at eye level. Three consecutive tests were performed: i) Cotton test (COT6), which consisted in biting two cotton rolls positioned on the occlusal surface of the posterior teeth behind the first premolar in order to calibrate maximum muscle activity of anterior temporalis, masseter, and sternocleidomastoid muscles in the absence of dental contact; ii) Clenching test (CLE6), performed in natural intercuspation; iii) Rotation test (ROT6), which consisted of asking the participants to rotate their head—first on one side, then on the other—while the operator ensured they did not tilt their head or move their shoulders away from the back of the chair
The first two tests allowed measurements of muscle activity in maximum intercuspation. The Teethan software (BTS S.p.A., Garbagnate Milanese, Milan, Italy) allowed to extract the following indices: i) POC: percentage overlapping coefficient (norm values 83% ≤ X ≤ 100%), i which indicates the predominance of one of the two sides of each pair of muscles (100% indicates perfect symmetry); POC TA stands for the anterior temporalis muscles, POC MM for the masseter muscles, and POC SCM for sternocleidomastoid muscles; ii) BAR: percentage overlapping coefficient between temporalis and masseteris muscles (norm values 90% ≤ X ≤ 100%); iii) CL: cervical load, which indicates the percentage of co-contraction of the sternocleidomastoid muscles during a clenching test; iv) TORS: torsion index (norm values 90% ≤ X ≤ 100%), which indicates the percentage of torsion of the mandible; the prevalence of one pair of crossed muscles over the other indicates a torsion of the lower jaw; the greater the torquing effect, the more the TORS approaches zero; v) IMP: impact index (norm values 85% ≤ X ≤ 115%), which indicates the muscle workload during clenching; lower values indicate reduced muscular strength; vi) ASIM: asymmetry index (norm values −10% ≤ X ≤ +10%), which indicates the distribution of the occlusal contacts on the right and left side, comparing the activity of TA and MM of the left side with TA and MM of the right side; a value of zero indicates perfect symmetry; conventionally, negative valules indicate a predominance of the left couple.

Termography

The thermography procedure can be performed in minutes by a qualified operator and a high-quality thermography system consisting of an infrared camera, thermal control unit and image analysis software. The images are obtained using a FLIR SC655 digital thermal camera, capable of detecting the infrared thermal radiation emitted by the participant, allowing the realization of a thermographic plot that describes the cutaneous thermal distribution of the area of interest.[40] Participant was seated in a relaxed position, equidistant and adequately spaced from all surrounding walls, for at least 15 minutes prior to the examination.
Using the ThermaCAM Researcher Professional 2.10 software, thermal images captured the hemiface of the participant, including the head and neck. The following thermograms were recorded for both the right and left profiles: i) resting position: swallowing and maintaining the dental arches in a rest position, approximately 2 mm apart; the thermogram was captured by the operator after 2 minutes; ii) dental contact: bring the dental arches into contact, achieving the maximum number of tooth contacts; the thermogram was taken after 10 seconds; iii) resting position: returning to the initial resting position, with the dental arches slightly separated, for 2 minutes; no thermogram was captured at the end of this phase; iv) maximum mouth opening: opening the mouth as wide as possible; the thermogram was captured after 10 seconds; v) resting position: a thermogram is acquired after 10 seconds; vi) clenching: bring the dental arches into contact and clench the teeth; the thermogram was taken after 10 seconds.
Among the acquired thermograms, four were selected for evaluation: the first and last resting positions, dental contact, and maximum mouth opening. Once the thermographic images were obtained, three Regions Of Interest (ROIs) were identified and analyzed for both the right and left sides: i) AR01 was assigned to the masseter muscle; ii) AR02 to the temporalis muscle; iii) AR03 to the sternocleidomastoid muscle.
For each ROI, the following thermal parameters were recorded: maximum and minimum temperatures, the temperature difference between the two, the Average temperature (Avg), and the standard deviations.

Data analysis and statistics

Data from the software ScriptAN were exported into .xls files to compute the median of pen's pressure from a minimum of 0 to a maximum of 4096 customized units. It referred to the pressure exerted by the digital pen on the tablet

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screen. The software was specifically developed by Dr. Anacleto Navangione and installed into a Microsoft Surface Pro 6 equipped with the digital pen.

Statistical comparisons were performed using Jamovi Version 2.3.21 software (https://www.jamovi.org), and graphs were created with GraphPad Prism Version 10.0.1 (GraphPad Software, LLC). Normality of distribution was checked with the Shapiro-Wilk test. Outliers were computed with the ROUT method (Q=0.5%). To compare the results of motor test, graphomotricity, and stabilometry across time, a series of repeated measures analyses were used; after observing Q-Q plots of residuals, either RM-ANOVA (with the Greenhouse-Geisser correction for sphericity) or Friedman test were used, registering each p value and effect size. Then, the test at t1 was removed and a series of RM ANOVA were used, including time and the use of device as within factors. To compare the results of electromyography and termography acorss time, either RM-ANOVA (with the Greenhouse-Geisser correction for sphericity) or a lienbar mixed model or Friedman test was used. To compare the results of mandibular offset, a paired sample t-test was conducted, after checking the assumptions of normality of residuals; repeated measures Edges' g was computed as effect size (https://effect-size-calculator.herokuapp.com).

The 4 participants who completed the biomechanical analysis were included into the graphical reports of radar graph (realized with Microsoft Excel Version 16.66.1), which consisted of the following variables: i) handgrip strength, ii) *Floppy* test time, iii) pressure on M-task, iv) pressure of W-task, v) mandibular offset, vi) side-to-side percent changes on handgrip strength test, vii) side-to-side percent changes on *Floppy* test, and viii) global offset and ix) spinal offset from posturometric analysis. Variables 1-to-7 were computed as percent changes from t0 to t2, in both time points averaging the two results obtained with and without the mouth device. Specifically, the variables were graphed subsequent to the re-scaling of the results to the normalized percentiles that had been computed from the minimum to the maximum of each variable.

Results

The intervention was effective in reducing the mandibular offset on the frontal plane ($p<0.001$, Hedges' g for repeated measures=1.165). In particular, the reduction was observed in all the 8 participants who completed the time course, with a mean difference of 0.475 mm (Figure 3).

For what concerns motor tasks, as expected in developmental age, handgrip strength increased over time, in both dominant ($p=0.038$, $\eta^2_p=0.526$) and non-dominant hand ($p=0.041$, $\eta^2_p=0.566$); these differences were not influenced by the immediate wearing or removal of the device. Instead, the performance on the *Floppy* test did not increase over time on either side. For what concerns the symmetry, the dominant hand obtained better performances in both tests, with higher values in the handgrip strength test (median percentage difference: +14.36%) and a lower time of completing in the *Floppy* test (mean percentage difference: –8.25%). These values remained quite stable over time, since no robust changes were observed on either handgrip strength or *Floppy* test performances; the immediate wearing or removal of the device only slightly influenced the results, since there was a statistical tendency for reduced asymmetry while wearing the device (asymmetry index for floppy test, $p=0.121$, $\eta^2_p=0.352$).

Pen's pressure on the tablet screen during the tasks did not increase over time and the immediate wearing or removal of the device did not influence the performances. The pressure exerted during the tasks was similar during the two tasks.

The radar graphs show that the different domains were not related homogeneously across participants (see Figure 4). One can observe that both the amount of variations and the relationships across the domains greatly vary across the four participants.

With regard to the plantar pressures, baropodometric analysis allowed the determination of the distribution of loads or pressures across various plantar zones. Consequently, this analysis enabled the evaluation of the direct influences of the forces applied, their intensity, and their duration, as illustrated in Table 1.

For what concern stabilometry (Figure 5), the main change across study timeline, despite non statistically significant, was observed for variance velocity in resting position ($p=0.084$, $W=0.229$). Moreover, there was an interaction effect time × device that affected the results, since CoG displacement on x-axis was reduced in the second test both at t0 and t2 ($p=0.016$, $\eta^2_p=0.798$).

For what concerns electromyography (Figure 6), no homogeneous and clinically appreciable changes were observed for both POC TA ($p=0.551$), POC MM ($p=0.170$), BAR ($p=0.783$), TORS ($p=0.551$), IMP ($p=0.302$), ASIM ($p=0.848$), POC SMC ($p=0.260$), and CL ($p=0.892$). As shown in Figure 6, heterogeneous results were observed inter-individuals and across the study timeline. The values were often out of normative ranges, indicating a non-balanced muscular function.

Nor any homogeneous and clinically appreciable changes from termography were observed for the three muscle groups in all testing tasks (p values ranging from 0.284 to 0.632, R^2 ranging from 0.058 to 0.164). Furthermore, it was determined that the temperature of the area corresponding to the masseter muscle is consistently the lowest when compared to the areas corresponding to the temporalis and sternocleidomastoid muscles (Figure 7).

Discussion

From a clinical perspective, the study demonstrated that RPE resulted in a reduction of mandibular offset, interpreted as an improvement of the occlusal condition. However, electromyographic and thermographic tests did not reveal any clinically significant changes across the follow-up period.

For what concerns whole body function, stabilometry was only slightly affected. We can speculate that the fact of adding or removing the device altered itself the CoG displacement of x-axis, as a non-specific perturbation of the whole static balance function.

The improvement of motor performances over time was hypothesized.[35] The enhancement in handgrip strength was unmistakable; however, this was not observed in the *Floppy* test. The handgrip strength test is determined by a rudimentary motor task, whereas the *Floppy* test, as a tool-related action test determined by manual dexterity and characterised by progressive difficulty, represents a more intricate task. An individual's developmental trajectory is more influenced by the dynamic interplay between the individual, the task at hand, and the surrounding environment, as task difficulty increases. The enhancement of fine motor skills is contingent upon the deliberate and consistent practice of these skills.[36]

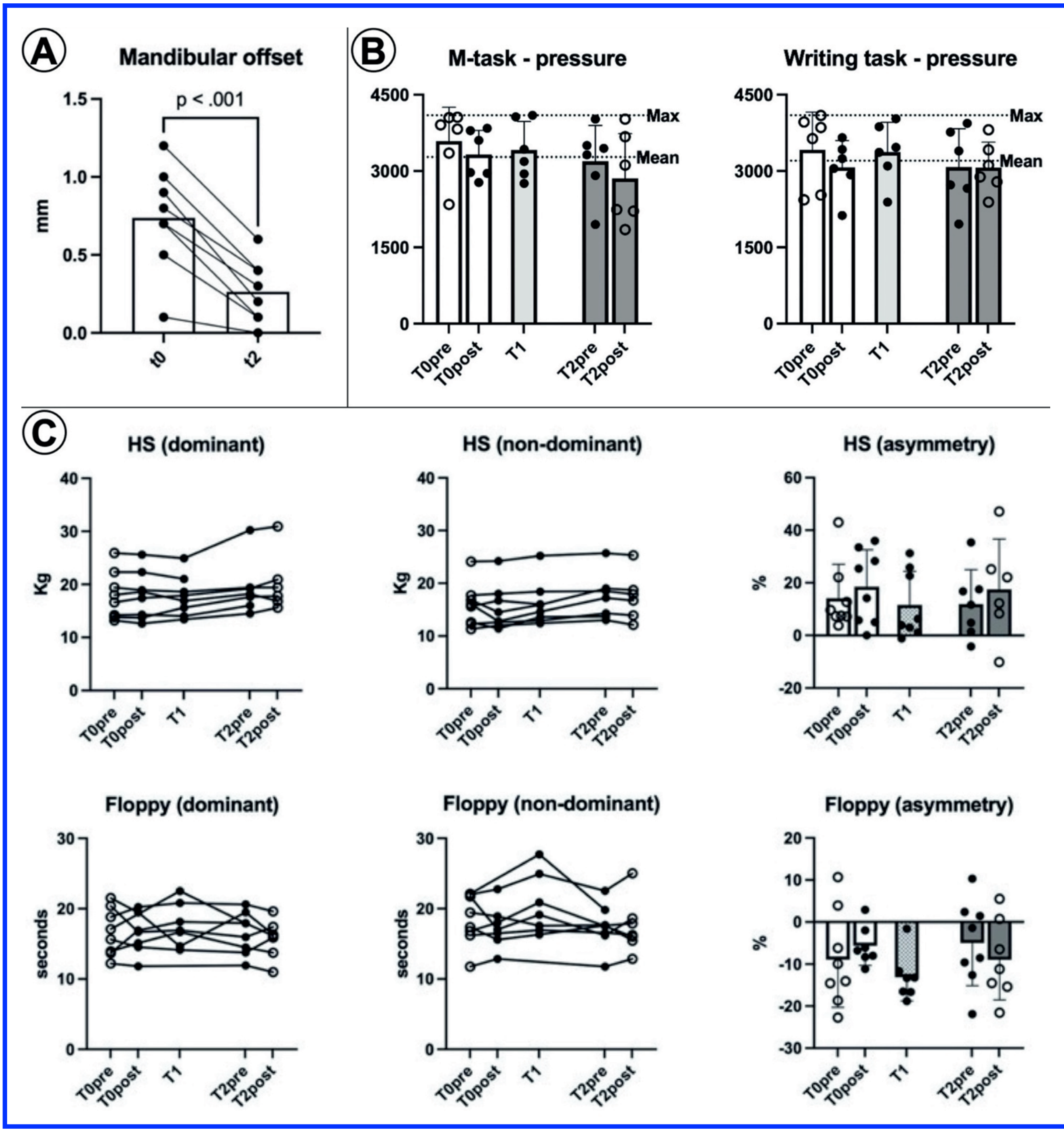

Figure 3. A, Mandibular offset was reduced as a result of the treatment in all participants; B, Pen's pressure on the tablet screen during the tasks did not increase over time and the immediate wearing or removal of the device did not influence the performances The pressure exerted during the tasks was similar during the two tasks; C, Handgrip strength increased over time, in both dominant and non-dominant hand; with robust increment at t2 compared to t0 and t1. Instead, the performance on the Floppy test did not change homogeneously over time.

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Of particular significance was the study of the symmetry changes, if any, resulting from the intervention. As expected, the dominant side demonstrated superior performance in both handgrip strength and the *Floppy* test, thereby substantiating a pronounced functional lateralization in complex coordinative tasks and in maximal strength during the developmental age, with a considerable inter-individual variability. Despite the intervention proved effectiveness in reducing the mandibular offset, this was not reflected in altered functional symmetry on motor tasks.

Table 1. *Results of gait analyses.*

Global offset frontal	Spinal offsets frontal	Differences L-R PSIS	Differences L-R HIP	Mean support			
				Statics		Motion	
				RF	LF	RF	LF
7.3	-11.5	00.8±0.5	-00.2±1.1	6.7	-12.8	-3.8	-0.2
6.8	-2.2	01.6±0.5	02.2±1.4	1.4	-0.3	2.0	-13.8
-8.9	-11.9	08.3±0.1	13.6±0.3	3.3	0.2	13	-5
6.0	-3.1	01.8±0.3	04.7±0.5	4	3.6	8.1	-2.5

RF, right foot; LF, left foot.

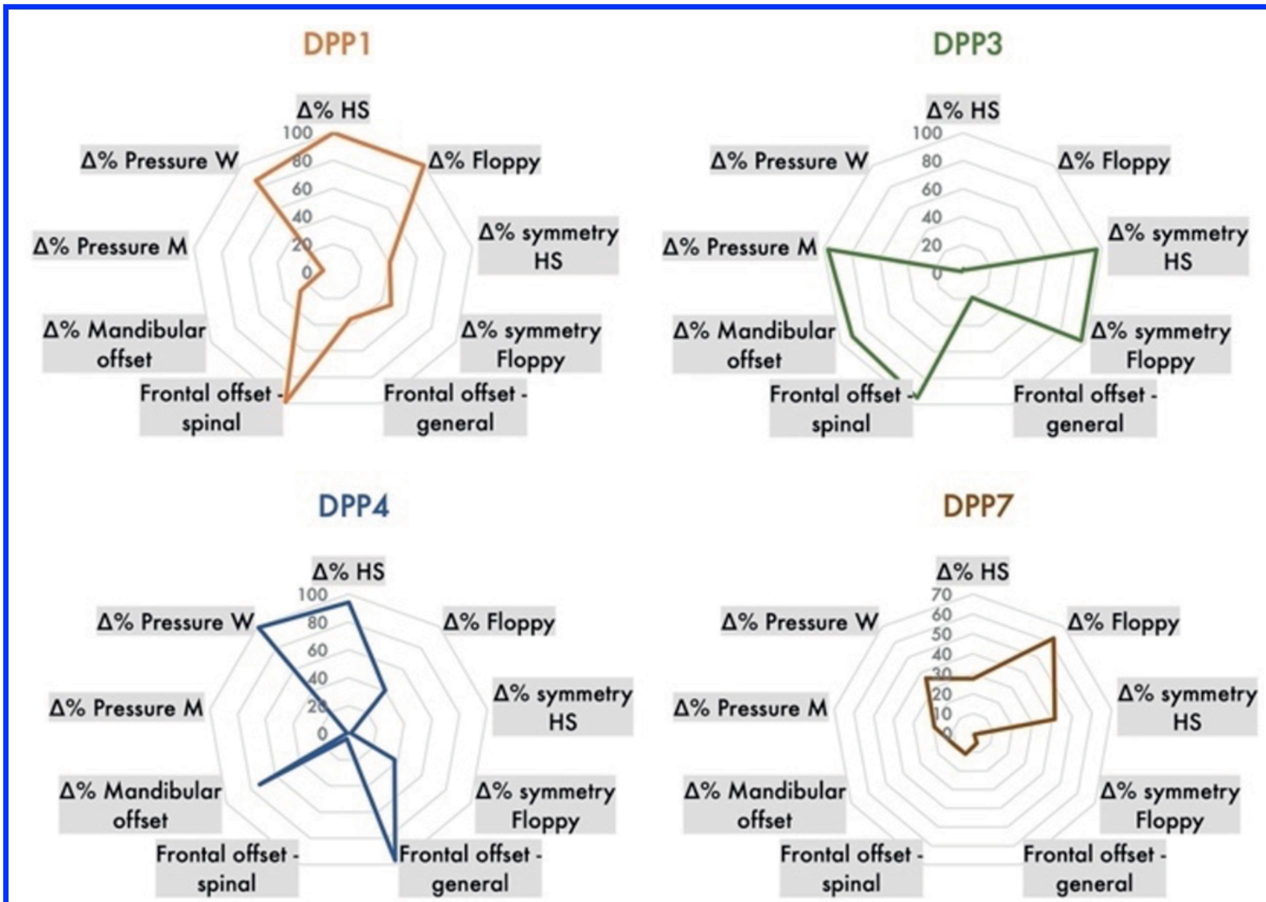

Figure 4. *Radar graphs; HS, handgrip strength; variables 1-to-7 were computed as percent changes from t0 to t2; DPP stand for the ID attributed to participants in this study.*

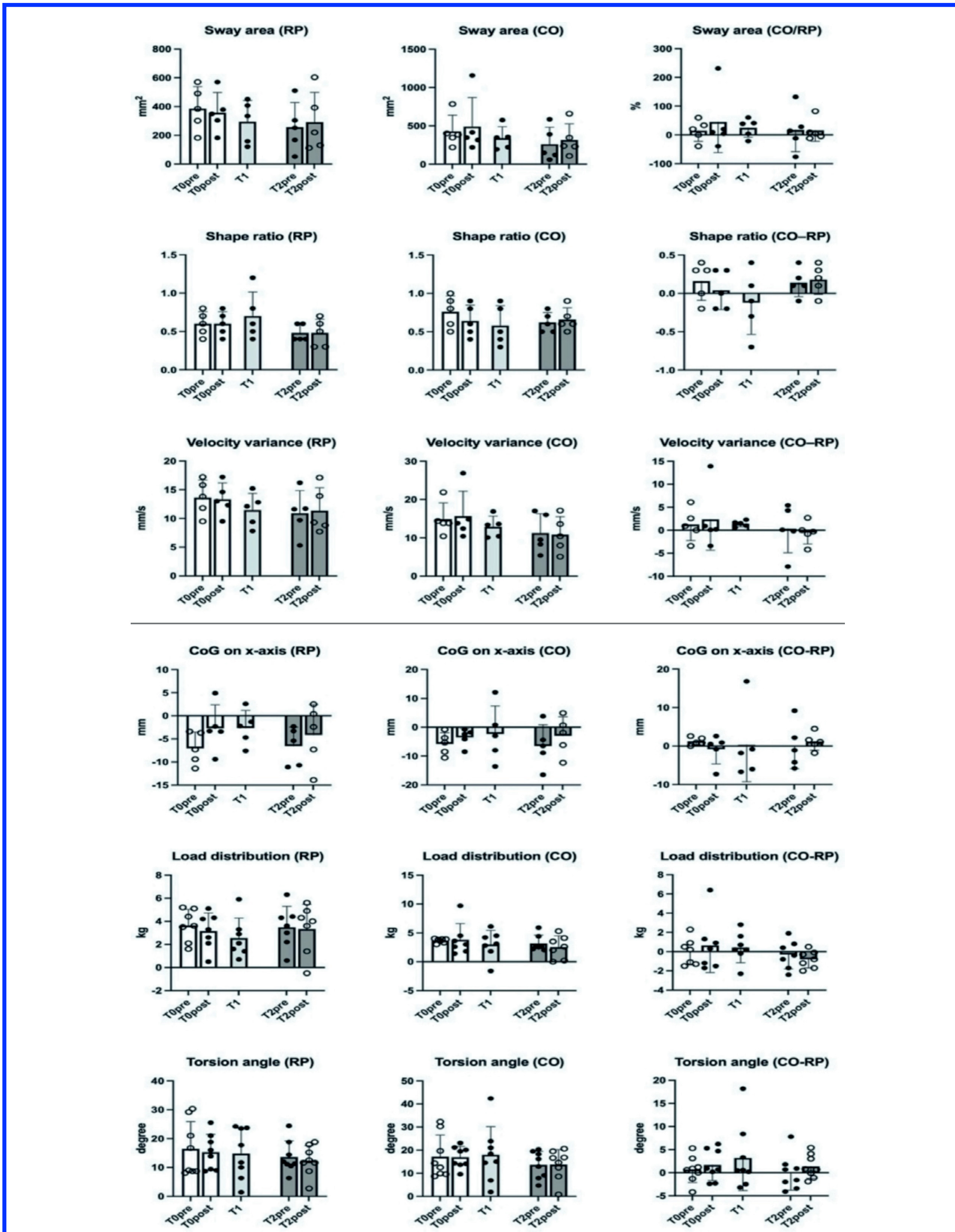

Figure 5. Results of stabilometry, Upper panel. To be noted that treatment affected velocity variance most of all. Lower panel. None of the three parameters were observed to change homogeneously across time, nor the open vs *closed eyes conditions influenced substantially the results.*

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This finding indicates that motor imbalances are both joint and task-specific. It also demonstrates that compensatory mechanisms are in continuous operation, counteracting such imbalances and the individuality that defines the responders' type concerning different motor tasks.[41]

A very large heterogeneity in functional motor responses was observed. The radar graphs tuned this argument, indicating that the various domains, at least in this pilot sample, were not related, resulting in individual trajectories of motor performances and individual responses to morpho-func-

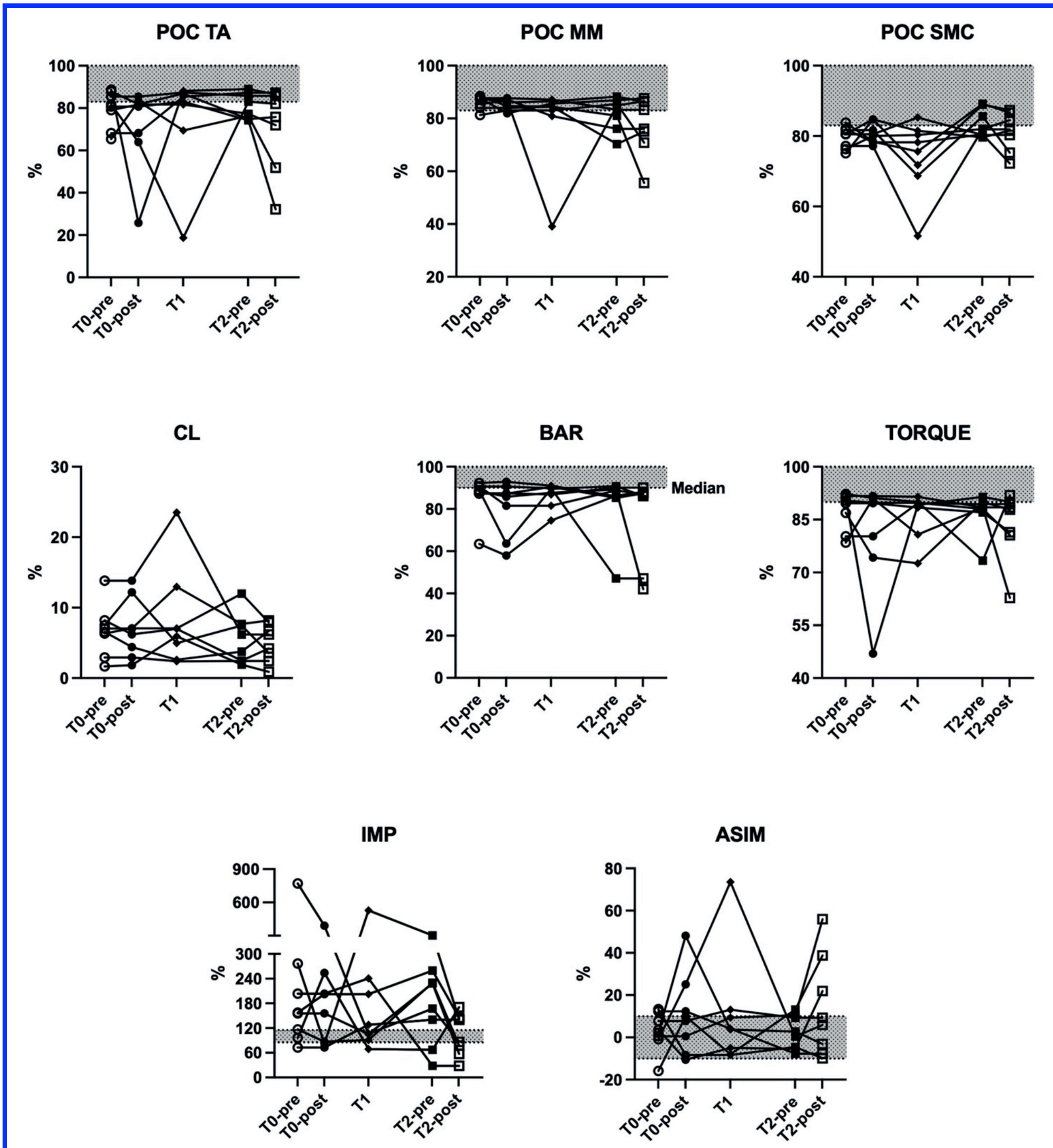

Figure 6. *Results of electromyography. To be noted the great hetergeneity across participants and in the individual trajectories. POC, percentage overlapping coefficient; TA, temporalis anterior; MM, masseter muscle; SMC, sternocleidomastoid muscle; CL, cervical load; BAR, baricenter; IMP, impact index; ASIM, asymmetry index; the filled area refers to the normative range.*

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tional interventions. The neuromuscular and biomechanical effects due to temporo-mandibular system changes can be transmitted to the whole body via neural connections as well as active and passive tissues,[11] depicting a huge complexity of acute and chronic adaptations.

The fact that the intervention did not affect the handwriting pressure on both tasks can rely on the complexity of neuromotor drives during grapho-motor tasks, on the task-specific coordinative development,[42] on the exploitation of natural biomechanical tendencies of children while exerting grapho-motor tasks, and on the huge age range, since stronger perception–action coupling emerges as age increases.[43] The natural biomechanical tendency indeed emerges if considering that the pressure exerted was similar during the two grapho-motor tasks, despite the difference in the content and context of the performances, *i.e.*, the W-task is constrained by the time while the M-task only require to focus on the accurateness.

The findings of the present study demonstrated that the dominant side exhibited superior performance in both the handgrip test and the floppy test, resulting in a preserved symmetry of the sides with no alteration in both forces exerted and dexterity. However, the findings of this study demonstrate that the intervention did not uniformly impact

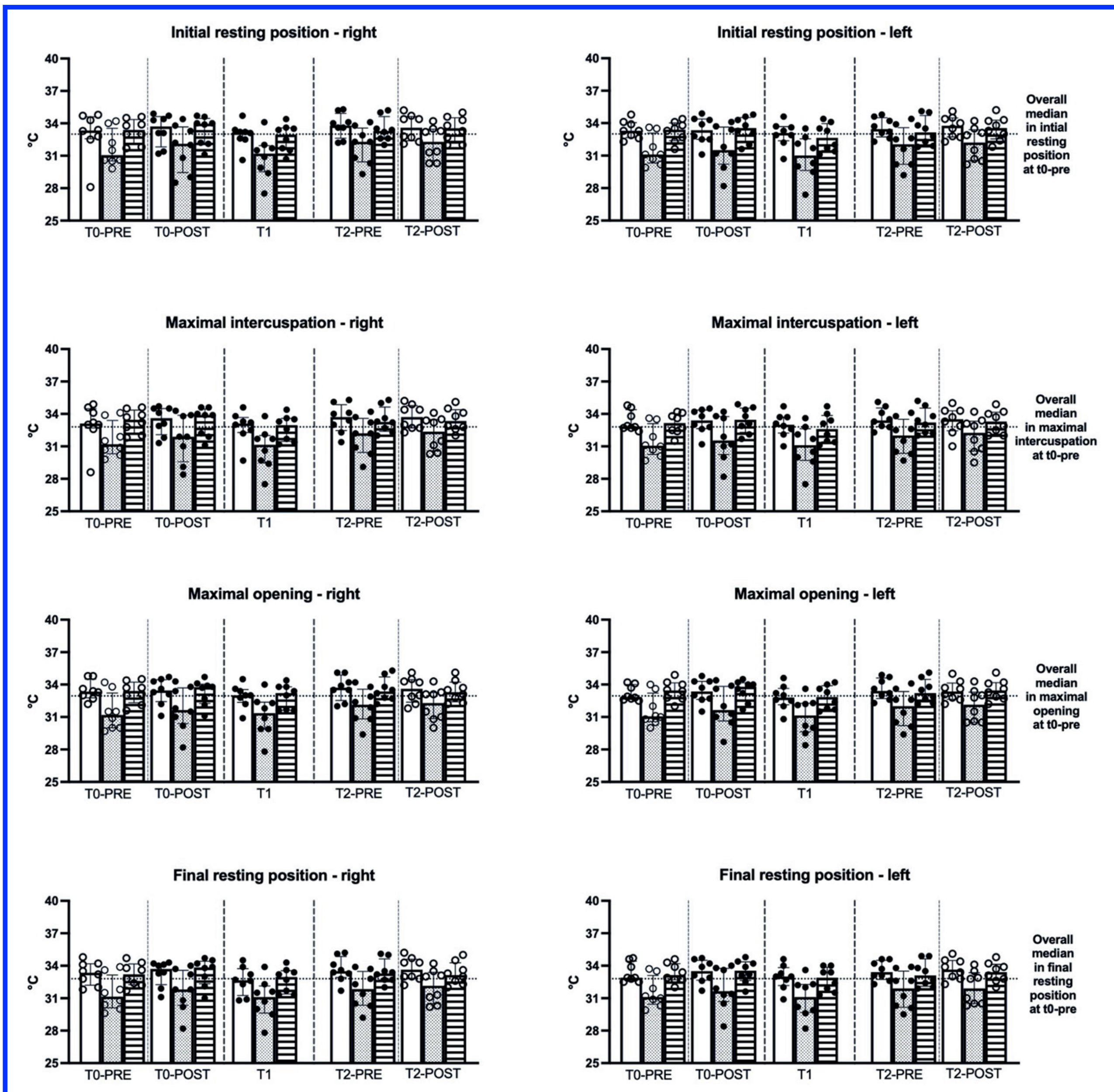

Figure 7. *Results of thermography. The white columns refer to temporal muscle area, the grey columns to masseter muscle area, the stripped columns to sternocleidomastoid muscle area.*

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the development of motor function or the pressure exerted during grapho-motor tasks among the participants. Consequently, the enhancement in occlusion, attributable to the RPE, as evidenced by these preliminary findings, did not manifestly modify motor functions or motor symmetry in children who were not afflicted by coordination dysfunction.

The orofacial area is particularly challenged by the growth and development of the jaws and the transition from primary to permanent dentition[44] and children have a characteristic chewing pattern whose movement parameters (jaw opening and closing velocities) change as age increases.[45] In children with normal occlusion have shown that chewing and jaw motor skills develop gradually with age.[46] The present study investigates the hypothesis that orthodontic treatment contributes to the restoration of this neuromotor development while affecting motor functions and any muscular asymmetries that may lead to problems with writing. In the clinical practice of dentists, the use of these fine motor assessments can significantly serve as "sentinels" to detect, if any, early writing deficits or motor dysfunctions that can affect the quality of life of children, their cognitive abilities and their developmental trajectories. There remain to ascertain whether orthodontic interventions result in enduring alterations in fine motor capabilities, such as handwriting.

Our results showed a lower relative temperature of the masseter muscle. This result is in accordance with the electromyographic findings, which indicated that the masseter muscle exhibited reduced activity in comparison to the temporalis muscle during the course of the measurements. Indeed, a considerable body of research has been dedicated to the investigation of asymmetric muscle activation in patients exhibiting various malocclusions, including unilateral cross-bite. A substantial increase in the asymmetry index in relation to the activity of the temporal and masseter muscles in patients with unilateral cross-bite has been demonstrated.[47]

A study by Alarcón and colleagues sought to establish a correlation between malocclusion and electrical activity of muscles; the study population comprised 30 subjects with unilateral cross-bite in the test group and 30 healthy subjects in the control group; the results showed that masseter activity was lower in those with malocclusion.[48] This finding aligns with the results of our experimental study, which demonstrated a predominant temporal activity, as evidenced by both electromyographic and thermographic recordings. Notably, the temperature consistently exceeded that of the masseter muscle. The masseter temperature exhibited an incremental rise over the course of the six-month period following device cementation, from T0 to T2. This finding aligns with the implications arising from the resolution of malocclusion, as the temporal musculature exhibits certain disadvantages, including reduced functional stress, incomplete development of the bone structure, more superficial mastication of food, inadequate mandibular advancement, modest abrasion of the deciduous, uncertain position of the first molars, which are not guided by the musculature in the correct first-class relationship, and a greater tendency to second-class due to incorrect growth stimulation on the condyle.

Limitations of the study

As a pragmatic trial, this study relied on a small sample size (herein a bit heterogeneous), included complex interventions, consisted of several interacting components, and involved the skills and experience of health care professionals and scholars to deliver the intervention and conducting the functional tests, all features that inherently limit the ability to answer clinical questions of interest and robustly infer insights. The relatively low sample size and the huge age range of our study may have indeed affected the results. By carrying out postural assessments a priori both in a seated and standing position would make possible integrative assessments. Moreover, the lack of case-controls affects the real predictability of changes in the parameters before and after orthodontic treatment.

The temporal framework employed in this study is not negligible in the context of developmental age, as the rapidity of biological changes may have exerted an influence on the variables. This phenomenon is evidently discernible for handgrip strength, which exhibited an upward trend, thus interpreted as an improvement contingent on developmental trajectories. However, for the other variables, the potential for enhancement is not as readily hypothesised and modelled.

Perspectives and conclusions

Poor posture and altered dental occlusion have been associated with increased muscle tension in the head and neck, leading to changes in the position of the shoulders, arms, and hands during handwriting, along with possible influences on the strength and coordination of the muscles involved in handwriting, leading to putative changes in the quality and speed of writing.

It can thus be concluded that the positive results recorded at the occlusal level using the palatal expansion device were not accompanied by changes at the muscular and motor levels. It is important to note, however, that the participants included in the study were limited in number and did not have any known pathologies at the muscular or motor level. Future studies could aim to compare groups of patients with and without such limitations to determine whether improvements in pathological conditions occur. Furthermore, the sample analyzed was treated during the most favorable period for malocclusion resolution: during the developmental age. A subsequent study could involve the analysis of adult subjects, in whom deviations from normal occlusion have already caused compensations and muscular problems. This would involve analyzing the muscular response starting from an initial non-physiological condition.

Our data showed how the use of a tablet computer in figure tracing could be useful even in the daily clinical practice of dentists. It can help to identify problems related to children's fine motor skills, to be integrated with evidence on body posture. Postural analyses showed a non-homogeneity of the plantar pressure on the side of the crossbite. This highlights the direct correlation of alteration of the forces exerted due to the malocclusion. It would be interesting to investigate whether scoliotic disorders and/or orthodontic diseases in children can affect the strength and coordination of the muscles involved in handwriting. This could lead to changes in the quality, kinematics and dynamics of handwriting itself. Despite extensive research on the links between handwriting, human posture and dental occlusion, there is still much to be understood about the mechanisms underlying these relationships.

Contributions

Conceptualization, Chiara Lopes, Rossana Pipitone, Danilo Bondi, and Michele D'Attilio; methodology, Chiara Lopes, Rossana Pipitone, Danilo Bondi, Moreno D'Amico, and Michele D'Attilio; software, Anacleto Navangione; formal analysis, Chiara Lopes, Rossana Pipitone, and Danilo Bondi; investigation, Chiara Lopes, Rossana Pipitone, Imena Rexhepi, Moreno D'Amico, Lucia Lazetera, Ludovica Valentino, Danilo Bondi, Edyta Kinel, Beatrice Di Carlo, and Michele D'Attilio; resources, Moreno D'Amico, Bruna Sinjari, Anacleto Navangione, Stefania Fulle, Tiziana Pietrangelo, and Michele D'Attilio; data curation, Chiara Lopes, Rossana Pipitone, Moreno D'Amico, and Danilo Bondi; writing—original draft preparation, Chiara Lopes, Rossana Pipitone, Imena Rexhepi, and Danilo Bondi; writing—review and editing, Moreno D'Amico, Lucia Lazetera, Ludovica Valentino, Edyta Kinel, Beatrice Di Carlo, Bruna Sinjari, Anacleto Navangione, Stefania Fulle, Tiziana Pietrangelo, and Michele D'Attilio; visualization, Chiara Lopes, Rossana Pipitone, Imena Rexhepi, and Danilo Bondi; supervision, Tiziana Pietrangelo and Michele D'Attilio; project administration, Michele D'Attilio; all authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

Ethics approval

The study was conducted in accordance with the Declaration of Helsinki and approved by the local Ethics Committee (protocol n4-04052017). Informed consent was obtained from children's parents involved in the study.

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Data availability statement

Data will be available upon reasonable request.

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