Are changes in the stomatognatic system able to modify the eye balance in dyslexia?

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ABSTRACT

Objectives: To clarify the link between eye muscle function and oral information by comparing 21 dyslexic readers (DR) and 14 normal readers (NR).

Methods: Changes in vertical heterophoria (VH) were measured using the Maddox Rod Test performed according to oral modifications and postural conditions. The Spearman correlation was used to assess whether reading delay was correlated with the lability index.

Results: Overall, 50% of NR children and 81% of DR experienced at least one variation in visual perception ($p = 0.053$). Among DR, the less reading delay they had, the higher their index of lability ($p = 0.026$), whereas there was no significant correlation among NR. Changes in the Maddox Test were more frequent in DR than in NR after the addition of sensory and postural stimuli, except for one specific posture. For sensory stimuli, the mean lability index was 1.35 in NR and 4.19 in DR, ($p = 0.001$). For postural stimuli, it was 0.71 and 2.61, ($p = 0.003$).

Conclusions: It is possible to modify visual perception by changing sensory or mechanical stimuli. Changes are more frequent in DR than in NR. Postural control can be improved with guided oral stimulations.

Significance: These results reinforce the importance of professional cooperation in the care of dyslexic readers.

1. Introduction

Developmental dyslexia is a specific learning difficulty that primarily affects the skills involved in accurate and fluent reading and spelling. It is generally considered to be the result of specific impairments relative to phonological representation. It is characterized by difficulties with processing speed, working memory and rapid naming, and is not influenced by exogenous factors such as lack of intelligence or educational access. Dyslexia affects around 10% of the population and is categorized into three distinct clinical types\textsuperscript{a}:

i) Surface: difficulty in recognizing the visual form of written words, especially if they are irregular,
ii) Phonological: a specific inability to handle speech sounds and the graphene-phoneme conversion,
iii) Mixed: the most frequent type, combining surface and phonological anomalies.

Previous studies have emphasized that children with dyslexia may have multi-deficit disorders including deficits in the auditory, visual and motor system.\textsuperscript{7} Among dyslexics, abnormal motor skills can be expressed by anomalies in body tone and posture.\textsuperscript{5,6} Other peculiarities can affect the fine motor skills, especially the ocular and oral muscles.\textsuperscript{5,6}

Reading is a complex oculomotor and cognitive activity whose exact mechanisms are still poorly understood. Eye movements must be very precise to allow the visual capture of written words by fixing the center of both retinas (fovea) at a particular location within the word designated as the center of gravity of the word. Concerning muscular function, this position is coded from the efferent oculomotor control information and from the afferent proprioceptive information originating in the eye muscles, although the relative importance of each of these two elements remains unknown.\textsuperscript{7} Ocular proprioception, which depends on the trigeminal nerve, is primarily used for error correction and to modulate visual attention.\textsuperscript{7} Abnormal ocular muscle function could be responsible of binocular dyscoordination during reading.\textsuperscript{7}
dyslexia, coordination disorders affect horizontal but also oblique and vertical eye movements.9

Fine oral articulatory movements are crucial for the appropriate production of sounds when reading aloud. Beyond their local motor action, they also have an important role in the perception of sound units.10 That is why, according to the motor theory of speech perception proposed by Liberman, abnormal oral muscle function could play a role in phonological dysfunction which is one of the main characteristic of dyslexia.11

This idea is at the origin of the motor-articulatory feedback hypothesis of developmental dyslexia which suggests that phonological awareness may be linked to an abnormal production of intended oral articulatory gestures.12 We thus attempted to clarify the link between eye muscle function and oral information, using two indicators: heterophoria, taken as a measure of coupling of the eyes during a visual task and dental information as a trigeminal mechanical input.

The purpose of this exploratory study was to compare a group of dyslexic readers (DR) to a group of normal readers (NR) in order to answer the following questions:

1. Is it possible to modify visual perception by modifying oral sensory information?
2. Do these changes vary for DR and NR?
3. Is there a difference in response when the stimuli is sensory or mechanical?
4. Is there a relationship between the lability of the visual axes and changes in oral, spinal or podal positions?
5. Could the mouth be a link between the ocular and phonological signs of dyslexia?

2. Subjects and methods

2.1. Participants

Children were recruited during pediatric ophthalmological consultation. Exclusion criteria were: a history of neurological, psychiatric or genetic disease, delayed surgery or abnormal psychomotor development, IQ below 85, orthodontic treatment in progress, children under psychotropic treatment (especially drugs from the phenylethylamine group or anti-epileptics). After consent was obtained from the children and their parents, they were tested within the guidelines of the declaration of Helsinki. Children with a visual acuity of 20/20 in both eyes with no refractive error and no organic abnormalities of the anterior or posterior segments were retained. Children with the following visual features were excluded: strabismus with or without surgery, orthoptic rehabilitation in progress, re-educated amblyopia, stereopsis > 100 s. The inclusion criteria for the dyslexic children were a documented diagnosis of dyslexia and a score of at least 24 months of reading delay on the WWIT/TIME 3 test (Written Word Identification Test).13 This test identifies the decoding skills and the comprehension and spelling of 40 words for children aged 7 to 15. In the group of dyslexic children only, the use of the Odedys Battery helped classify the type of dyslexia.14

Children were recruited from consecutive consultations. A total of 35 children fulfilled the inclusion criteria: 21 DR children (11 males and 10 females) participated in the study and were compared with a group of 14 NR children (9 males and 5 females). The average delay in reading months was 11 ± 9 months in the DR group. Odedys tests found mixed dyslexia for all the dyslexic children.

When the latter is impaired, the eye axes tend to deviate slightly. This deviation is called heterophoria. The parallelism of the ocular axes is almost perfect in the vertical plane (0.12° of deviation) and the natural compensation possibilities are very low. This is why we studied vertical heterophoria (HV) while the oral information changed, either by sensorimotor variations in the tongue or lips, or by mechanical variations of the dental occlusion. As the eyes and the mouth are established sensors influencing the postural regulation, we also investigated the influence of four different bodily positions on lability.15,16

2.2.2. Oral modifications

The test was performed using five well-defined oral conditions (Movie 1).

- Three conditions that do not affect dental occlusion:
  - the tip of the tongue firmly touching the central retro-incisor papillae
  - the lips tightly closed
  - the tip of the tongue planted against the lower incisors
- Two conditions that modify dental occlusion:
  - dental rolls between the molars
  - use of a dental splint.

2.2.3. Postural modifications

The five oral modifications described were done in four different postures:

- child sitting in a spontaneous and natural position without plantar support
- sitting straight up without plantar support
- standing in a natural position to add the information from the
Notes: Thumb up represents red line above the light, horizontal thumb represents red line strictly in the center of the light, and thumb downward represents red line under the light.

Fig. 1. How to indicate the position of the red line without changing information from the mouth.

- plantar sole with the mouth also in a natural position
- standing with a foam insole between the foot and the ground to decrease exteroceptive plantar information

At the end of the test, in each postural condition, an index of lability was created. It matches the number of times, as a result of a modification, that the VH changed when compared with the previous situation (see example Table 1). For each postural condition the index is thus between 0 and 5:

- 0 corresponds to no modification of the position of the red line,
- 5 corresponds to a modification of position of the red line in front of the right eye and/or the left eye for each of the oral stimulations, the result being compared to the position just before. Whether the line is above, below, or in the center of the light is not taken into account.

2.3. Statistical analysis

All studied parameters were collected for the 35 children. Univariate analyses that compared the characteristics of DR and NR children were done with i) Chi2 test for qualitative variables, ii) Student’s T test for quantitative variables after validation of homoscedasticity using Bartlett’s test. The normality of distribution was assessed with Shapiro-Wilk test. The Spearman correlation coefficient was used to assess whether reading delay was correlated with lability index. P < 0.05 was considered statistically significant. All statistical analyses were performed with Stata Statistical Software V.1.5.

3. Results

The proportion of DR and NR children did not significantly vary with sex (55% DR in boys vs 67% in girls, p = 0.486). Mean age was 125.0 months (SE ± 7.1) for normal readers and 134.6 months (SE ± 4.8) for dyslexics (p = 0.258).

Overall, 69% of children presented at least one change in visual perception using the Maddox Rod Test when the oral information was modified, whatever the stimulation. This proportion was 50% in NR and 81% in DR (p = 0.053). Considering the whole population, the index of lability varied significantly with the group of children: it was on average 9.76 (95% CI: [7.04–12.47] in DR and 4.21 (95% CI: [1.33–4.97]) in NR (p = 0.007).

We tested the relation between reading delay and index of lability: in DR, the Spearman correlation coefficient was 0.483 (p = 0.026). Among DR, the less reading delay they had, the higher their index of lability. In NR, there was no statistical correlation between literacy level and index of lability.

The proportion of children whose results on the Maddox Rod Test changed was significantly higher in the DR group than in the NR group after the introduction of sensory stimuli: tongue normally held in the mouth (p = 0.002), tongue firmly touching the central retro-incisor papillae (p < 0.001), and lips tightly closed (p = 0.005). The tip of the tongue pushing against the lower incisors had no significant effect (p = 0.091) (Table 2). The results were similar after the introduction of mechanical stimuli: dental occlusion modified by dental rolls between the molars (p = 0.009) or using a dental splint (p = 0.004).

The response to the Maddox Rod Test similarly varied whether the stimuli were sensory or mechanical. For the three tests, the mean lability index was 1.35 (95% CI: [0.38–2.33]) in normal readers and 4.19 (95% CI: [3.01–5.36] in dyslexics, (p = 0.001). For mechanical stimuli, the mean was 0.71 (95% CI: [0.01–1.44]) for NR, and 2.61 (95% CI: [1.70–3.53] for DR, (p = 0.003). The index of lability was thus 2 to 3 times higher in dyslexic children whatever the type of stimuli.

The lability caused by changes in the spinal and podal sensors differed for a given oral condition. The proportion of DR presenting at least 1 modification of VH with the Maddox test was significantly higher than for NR when the oral modifications were performed in patients sitting in natural position (p = 0.005), sitting straight up (p = 0.036), or standing in a natural position with the mouth also in a natural position (p = 0.035) (Table 3). Standing with a foam insole between the foot and the ground had no significant influence. Conversely, the lability caused by changes in the oral sensor differed for a given spinal or podal condition.

4. Discussion

The main results of this study strongly suggest that manipulation of oral conditions modify visual perception and that changes affect differentially dyslexic children than normal readers.

Global effect of oral stimulations on the visual axis: Using the Maddox rod test, which weakens the binocular balance, we demonstrated for the first time that it is possible to modify visual perception by changing the oral sensory information for 69% of dyslexic and non-dyslexic children. Changes were significantly more frequent in the dyslexic population, and the variation (lability) was drastically higher in dyslexics. The
mechanism of the variation of the ocular axes remains unclear. The quality of the images was not changed during the oral manipulation. However, it should be noted that the quality of the binocular balance depends not only on the fusing of the retinal images of both eyes but also on maintaining the tone of the ocular muscles. This tone is regulated by the internal monitoring of the innervations sent to the muscles (efference copy) with the afferent proprioceptive discharge. The role of eye proprioception discharge is enhanced for visual localization when there is a conflict with the oculomotor plan perception, as was the case in our study. Because proprioceptive information from the eye muscles is carried by the upper branch of the trigeminal nerve, it is therefore not so surprising that oral changes may interfere when ocular

Table 1
Example of calculating the index of lability (postural condition = sitting in natural position without oral modification).

<table>
<thead>
<tr>
<th>Condition: SITTING IN NATURAL POSITION WITH NO ORAL MODIFICATION</th>
<th>Tip of the tongue planted against the lower incisors</th>
<th>Dental rolls between the molars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Points for stability index</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Normal readers</td>
<td>0 change</td>
<td>93%</td>
</tr>
<tr>
<td>≥ 1 change</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Dyslectic readers</td>
<td>0 change</td>
<td>71%</td>
</tr>
<tr>
<td>≥ 1 change</td>
<td>29%</td>
<td>29%</td>
</tr>
</tbody>
</table>

Abbreviations: O, line in the middle of the light; h, line over the light; H, line under the light.

Table 2
Comparison between normal readers and dyslexic readers for changes in vertical heterophoria measured using a Maddox Rod Test according to oral conditions.

<table>
<thead>
<tr>
<th>Oral condition</th>
<th>Normal readers</th>
<th>Dyslectic readers</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 1 change</td>
<td>14%</td>
<td>67%</td>
</tr>
<tr>
<td>0 change</td>
<td>86%</td>
<td>33%</td>
</tr>
</tbody>
</table>

Abbreviation: VH, visual heterophoria.

Table 3
Comparison between normal readers and dyslexic readers for changes in vertical heterophoria measured with the Maddox Rod Test according to spinal and podal then oral sensors.

<table>
<thead>
<tr>
<th>Sensors</th>
<th>Normal readers</th>
<th>Dyslectic readers</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥ 1 change</td>
<td>29%</td>
<td>71%</td>
</tr>
<tr>
<td>0 change</td>
<td>71%</td>
<td>29%</td>
</tr>
</tbody>
</table>

Abbreviation: CHI2, chi-squared test.

balance is unstable because of changes in retinal fusion.

Specific effects of oral stimulations on visual axis: each of the oral stimuli led to a huge difference between normal readers and dyslexics, except for inferior incisor stimuli. Three of the oral modifications were located exclusively in the anterior part of the mouth and were chosen because their effect is supposed to be more sensory than mechanical:

1) the tip of the tongue firmly touching the central retro-incisor papillae stimulates recovery of a corporal postural reflex related to contact with the lingual and palatine mucosa,

2) the stimulation of the facial nerve with lips tightly closed has an antagonist action on the trigeminal nerve (Bratzlavsky reflex),

3) the tip of the tongue planted against the lower incisors mechanically stimulates the periodontal ligaments that may be involved in one aspect of the feeling of body ownership.

Compared to stimuli involving the tongue and the lips, the action of the other stimuli was located further back between the molars (dental rolls) or the entire dental arch (splint). They are supposed to have a stronger action on the temporomandibular joint and its proprioceptive sensors, and modify occlusion intensely. Their action is obviously more mechanical, and the stimulation of the periodontal ligaments is more global and less precise. However, in our study, the effect on the visual axis was not different. This suggests that any action in the mouth is likely to have an impact on visual perception when the binocular balance is unstable.

Oral stimulations and posture regulation: the lability of the ocular effect depends on changes on spinal and podal sensation. This dependence was significantly more marked for dyslexic children and higher after oral stimulation. These results suggest the existence of links between eye stability, trigeminal information and postural regulation. They also suggest that these links could be more unstable in dyslexia. Postural adjustments use feed-back and feed-forward mechanisms. Feed-back information includes several types of afferent inputs: exteroceptive (skin sensitivity in the feet), proprioceptive (especially from the cervical, hip, ankle, and knee joints), vestibular (utriculus, sacculus, semicircular canals), and visual (retinal and muscle proprioception). For visual inputs, retinal flow, efferece copy and extraocular muscle afferent information consecutive to eye movements operate congruently. Interestingly, the presence of small vertical eye deviation like VH can alter postural balance in young healthy adults and VH correction improves postural stability. Thus the appearance of a small vertical deviation of ocular axes during oral changes could be one of the mechanisms connecting the mouth modifications and postural imbalances. This phenomenon could be explained by the narrow relationship between the muscles of the eye and mouth in the trigeminal nerve nucleus. Indeed, the sensory neurons of extraocular muscles are present as along with the primary afferent neurons associated with muscles for chewing, tooth pulp, and periodontal ligaments. There are also direct links between the trigeminal nucleus and the superior colliculus which receives visual, somesthetic, and proprioceptive af- ferent fibers and is involved in posture control and gaze movements.

The link between VH and sensory oral modification is interesting because in the scientific literature, the relationship between the stomatognathic system and posture regulation is mainly centered on the responsibility of malocclusion or temporomandibular joint pathology, that is to say mechanical dysfunction. The stomatognathic system, which is composed of muscle and ligament structures linked to the cervical region, is considered a functional complex known as the “craniocervico-mandibular system". A change in the position of the mandible may affect the center of foot pressure (COP) position and gait stability. In this case, proprioceptive and periodontal afference is sometimes said to be responsible, but mostly the mechanism is thought to be predominantly mechanical though it has been shown that anesthesia of the lower branch of the trigeminal nerve causes postural imbalance. Nevertheless, the importance of mechanical
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References
