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Modalities of reading acquisition in three siblings with infantile-onset saccade initiation delay (Cogan congenital ocular motor apraxia): A longitudinal study

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ABSTRACT

This study aims to ascertain the impact of congenital ocular motor apraxia (COMA), alternatively called infantile-onset saccade initiation delay (ISID), on reading acquisition. More specifically, the consequence of defective initiation of horizontal saccades during reading acquisition was investigated. Three siblings (A: male, 11y3m at the first time-point of testing (i.e. T1 hereafter); B: female, 7y3m at T1 and C: male, 5y9m at T1) suffering from ISID were assessed longitudinally over 3 years in various reading tests and their eye movements simultaneously registered. At each time-point, they were compared to control participants matched on reading level. Eye movements during reading tasks were markedly abnormal in children with ISID at the beginning of reading acquisition and their reading scores were poor. With time, the number of fixations, small amplitude saccades and their reading abilities became comparable to those of control children. Despite the abnormal eye movements and difficulties in specifically directing the eyes to the appropriate position, children with ISID do not seem to encounter major difficulties during reading acquisition, although mild delays might be observed during the early stages.

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1. Introduction

In 1952, Cogan described an isolated developmental gaze disorder and suggested the name congenital ocular motor apraxia (COMA).[1] This disorder is typically characterized by the inability to initiate voluntary horizontal saccades, while reflexive saccades obtained by the optokinetic and vestibulo-ocular reflexes may remain intact.[2] Since both voluntary and reflexive horizontal saccades are commonly impaired in this condition, Salman has argued that the term "apraxia" is inaccurate and this entity has been renamed Infantile-Onset Saccade Initiation Delay (ISID).[3,4] From early on, children with ISID tend to compensate by initiating horizontal saccades by jerky head movements and/or eye blinking.[4] Usually, the head movement begins just before or synchronously with the saccade initiation. Impaired initiation of saccades, labeled "ocular motor "apraxia" can also be seen in a variety of neurological disorders such as Gaucher disease and Ataxia Telangiectasia.[4] It is also a cardinal ocular manifestation of Joubert Syndrome and related disorders (JSRDs), and some children labeled initially as having "COMA" have later been shown by imaging (MRI) to belong to the JSRD spectrum, raising the question as to whether COMA/ISID exists as a true distinct and isolated entity.[5,6] On imaging, all children with JSRD have in common a complex midbrain/hindbrain malformation responsible for an easily identified MRI landmark, the molar tooth sign.[7] In contrast, children with ISID have been found to have either normal MRI or subtle structural abnormality also involving the cerebellar vermis, a finding compatible with the important role of the vermis in the processing of saccades.[6,8–12]

While cognitive impairment is well reported in children with JSRD, the impact of ISID alone on cognitive development and scholastic skills has been poorly documented. Previous studies comprise case reports or case series without any detailed assessment of cognitive and academic skills. Marr and colleagues reported that 11 of the 14 patients diagnosed with ISID without associated abnormalities had delays in motor, language, social behavior or academic areas.[13] Language areas (i.e. production and comprehension skills) were particularly affected. Kondo and colleagues also reported motor, speech and reading delays in the majority of children.[9] These findings are in line with previous reports (Table 1).[9,13–17] Difficulties in learning to read were often reported in children suffering from ISID, but to our knowledge, there has been no study formally investigating this issue, by including reading assessment into the protocol. Beyond the learning to read process in children with ISID, studying these children in detail can give valuable insights into the importance of ocular saccades in reading acquisition.[18–20]

Before becoming words bearing meaning, sequences of letters are seen as isolated visual entities and it is explicit reading instruction, mostly based on letter–sounds relationship (phonics) - that will gradually accord them meaning. Indeed, at first, for phonetic reading, the child needs to recognize the individual letters that make up each word. Progressively, with the acquisition of the letter-sound mappings, the child becomes able to decode the word and access the meaning through the activation of the phonological form. In order to recognize letters, the child also needs to master specific eye movements during the learning to read process: fixations and saccades.[18] Because visual acuity drops off rapidly outside the fovea, the reader needs to make optimal eye movements that bring relevant information into foveal vision.[20] This is why novice readers make many fixations and saccades of small amplitude, whereas skilled readers make few of them, typically landing every 7–8 space characters.[20] Skilled readers can recognize a word rapidly, using the length of the word, some of its characters and the context of the sentence, to predict upcoming words. When words are presented alone, without context, readers need to land the fixation on the optimal viewing position (OVP), which represents the position in which the whole word can be seen in both foveal and parafoveal vision. It is usually situated one character to the left of the center of the word.[21]

Based on this theoretical framework, we can expect children with ISID to demonstrate difficulties in landing their eyes on the OVP during isolated word reading, leading to reduced reading fluency and abnormal eye movements during text reading. The present study aims to investigate these assumptions and to describe the development of reading skills in three siblings affected by ISID.

2. Material and methods

Three siblings affected by ISID were recruited: A, B and C. All participants were diagnosed in infancy with ISID by two of the authors (JF, RdH). Brain MRIs of child A and B have been previously reported.[6] Interestingly, in child A, the eldest son of the family, the midbrain-hindbrain morphology was consistent with the molar tooth sign (MTS), while his sister (child B) has only subtle findings, with mild asymmetrical elongated

Table 1 – Associated learning impairments in ISID/COMA patients.

Study	Type	Participants (n)	Age range	Reading difficulties	Speech delay	Motor delay	Academic difficulties
Fielder et al.[15]	Case report	9 patients		NA	9/9	9/9	NA
Harris et al.[17]	Case report	2 siblings	10–11 y	2/2	1/2	2/2	2/2
Jan et al.[16]	Case report with speech and cognitive assessment	8 children	6–16 y	NA	4/8	NA	8/8
Philips et al.[14]	Case report	4 siblings and their father	3–10 y	Father	No information		
Marr et al.[13]	Retrospective case-note study	14 children	0–13 y	3/14	6/14	10/14	4/14
Kondo et al.[9]	Case report	10 patients	4–37 y	5/10	6/10	7/10	5/10

cerebellar peduncles (Fig. 1). No MRI was performed in child C. None of the siblings had any neurological or systemic signs that could be in line with JSRD.

All three siblings presented with early onset (first weeks of life) abnormal horizontal gaze movements. Patient A and patient B showed head nodding in the first few weeks of life that disappeared during infancy. Head thrusts were efficiently used to drag the gaze on to the fixation stimulus by age six months; eye blinking, and sometimes discrete horizontal mandibular displacement, appeared later, facilitating saccade initiation. In patient A, head thrusts were asymmetrical and related to asymmetric defect of horizontal saccades; in fact whole body turns to the right side were sometimes used to obtain proper fixation on to the target. In all three children, horizontal volitional saccades were most affected with markedly delayed initiation and multiple hypometric saccades. Reflexive saccades on light or noise stimulus were also affected, but to a lesser extent. Delay in initiating horizontal saccades was improved when the stimulus was repeated and memorized, although still abnormal. Horizontal vestibulo-ocular reflex (VOR) induced a gaze deviation («locked-up» gaze position) due to normal vestibular slow phase and missing correcting saccades. Correcting saccades were present in vertical VOR although hypometric. Pursuit gain was appreciated clinically as the ability to follow a moving target at an estimated speed of 30°/sec. Horizontal pursuit gain was decreased with frequent small amplitude catch-up saccades even for slow movement of the fixation target (markedly less than 30°/sec). Vertical pursuit was considered subnormal with less catch-up saccades at target speed estimated close to 30°/sec. Optokinetic nystagmus (OKN) showed markedly reduced gain of the slow phase and defective correcting saccades. Neither nystagmus nor strabismus was observed. In all three patients, convergence was reduced. Visual acuity and stereoscopy were normal.

On follow-up, all three patients showed improvement in their horizontal gaze movements, with less apparent head thrusts, nearly imperceptible blinking, decreased delay in initiation of horizontal saccades and more correcting saccades on VOR.

Neuropsychology assessment demonstrated preserved intellectual abilities in all three siblings, with heterogeneous developmental profile as shown in Table 2.

The three children underwent the same experiment in August 2015 (T1), October 2016 (T2) and May 2017 (T3). As child C was still in kindergarten at T1, and in the very beginning of Grade 1 at T2, the experiment was adapted and reading tasks were proposed at T3 only. Participants A, B and C were compared to control participants matched on reading level among a control group of 28 typically developed participants.

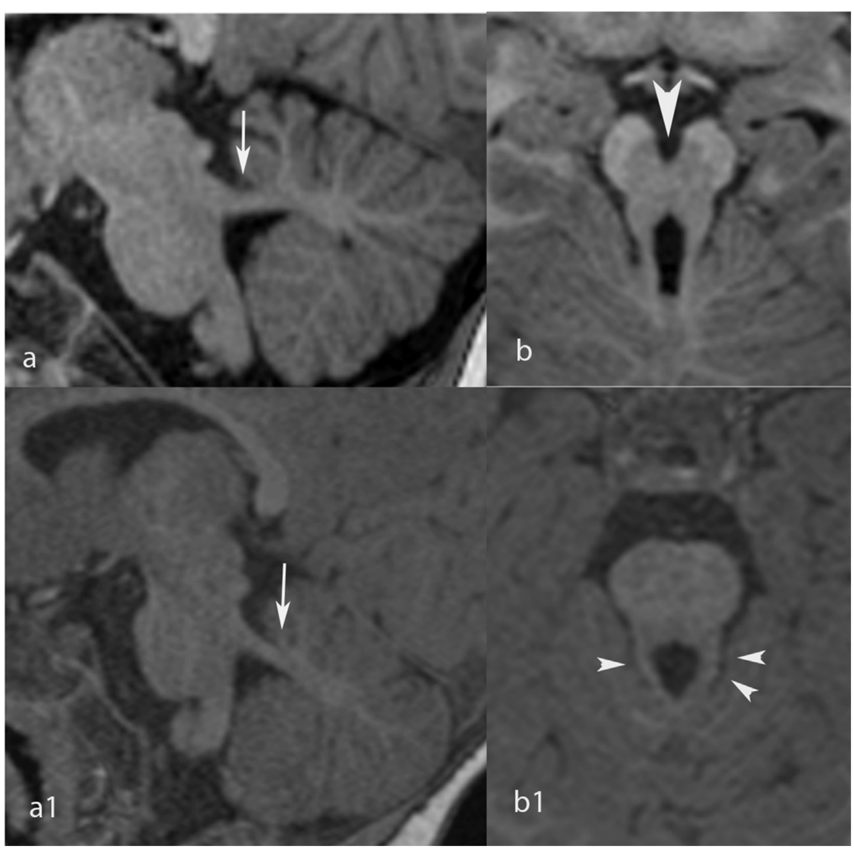

Fig. 1 – Images a and a1: sagittal T1W sequences at the level of the left superior cerebellar peduncles (SCP). Images b and b1: axial T1W sequences at the level of the interpeduncular fossa (b) and upper pons (b1). In subject A (a and b), the peduncles are symmetrically thick, elongated and horizontal (a arrow). In addition, there is a deep interpeduncular fossa (b arrowhead) In patient B, SCP are asymmetrically thick, left more than right (b1 arrowheads), less horizontalized and are mostly visible at the level of upper pons due to their orientation (a1 arrow).

Table 2 – Participants' information and reading scores.

Child	Gender	Learning difficulties	Cognitive skills		Age (y; m)	Text Reading	Regular words		Irregular words		Pseudo-words	
							Accuracy	Time	Accuracy	Time	Accuracy	Time
A	M	Mild attention deficit (under methylphenidate) and developmental coordination disorder manifested by clumsiness	IQ = 91	T1	11; 3	−0.53	0.33	−1.55	**−9.33**	**−4.98**	−0.12	−1.33
				T2	12; 5	−0.50	0.01	−0.65	0.44	−0.56	−0.44	0.17
				T3	13; 3	0.25	0.01	−0.38	0.44	−0.19	−0.44	−0.56
B	F	Isolated expressive language delay (speech-therapist intervention before T1)	IQ = 93	T1	7; 3	−1.71	**−3.06**	**−5.51**	**−5.58**	**−4.06**	−0.22	**−4.01**
				T2	8; 6	−1.65	−0.65	−0.52	**−3.36**	−0.34	0.12	−0.17
				T3	9; 4	−1.63	0.97	0.32	**−4.03**	−0.81	0.46	0.55
C	M	Isolated writing difficulties	Not assessed	T1	5; 9	NA	NA	NA	NA	NA	NA	NA
				T2	6; 11	NA	NA	NA	NA	NA	NA	NA
				T3	7; 9	−1.46	−0.10	−1.27	**−2.40**	−0.60	0.06	−1.04

Note. All scores are presented in z-scores, bold indicates scores below - 2 standard deviations.

Behavioral measures were converted into z-scores and Crawford's t-tests were used for eye-movement variables.

The project was approved by the local Ethical committee and parents' and children's written consent was collected at each time-point.

Three tasks (i.e. optimal viewing position, text reading and large amplitude saccades task) were performed under eye-tracking recording using the SMI device (SensoMotoric Instruments, "RED/RED250/RED500" http://www.smivision.com/en/eye-gaze-tracking-systems/products/red-red250-red500.html, 2011). Tasks were implemented in E-prime software (E-studio) in combination with the SMI device. Reaction times for the OVP task were extracted with speech-analysis software (Check-Vocal, Protopapas, 2007). Eye movement information was pre-analyzed and analyzed in Matlab (MATLAB and Statistics Toolbox Release 2012b, The MathWorks, Inc., Natick, Massachusetts, United States). For each task, fixation and saccade information was extracted from a continuous eye-movement recording during the task using the Hidden Markov Model algorithm (I-HMM).[22] The I-HMM algorithm calculates point-to-point velocities for each point in the protocol. Then, it decodes velocities to identify points as fixation or saccades points. The I-HMM collapses consecutive fixation points into a fixation group, the returned fixation information corresponds to the centroid of the map of each fixation group. Fixations were then defined as periods during which eyes are relatively still. Acceleration and velocity thresholds define onset and offsets. Saccades were defined as high velocity movements between two fixation points and were extracted from the continuous signal based on speed information (i.e. interval during which the eye's velocity exceed 40° per second). In the subsequent analyses, the number of fixations and saccades were used as dependent variables.

2.1. *Optimal viewing position (OVP)*

In this task, words are presented one by one at the center of a computer screen. Each word is preceded by a fixation cross displayed either in the upper left quadrant, the upper right quadrant, the lower left quadrant or the lower right quadrant of the screen. Children are instructed to pay attention to the cross and then read aloud the word as fast and accurately as they can. Forty words were presented allowing the recording of small amplitude saccades from the fixation cross to the word to be read. Between each trial, a central fixation cross was displayed on the screen. Eye movements and oral responses were recorded.

2.2. *Text reading with registered eye movements*

The French text "Le Géant Egoïste" from the Evaluation de La Fluence en Lecture battery (E.L.F.E, Lequette, Pouget, & Zorman, 2008) was used. The text is split in two parts and displayed on two screens in order to record eye movements. Children were asked to read the text. Aloud Eye movements and oral responses were recorded.

2.3. *Large amplitude saccades task*

Children were asked to name 4 isolated letters per screen as they appeared on the opposite side of the screen (i.e. from left to right and from up to down) in order to get information about large amplitude saccades (total number of letters = 28).

2.4. *Reading performances*

2.4.1. *Text reading*

A second text "Monsieur Petit" was borrowed from the E.L.F.E battery to evaluate reading fluency. The children were instructed to read it aloud and were stopped after 1 min. The text reading score was computed based on the number of words correctly read within 1-min and then converted into a z-score.

2.4.2. *Word list reading*

Three reading lists from the ODEDYS battery (ODEDYS2, Jacquier-Roux, Valdois, & Zorman, 2008) were used, containing either regular words, irregular words or pseudo-words. Each list comprised 20 stimuli organized in one column. For this test, two reading z-scores were computed: fluency and accuracy per list.

3. Results

Children A, B and C have increased their reading performances at each time point (Table 2). In the following section, we will present the eye movement results for each child.

3.1. *Participant A*

During the OVP task, at T1, A made on average 11.35 saccades per word whereas the control group (n = 6) made on average 1.40 saccades per word (σ = 0.70; Fig. 2). Concerning fixations, A made twice as many fixations as the control group. At T2, A's eye movements were still different from those of the control group (n = 4) with on average 14.75 saccades per words versus 1.69 saccades per word for the control group (σ = 6.13). However, the number of fixations was equivalent between A and the control group, at T2 (Fig. 3). Indeed, A made the same amount of fixations upon words in order to read them as the control group, but programming and executing saccades between fixations remained difficult and results in eye movements landing outside the screen between almost each fixation on the word. A did not look at the fixation-cross displayed before the word, in order to minimize both the number and the amplitude of the saccade to be initiated to read the word (Fig. 3). However, A demonstrates an improvement in saccade execution between T1 and T2 as his saccades duration (i.e. the time taken to complete the saccade) was on average 102 ms at T1, whereas at T2 their duration was 62 ms. The large amplitude saccade task at T3 revealed that A did initiate large amplitude saccades without moving the head, resulting in 84% of eye movements landing inside the screen during the task (Fig. 4). As for the OVP task, A did not look at the fixation cross prior to the letters and already landed his eyes on the upper left corner of the screen. However, in order to name 4 letters displayed on the screen, A made on average 22 fixations and 48 saccades which differs significantly from the control group (n = 6; on average 8 fixations (σ = 2.87) and 10 saccades (σ = 1.78) per trial). As for the OVP task, half of the fixations and saccades were located outside the screen (Fig. 4). During the text reading task, A is comparable to the control group at both T1 and T2 in terms of the number of saccades and number of fixations. However, we also observed saccades landing outside the screen, particularly on line changes.

3.2. *Participant B*

During the OVP task, B made on average 10.5 saccades per word at T1 and 14.45 at T2, whereas the control group made on average 1.8 saccades per word at T1 (n = 5; σ = 0.66) and 5.12 at T2 (n = 8; σ = 4.80). B gained in efficiency when executing saccades between T1 and T2. At T1, B's saccade duration (i.e. the time taken to complete the saccade) was on average 151 ms, while at T2 saccade duration was on average 74 ms. In sum, at T2, B made more saccades, but much shorter than at T1. Concerning fixations, B made fewer fixations than the control group at T1 (3.1 versus 4.75), because B tried to guess the word by only fixating the first two or three letters. At T2, B made 3.6 fixations per words, which is similar to the control group and, contrary to T1, B's fixations were all located within the word (Fig. 3). At T2, B did not guess the words and read them properly. At T1, B did look at the fixation-cross displayed prior to the word, but at T2 she did not and tried to keep her eyes on the middle of the screen, presumably as an adaptive strategy to reduce saccades programming (Fig. 3). We observed a similar strategy during the large amplitude saccades task at T3. Even without looking at the fixation cross, B encountered difficulties in this task. B still needed to move her head to initiate large amplitude saccades, resulting in 38% of eye movements falling outside the screen (Fig. 4). B also tended to use the parafoveal vision to its best advantage in order to reduce the amount of saccades and fixations (Fig. 4). On average, B made 17 fixations and 45 saccades in order to name 4 letters, where control children (n = 5) made on average 10 fixations (σ = 2.35) and 14 saccades (σ = 1.64). During text

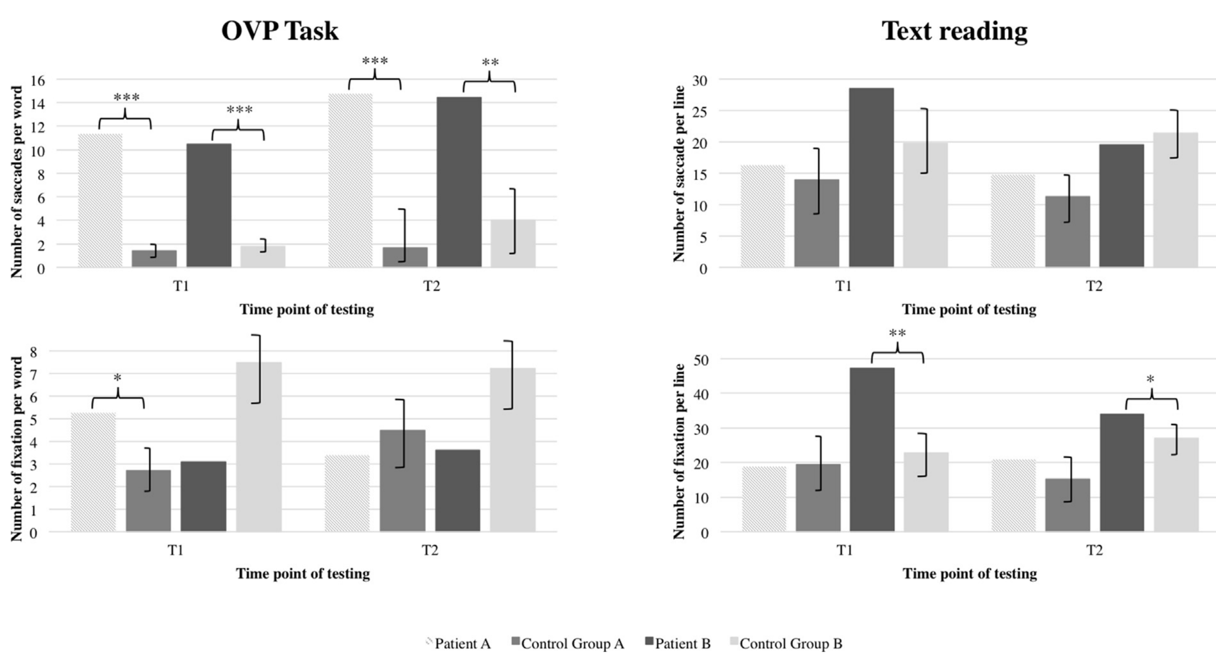

Fig. 2 – Number of fixation (upper panel) and saccade (lower panel) during the OVP (left panel) and Text reading (right panel) tasks for A and B and their respective control group at T1 and T2. Significant differences revealed by Crawford's t-tests are indicated on graphs. $^{***}p < .001$; $^{**}p < .01$; $^{*}p < .05$.

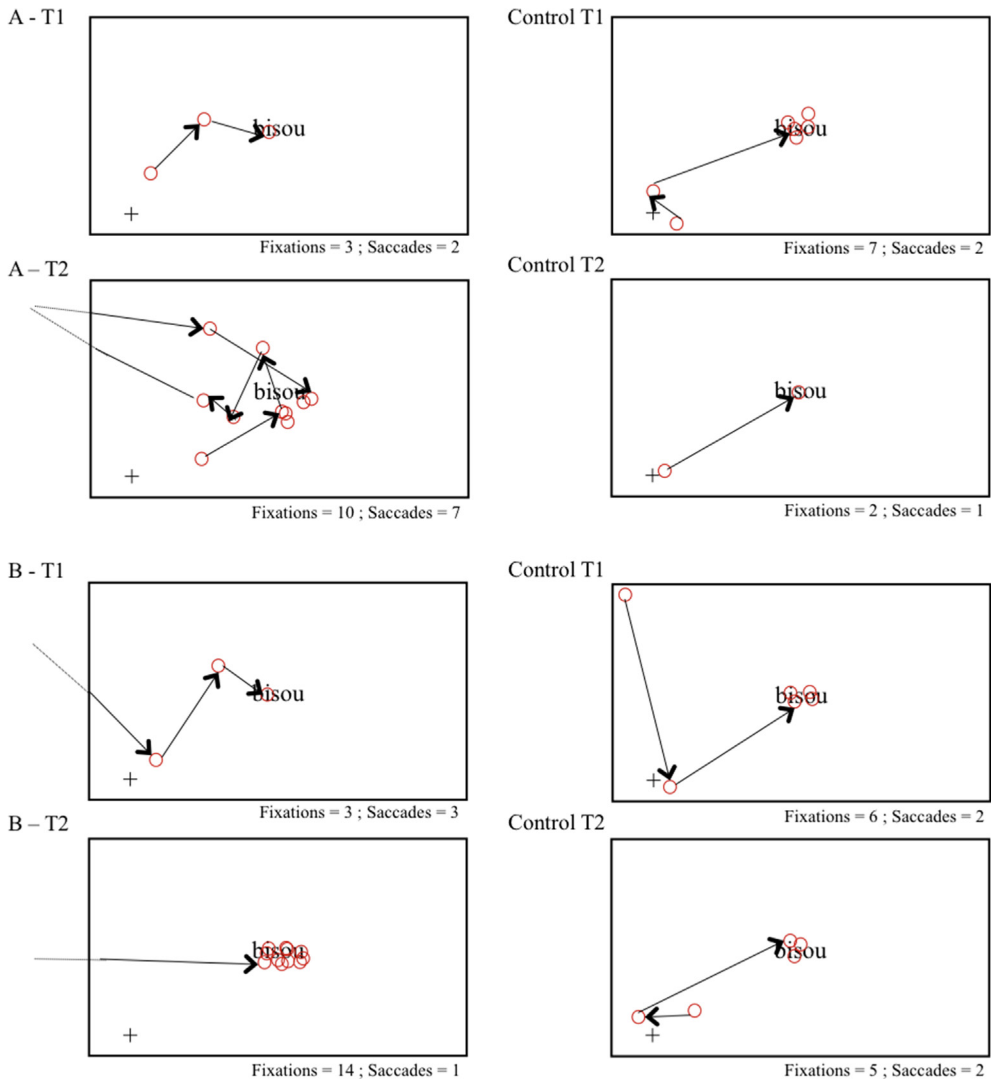

Fig. 3 – Illustration of saccades and fixations for the word "bisou" during the OVP task for A, B and a child from the control groups at T1 and T2. Saccades are displayed with arrows, fixations with red dots. Saccades falling or initiated out of the screen are represented by doted lines. The total number of saccades and fixations is indicated below each illustration. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

reading, at T1, B made twice as many saccades and fixations compared to the control group. At T2, the number of saccades and fixations fall within the control range. Like in child A, we observed a lot of saccades landing outside the screen on line changes.

3.3. *Participant C*

Eye movements at T2 during the OVP task were not interpretable for participant C. Actually C used major head movements in order to initiate saccades, which resulted in a constant signal loss by the eye-tracker. We did not manage to record fixations and saccades during the task. The text reading task was still too difficult at T2 for C. However, at T3, C performed the large amplitude saccades task under eye movements recording (Fig. 4). At T3, only 12% of the recorded eye movements landed onto the screen, the remaining 88% falling outside of the screen presumably due to the difficulty of programming appropriate saccades (Fig. 4). In order to name 4 letters, C was making on average 3.14 fixations and 22.71 saccades, and was producing letter names errors. C's reading scores at T3 fall within the normal range with the exception of irregular word reading, which scored at −2.40 σ.

4. Discussion

Three siblings affected by ISID[1] were followed during three years. At each time-point their reading abilities and their eye

[1] We have retained here the diagnosis of ISID in the absence of clinical signs in favor of JSRDs although some ophthalmological characteristics depicted in this family could indicate a "forme fruste" of JSRD. There is likely an overlap between these two entities that might by clarified by future genetic studies. We would like to emphasize that this controversy is beyond the scope of this article, which was essentially focused on the development of reading skills in the setting of atypical horizontal saccadic control.

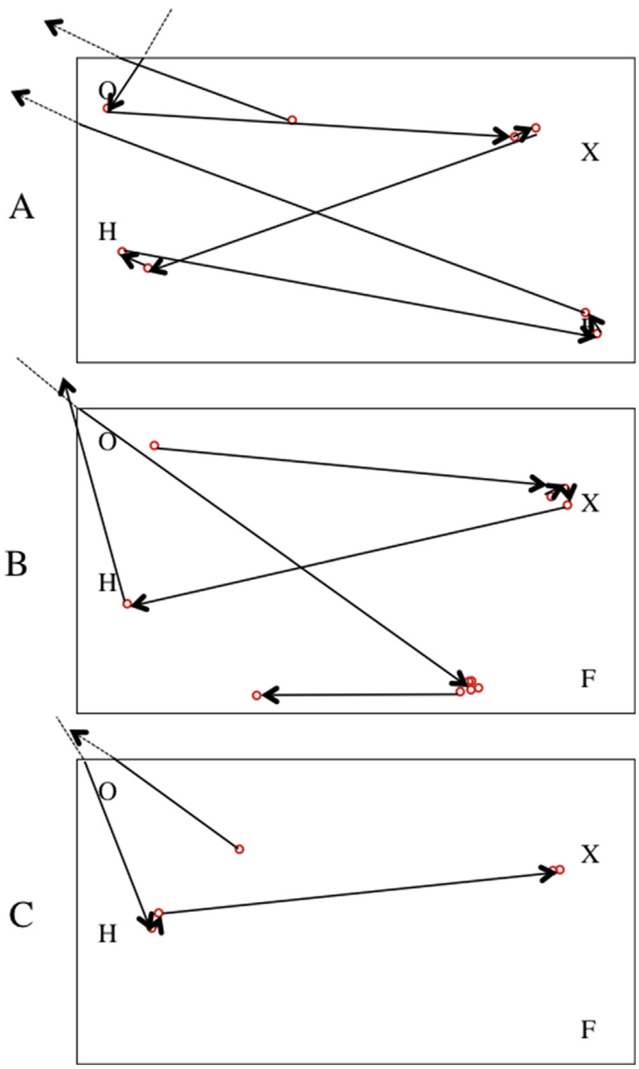

Fig. 4 – Illustration of eye-movements for A, B and C during the long distance saccade task. Fixations are represented by red circles, saccades by arrows. Saccades falling or initiated out of the screen are represented by doted lines. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

movements over isolated word reading and text reading were assessed.

We report here a significant intra-familial heterogeneity despite similar cardinal ophthalmological manifestations of ISID.

A, B and C do not present similar reading profiles, neither do they have the same associated developmental disorders. At T1, A reading scores were already within the normal range with the exception of irregular word reading. From T2, all reading scores were within the normal range and even above the mean for some of them. B suffered from a transient speech delay, which is known to impact reading abilities in the early grades.[23] However, reading scores on regular and pseudo-words fall within the normal range from T2, and text reading is in the inferior part of the normal distribution but non-pathological. Irregular word reading is still out of the normal range at T3 in terms of accuracy. Indeed, B always chose time over accuracy in timed tasks. During text reading, we observed the same strategy with many errors but a large number of words read in 1 min. B tends to rely heavily on context while reading and tries to guess the next word based on context and the first two letters. This is the strategy used by expert readers in order to gain in reading fluency. However, B does not have yet a large enough vocabulary to correctly guess the upcoming words. As a result, B continues to make a lot of errors and does not get a clear understanding of what is being read out loud. C could not be assessed on reading until T3, and presented typical reading scores at this time-point.

Interestingly, despite their difficulty in initiating horizontal saccades and their distinct phenotype, A B and C perform globally well on reading tasks. For each child, we observed more difficulties with irregular words in the early grades. This specific difficulty can be explained by the fact that the ocular motor behavior of A, B and C, although adaptive and allowing reading, is not fine enough in the early grades to grant a direct recognition of the orthographic form, i.e. the letter sequence that constitutes a given word. As irregular words cannot be read by letter-sound conversion, fixating the word in several places is not helpful. Irregular words need to be processed as a whole orthographic form linked with a specific phonological code. For children with ISID, the abnormal eye movements may hamper this immediate recognition of a whole orthographic form. This may explain why previous studies also reported reading delay in logographic writing systems[9] in which whole word recognition is employed from the outset.

Along with the progression on reading, their abnormal eye movements also tended to diminish with time. At the beginning of learning to read, the children in this study keep their use of head movements to initiate saccades. This behavior resulted in a high signal loss during eye-tracking recording for children B and C. Along with the head movements; saccades often fell out of the screen, which explains the large number of saccades. Interestingly, as they become older they seem to rely on another strategy – probably based on subtle movements of muscles around the eye, and/or eye blinking – resulting in far less head movement during reading. This could be due to the fact that reading does not require large amplitude saccades, but small amplitude ones. Small amplitude saccades might be easier to program and initiate for children with ISID. However, A does not seem to have difficulties with longer saccades, even if we can see an intensive use of the parafoveal information for naming letters. Indeed, A preferentially looked at the left side of the screen, on which fixations land on letters to be named. On the contrary, on the right side of the screen, saccades tend to land close to the letter, but not on the letter to be named. We observed the same strategy for B. C presented real difficulties in initiating high amplitude saccades during the task. One should also stress that child A was under psycho-stimulant medication during the experiment for associated Attention Deficit/Hyperactivity Disorder (ADHD). It is possible that the treatment along with maturational process could have also positively influence the control of voluntary saccades.[24]

Overall, the present results suggest that children suffering from ISID can develop fluent reading skills and undergo reading acquisition without major disorder. Reading remained difficult and slow during early grades but with time a steady progression of reading skills along with finer eye movements during reading was observed. At the age of 12 years, A was comparable to typically developed children on reading scores and eye movements. Differences with typically developed children are only notable for reading reaction time during the OVP task.

5. Conclusion

The present follow-up study of three siblings with ISID suggests that despite some notable difficulties at the beginning of reading instruction, ISID does not prevent normal reading acquisition. The most interesting result reported here is that despite abnormal eye movements and persisting difficulties to program large amplitude saccades, children can reach normal reading outcomes when assessed longitudinally. The reading difficulties reported by previous studies and thought to explain the educational delay in children with ISID may concern exclusively the first grades or may be due to developmental disorders associated with ISID. Despite the common genetic origin of the siblings, we believe that this study of three cases of familial ISID may help understand the improvement of reading and the natural history of this uncommon supranuclear eye movement disorder.

Declaration of interest

None.

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REFERENCES

1. Cogan DG. A type of congenital ocular motor apraxia presenting jerky head movements. *Trans Am Acad Ophthalmol Otolaryngol* 1952;**56**:853–62.
2. Orssaud C, Ingster-Moati I, Roche O, Bui Quoc E, Dufier JL. Familial congenital oculomotor apraxia: clinical and electro-oculographic features. *Eur J Paediatr Neurol* 2009;**13**:370–2.
3. Salman MS, Ikeda KM. The syndrome of infantile-onset saccade initiation delay. *Can J Neurol Sci* 2013;**40**:235–40.
4. Salman MS. Infantile-onset saccade initiation delay (congenital ocular motor apraxia). *Curr Neurol Neurosci Rep* 2015;**15**:24.
5. Wente S, Schroder S, Buckard J, Buttel HM, von Deimling F, Diener W, Haussler M, Hubschle S, Kinder S, Kurlemann G, et al. Nosological delineation of congenital ocular motor apraxia type Cogan: an observational study. *Orphanet J Rare Dis* 2016;**11**:104.
6. Merlini L, Vargas MI, De Haller R, Rilliet B, Fluss J. MRI with fibre tracking in Cogan congenital oculomotor apraxia. *Pediatr Radiol* 2010;**40**:1625–33.
7. Poretti A, Boltshauser E, Valente EM. The molar tooth sign is pathognomonic for Joubert syndrome! *Pediatr Neurol* 2014;**50**:e15–6.
8. Salman MS, Ikeda KM. Do the clinical features in infantile-onset saccade initiation delay (congenital ocular motor apraxia) correlate with brain magnetic resonance imaging findings? *J Neuro Ophthalmol* 2014;**34**:246–50.
9. Kondo A, Saito Y, Floricel F, Maegaki Y, Ohno K. Congenital ocular motor apraxia: clinical and neuroradiological findings, and long-term intellectual prognosis. *Brain Dev* 2007;**29**:431–8.
10. Ramat S, Leigh RJ, Zee DS, Optican LM. What clinical disorders tell us about the neural control of saccadic eye movements. *Brain* 2007;**130**:10–35.
11. Thier P, Dicke PW, Haas R, Thielert CD, Catz N. The role of the oculomotor vermis in the control of saccadic eye movements. *Ann N Y Acad Sci* 2002;**978**:50–62.
12. Federighi P, Ramat S, Rosini F, Pretegiani E, Federico A, Rufa A. Characteristic eye movements in ataxia-telangiectasia-like disorder: an explanatory hypothesis. *Front Neurol* 2017;**8**:596.
13. Marr JE, Green SH, Willshaw HE. Neurodevelopmental implications of ocular motor apraxia. *Dev Med Child Neurol* 2005;**47**:815–9.
14. Phillips PH, Brodsky MC, Henry PM. Congenital ocular motor apraxia with autosomal dominant inheritance. *Am J Ophthalmol* 2000;**129**:820–2.
15. Fielder AR, Gresty MA, Dodd KL, Mellor DH, Levene MI. Congenital ocular motor apraxia. *Trans Ophthalmol Soc UK* 1986;**105**(Pt 5):589–98.
16. Jan JE, Kearney S, Groenveld M, Sargent MA, Poskitt KJ. Speech, cognition, and imaging studies in congenital ocular motor apraxia. *Dev Med Child Neurol* 1998;**40**:95–9.
17. Harris CM, Hodgkins PR, Kriss A, Chong WK, Thompson DA, Mezey LE, Shawkat FS, Taylor DS, Wilson J. Familial congenital saccade initiation failure and isolated cerebellar vermis hypoplasia. *Dev Med Child Neurol* 1998;**40**:775–9.
18. Liversedge SP, Drieghe D, Li X, Yan G, Bai X, Hyona J. Universality in eye movements and reading: a trilingual investigation. *Cognition* 2016;**147**:1–20.
19. Morrison RE, Rayner K. Saccade size in reading depends upon character spaces and not visual angle. *Percept Psychophys* 1981;**30**:395–6.
20. Rayner K, Clifton Jr C. Language processing in reading and speech perception is fast and incremental: implications for event-related potential research. *Biol Psychol* 2009;**80**:4–9.
21. Henderson JM, Ferreira F. Eye movement control during reading: fixation measures reflect foveal but not parafoveal processing difficulty. *Can J Exp Psychol* 1993;**47**:201–21.
22. Salvucci DD, Goldberg JH. Identifying fixations and saccades in eye-tracking protocols. In: Palm Beach Gardens, editor. *Proceedings of the 2000 symposium on Eye tracking research & applications*. Florida, USA: ACM; 2000. p. 71–8.
23. Nathan L, Stackhouse J, Goulandris N, Snowling MJ. The development of early literacy skills among children with speech difficulties: a test of the "critical age hypothesis". *J Speech Lang Hear Res* 2004;**47**:377–91.
24. Bucci MP, Stordeur C, Septier M, Acquaviva E, Peyre H, Delorme R. Oculomotor abnormalities in children with attention-deficit/hyperactivity disorder are improved by methylphenidate. *J Child Adolesc Psychopharmacol* 2017;**27**:274–80.