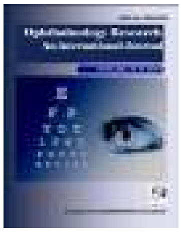

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Fast Eye Movements and Slow Eye Movements in Congenital Neurosensorial Deaf Subjects as Assessed by 2D video-Oculography™

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Authors' contributions

This work was carried out in collaboration between both authors. Author CA performed data analysis and wrote the first draft of the manuscript. Author LC designed the study and performed the experiment. Both authors read and approved the final manuscript.

Short Research Article

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ABSTRACT

Aims: There is evidence that the deprivation of a sensory system at early developmental stage may lead to a functional change of the remaining one(s). Even if this process has been widely studied, results are still controversial. In particular, the auditory system might affect the oculomotor control, since saccades or fast eye movements (FEMs) and slow eye movements (SEMs) are modulated by the cochleo-vestibular input. It follows that hearing impairment would affect the SEM and saccadic pattern. Therefore, in this study FEMs and SEMs have been evaluated in congenital deaf subjects in order to state whether early auditory deprivation has influence on the oculomotor function.
Study Design: Case-control study.
Place and Duration of Study: Sample: Department of Ophthalmology, University of Turin, duration of the study: 6 months.
Methodology: 20 congenital deaf subjects (12 males, 8 females: age range 7-15 years) and 21 age-matched normal hearing subjects (11 males, 10 females: age range 10-16 years) were recruited. Both groups, who had normal visual acuity, underwent SEM and FEM examination by means of 2D video-oculography. SEM left/right cycle gain and velocity and horizontal/vertical FEM latency, velocity and precision were analysed. Results were then compared in the two samples.
Results: No substantial differences in SEM and FEM efficiency were found between deaf

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and normal hearing subjects.
Conclusion: Auditory deprivation does not seem to lead neither to a compensatory enhancement nor to a worsening of the oculomotor function, in contrast to the improvement of peripheral spatial visual attention as reported in literature. We suggest fine ocular movements program, even though strictly influenced by cochleo-vestibular modulation, does not look to be linked to the auditory processing.

Keywords: Deafness; videoculography; ocular movements; FEM; SEM; multisensory Integration; cross-modal plasticity.

1. INTRODUCTION

Two opposite theories have been formulated about the origin and nature of the change in the visual functions observed after auditory deprivation. The deficiency theory starts from the supposition that integrative processes are essential for a normal sensorial development, so that multisensory integration looks to be critical for the maturation of each single sensory modality. Based on this hypothesis the deprivation of one sensorial modality would result in the deficiency in the others [1,2].

In turn, according to the compensatory theory the deprivation of one sense would lead to a compensatory enhancement of the remaining ones [3-5].

Indeed, for visual functions like brightness discrimination [6], contrast sensitivity [7], temporal discrimination [8] and temporal resolution [9,10], the visual threshold in deaf subjects is shown not to be lower as compared to normal hearing subjects. On the contrary, for more complex visual tasks, especially if tested in the peripheral visual field, there is some evidence that deaf individuals' visual performance is enhanced [11]. The improvement of the peripheral visual function in the deaf refers in particular to motion perception [12,13] and attentive functions [14,15,16,17]. It has therefore been suggested a reorganization of the attentional gradient across the visual field to take place in these subjects: indeed, attentive resources, which tend to be focused in the central field and decrease quite steeply from the center to the periphery in normal hearing people, are equally distributed across the visual field in deaf subjects [5]. A similar pattern has been found in congenitally blind individuals for the spatial distribution of auditory attention [18].

In spite of the large number of studies concerning visual sensorial function, oculomotor efficiency is still largely unknown in this class of subjects.

In fact, the evidence that the oculomotor system is abnormal in deafness is controversial, to date. Netelenbos & Savelsbergh. for example, found saccadic movements to be less precise in deaf individuals than in normal subjects when undergoing attentive tasks [19]. However, in a more recent investigation voluntary eye-movement orienting in adult deaf subjects is found not to be different compared to hearing age-matched subjects,as opposite to reflexive saccades, whose latency turned out to be shorter [20].

In order to clarify the effect of hearing deprivation on the saccadic pattern and on slow eye movements, FEMs and SEMs have been estimated in deaf children, who supposedly would be free from any additional sensory interaction other than the one under investigation, contrary to what could occur in the later phases of their life.

2. METHODOLOGY

Twenty subjects (12 males and 8 females) affected by congenital neurosensory hearing impairment (mean hearing loss: 104.8 ±7.6 dB), and, as controls, 21 normal subjects (11 males and 10 females) were recruited. Mean age was, respectively, 11±4 and 13±3 years. Exclusion criteria for both groups were ophthalmological or general diseases, genetic diseases (such as Usher syndrome), myopia/hyperopia > ±2 diopters and/or astigmatism > ±2 diopters, visual acuity <60/60. After a thorough ophthalmological examination, both groups underwent 2-D videooculography (2D VOG, Sensomotronic Instruments, Berlin, Germany). 2D VOG is a non-invasive infrared-based technique which exploits current technology in CCD sensors and digital image processing to provide quantitative measurement of eye movements (Fast Eye Movements, FEMs, and Slow Eye Movements, SEMs). Video images of the eye are acquired on a miniaturized CCD video sensor mounted in a mask, and the resulting video signal is processed online, yielding a measure of horizontal and vertical components. Eye movements are represented by sampling eye position at discrete time intervals (50 samples per second) and eye tracking is shown in real time on a PC screen, while subjects follow a moving target on a 17'' video (Samsung). The reference point for eyes position registration is the dark pupil centroid. This is performed by thresholding the incoming video image so that all pixels with intensity below a given value are identified as belonging to the pupil. For a full and detailed description see Clarke et al. and Schrerer et al. [21,22].

The fixation target was a circular white spot displayed on a grey background (100% contrast).

For the SEM estimate the target moved smoothly across 40 degrees from the left to the right of the screen and vice versa at a mean velocity of 5 deg/sec and with a sinusoidal acceleration profile.

For the horizontal/vertical FEM registration, the same target jumped along the horizontal (left to right and vice versa) or vertical (up to down and vice versa) axis, respectively.

The subjects sat in front of the screen with the mask worn, at a viewing distance of 50 cm. The observer was asked to look steadily at a white spot moving either smoothly leftward and rightward or abruptly displayed on the left, right, above or below the fixation point. This way, horizontal SEMs as well as horizontal and vertical FEMs were registered in random order. Before collection of the data, a practice period was preceded so as to make children accustomed to the procedure.

The SEM parameters considered were:

- Right and left Short Phase Velocity (SPV,deg/sec), that in normal conditions are expected to be equal to the fixation target velocity.
- Right and left Gain (G) expressed as per cent and computed according to the equation:

$$G= (SEM\ amplitude\ /SEM\ amplitude+FEM\ amplitude)\ *100$$

In the equation SEM amplitude refers to the width of the pursuit movement when fixating the moving target. Maximum SEM amplitude takes place when the width of the slow movement matches the spatial interval encompassed by the target. The gain, therefore, quantifies the

efficiency of the slow eye movement. If the ocular movement following the target results to be totally made of SEM, the Gain value will be 100%, while if saccades occur during the displacement target period, SEM gain decreases proportionally to their amplitude.
The FEM parameters considered were:

- latency (L), that is the time interval between target movement and saccade triggering,
- velocity (V) (deg/sec)
- precision (P), computed according to the equation:

$$P= (X_{FEM} - X_0 / X_T - X_0) *100$$

where: X_0 is the starting point of both target and eye movement, X_T is the final point of the target and X_{FEM} is the landing site of the saccade.

If P is around 100%, then FEM amplitude is adequate to the target position, if it is under or over 100%, it means that FEM amplitude is respectively too short or too long as compared to the target position.

Data collected from the two eyes of each participant were averaged. Results obtained in the two samples were therefore compared and appropriate statistical analysis has been performed. Significance level was set at $p \leq .05$.

We certify that the research followed the tenets of the Declaration of Helsinki, that informed consent was obtained from the subjects after explanation of the nature and possible consequences of the study and that all applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed.

3. RESULTS AND DISCUSSION

The obtained results are depicted in the following tables. No statistical differences were found in SEM and FEM pattern between the two groups except for left horizontal saccades precision, which resulted higher in cases as compared to controls. Right horizontal saccades precision turned out to be close to significant level (p=.06) (Table 1-5).

Table 1. SEM results in cases and controls.

	Gain left (%)	Gain right /%)	SPV left (deg/sec)	SPV right (deg/sec)
Cases	94 (25-123)	97 (3-184)	3 (0-13)	3 (0-11)
Controls	97 (46-111)	99 (46-114)	3 (1-9)	3 (1-8)
P	*.15*	*.14*	*.11*	*.36*

Gain left: Mann-Whitney U test= 916.5, Gain right: Mann-Whitney U test= 912, SPV left: Mann-Whitney U test= 895.5, SPV right: Mann-Whitney U test= 984. In brackets are median (min-max) values.

Table 2. Horizontal leftward FEM results in cases and controls

	Latency (msec)	Velocity (deg/sec)	Precision (%)
Cases	190 (86-400)	197,88(±85.01)	103 (30-165)
Controls	185.5 (111-236)	169,90(±68.75)	92 (31-209)
P	*.31*	*.08*	*< .005*

Latency: Mann-Whitney U test= 882.5, velocity: unpaired t-test t= 1.72, precision: Mann-Whitney U test= 580). In brackets are median (min-max) or mean (±SD) values.

Table 3. Horizontal rightward FEM results in cases and controls

	Latency (msec)	Velocity (deg/sec)	Precision (%)
Cases	181(101-301)	166,45(±78.38)	100 (3-118)
Controls	181 (140-270)	169,51(±57.07)	96 (50-206)
P	*.84*	*.84*	*.06*

Latency: Mann-Whitney U test= 757, velocity: unpaired t-test t= 0.19, precision: Mann-Whitney U test= 583.5. In brackets are median (min-max) or mean (±SD) values.

Table 4. Vertical upward FEM results in cases and controls

	Latency (msec)	Velocity (deg/sec)	Precision (%)
Cases	180.5 (21-295)	144.5 (73-438)	100 (7-152)
Controls	202.5 (40-400)	129.5 (17-268)	97 (22-166)
P	*.07*	*.2*	*.53*

Latency: Mann-Whitney U test= 823.5, velocity: Mann-Whitney U test= 896.5, precision: Mann-Whitney U test= 979. In brackets are median (min-max) values.

Table 5. Vertical downward fem results in cases and controls

	Latency (msec)	Velocity (deg/sec)	Precision (%)
Cases	195.5 (40-301)	155 (76-552)	97.5 (26-153)
Controls	205 (105-259)	166 (75-339)	100 (62-154)
P	*.92*	*.92*	*.79*

Latency: Mann-Whitney U test= 1022.5, velocity: Mann-Whitney U test= 1022.5, precision: Mann-Whitney U test= 1002. In brackets are median (min-max) values.

In conclusion, according to our results the saccadic and slow pursuit oculomotor pattern of the congenitally neurosensorial deaf sample seems to be neither better nor worse compared to the normal individuals, with the only exception of the leftward FEM movements, which turned out to be more precise in the former. On the one hand, the lack of significant differences in the two groups could be due to the recording system that processes eye movements with 50 Hz sampling rate. At least under the current stimulus conditions such a temporal resolution may not be high enough to allow for detecting subtle differences between the two samples. On the other hand, possible, albeit speculative explanation for the higher leftward saccadic precision could be related with visual field asymmetries for higher order visual functions such as motion perception or identity judgment of emotional faces in deaf subjects [23-25]. Hauthal et al in particular found a left visual field advantage for coherent movement perception in deaf observers [24]. It should be noted that in the present study neither left/right handedness nor a complete vestibular examination has been considered. In future investigation the assessment of these aspects could help to clarify this finding.

As reported in literature, the effect of deafness on the visual peripheral localization has its counter part in the same effect blindness has on auditory localization: for example auditory spatial attention is found to be improved in blind humans [18, 26-29]. This finding has been interpreted as a consequence of a reorganization of the neural substrates for early auditory selection. In other words, visual areas might be recruited for non-visual processing when visual input is not available [18]. So, if on the one hand the compensatory theory looks to hold in the perceptive domain both for visual and auditory systems, on the other hand according to our results it seems to fail in the oculomotor domain, since auditory deprivation does not lead to appreciable SEM/FEM improvement. As a matter of fact, it should be considered that if the similarity in the anatomofunctional architecture between temporal (auditory) and occipital (visual) areas is similar, the former are basically organised in a different way compared to the frontal oculomotor regions.

4. CONCLUSION

In summary, our findings suggest that an auditory deprivation does not lead to a substantial compensatory enhancement or worsening of the saccadic and slow pursuit oculomotor function.

In future investigations it may be interesting to study correlations between SEM and FEM parameters and different patterns of auditory frequencies deprivation as well as to take into consideration differences in audiometric profiles between the left and right ear.

CONSENT

The authors declare that written informed consent was obtained from the parents of the examined subjects for publication.

ETHICAL APPROVAL

The authors hereby declare that the experiment has been examined and approved by the appropriate ethics committee and have therefore been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

COMPETING INTEREST

The authors have declared that no competing interests exist.

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