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Hemodynamic responses during a visual orienting attention task in infants

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ABSTRACT

Introduction: Neuroimaging studies in adults and children of school age have described the role of parietal and frontal cortices in orienting attention. However, this activity has not been reported in infants in the first year of life. **Objective:** To describe changes in cerebral oxygenated hemoglobin (HbO) in the parietal and frontal cortex during a visual orienting attention task in infants at three different ages: 4, 8 and 12 months. **Material and methods:** Thirty-seven healthy infants were included. The neuroimaging technique of near-infrared spectroscopy (NIRS) was used. The task consisted in the presentation of moving images appearing in the center, left and right of a computer monitor. **Results:** During the task, we found the highest HbO concentration in the right parietal and frontal cortices in all three age groups; the 12 months-old group showed also a higher concentration of HbO in the left parietal and frontal areas. **Conclusion:** In the three age groups, the right parietal and frontal cortices were more active during a visual orienting attention task. Infants at 12 months-old have better visual attention abilities, as in adulthood.

Keywords: Visual attention, oxygenated hemoglobin, near-infrared spectroscopy, infants.

RESUMEN

Introducción: Estudios de la orientación de la atención hacia estímulos visuales en escolares y en adultos han descrito la participación de las regiones parietales y frontales de la corteza cerebral; sin embargo, no existen estudios durante el primer año de vida. **Objetivo:** Describir cambios en la hemoglobina cerebral oxigenada (HbO) en las cortezas parietal y frontal durante una tarea de orientación a estímulos visuales en lactantes de cuatro, ocho y 12 meses de edad. **Material y métodos:** Participaron 37 lactantes sanos y la tarea consistía en dirigir la mirada hacia el centro, la izquierda o la derecha de un monitor donde se presentaban imágenes en movimiento. Los cambios de HbO se midieron mediante espectroscopía de rayos próximos a los infrarrojos. **Resultados:** En todas las edades se observaron valores mayores de HbO en regiones frontal y parietal derechas durante la atención al estímulo que durante el reposo. A los 12 meses de edad, estos cambios también se observaron en las áreas frontal y parietal izquierdas. **Conclusión:** En los tres grupos de edad, las cortezas parietal y frontal derechas fueron más activas durante la tarea de atención de orientación visual. A los 12 meses de edad, los bebés tienen mejores capacidades de atención visual, como en la edad adulta.

Palabras clave: Atención visual, hemoglobina oxigenada, espectroscopía por rayos próximos a los infrarrojos, lactantes.

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[Respuestas hemodinámicas durante una tarea de orientación de la atención visual en lactantes]

INTRODUCTION

Neuroimaging studies with functional magnetic resonance imaging (fMRI) in adults have indicated that two brain systems participate in orienting attention to external stimuli:

a) The ventral attention network is involved in orienting attention to behaviorally relevant stimuli in the environment. This system involves the temporo-parietal junction and the ventral frontal cortex. This system is strongly lateralized to the right hemisphere.

b) The dorsal attention network is involved in spatial attention, and is also active when subjects expect to see moving stimuli. Especially when they appear in unexpected locations.[1] This system involves parietal structures as well as the superior frontal cortex (in particular, the frontal eye fields) in both hemispheres, and it corresponds to the parietal and frontal core regions, relevant to the orienting function.[2]

In orienting attention, both brain systems interact with each other: while the ventral network detects behaviorally relevant stimuli in the environment, the precise localization of the stimuli depends on the dorsal network.[3,4]

The parietal cortex (PC) is active when an external stimulus captures attention, while the frontal cortex (FC) is involved in the voluntary direction of attention. Lesion studies in the monkey have been used to study fundamental differences in function along the rostral-caudal axis and a dorsal-ventral axis of lateral frontal cortex.[5] However, these experiments have been performed in adult subjects and are difficult to transfer the results to infants.

Behavioral attention studies in infants have shown that at approximately two months of age, attention is primarily directed to salient and moving stimuli. At 2-3 months of life, infants fixate attention to a stimulus, and the attention sometimes does not disengage from these stimuli.[6] In the first months of life, orienting attention involves structures that are mature at birth, such as the superior colliculi.[7]

After four months of age, infants have better control in orienting attention due to developmental changes in the visual cortex that projects to cortical areas such as PC and frontal eye fields.[8,9] In addition, sustained attention periods increase with age. When infants are approximately two or three years old, the attention system comes under the control of the child's executive function, and is used in the service of cognitive, social, and emotional tasks.[7,10]

There are limited number of noninvasive techniques to measure localized-functional brain activity that can be applied in awake infants during a task, therefore little is known about the neuronal maturation related to different cognitive processes, including the orienting of attention.

The aim of this work is to describe the role of the PC and FC during a visual orienting attention task at three different ages: 4, 8 and 12 months. For this purpose, we used the near-infrared spectroscopy (NIRS) neuroimaging technique. The NIRS technique can measure the relative changes in the concentrations of oxyhemoglobin (HbO) and deoxyhemoglobin (HbR) associated with changes in cerebral blood flow. The advantage of NIRS compared to the fMRI technique is that NIRS is less affected by subject movements.[11-13]

SUBJECTS AND METHODS

Thirty-seven healthy, full-term infants from 4 to 12 months old (mean gestational age of 40 weeks, range of 39-41 weeks) without prenatal or postnatal risk factors for brain damage were selected. Ten infants were excluded from the final analysis because the recordings obtained had movement artifacts. Infants were grouped into three: 1) 4 months (range of age 4-4.5 months; n = 8; 5 girls); 2) 8 months (range of age 8-8.5 months; n = 9; 6 girls); and 3) 12 months (range of age 12-12.5 months; n = 10; 5 girls).

Procedures

During the task, the infants were sitting in their mother's or father's lap, and they were encouraged to watch the stimuli displayed on a 33-cm monitor screen at a distance of 70 cm from the infant. The experiment finished when the infant stopped cooperating.

To determine whether the infants were performing the task, we observed their eye movements in relation to the changing positions of the stimuli (center, left or right). The task consisted of two conditions, using the same colored pictures of animals opening and closing their eyelids:

1) The orienting attention condition consisted of the presentation of 13 consecutive images. Each picture was presented for 1.5 seconds on a monitor screen in one of three different positions randomized without replacement (left, center and right; this condition lasted for 19.5 seconds). A black screen was presented for 9.5 seconds followed the orienting condition.
2) The control condition consisted of a picture of one animal always presented in the center of the monitor for 18 to 22 seconds (changes in duration in the control condition were repeatedly performed to avoid the habituation process). A black screen was presented for 7 to 11 seconds following the control condition.

We used Mind Tracer Neuronic Software (2.0) to present the stimuli. Also, we used two 12-channel near-infrared optical topography instruments (ETG-4000, Hitachi Medical Corporation) to measure the time course of changes in HbO.[12-14] In this study, we

Table 1: Mean HbO concentrations during the orienting and control conditions.

Group	Condition	Mean ± SD	F	p
4 months				
Channel 14	Orienting	-1.79* ± 1.95	$F_{1,12} = 6.85$	0.02
RPC	Control	-0.48* ± 2.35		
Channel 22	Orienting	1.23* ± 1.7	$F_{1,12} = 5.40$	0.03
RFC	Control	0.21* ± 1.9		
8 months				
Channel 17	Orienting	-1.45* ± 2.28	$F_{1,16} = 7.72$	0.01
RPC	Control	1.96* ± 2.9		
Channel 21	Orienting	2.0* ± 3.54	$F_{1,16} = 4.57$	0.04
RFC	Control	0.52* ± 3.22		
12 months				
Channel 3	Orienting	0.32* ± 2.65	$F_{1,18} = 5.39$	0.03
LPC	Control	-2.91* ± 3.52		
Channel 4	Orienting	1.54* ± 1.96	$F_{1,18} = 7.62$	0.01
LPC	Control	-1.40* ± 2.75		
Channel 7	Orienting	1.19* ± 2.22	$F_{1,18} = 7.97$	0.01
C	Control	-2.30* ± 3.22		
Channel 12	Orienting	1.27* ± 1.45	$F_{1,18} = 4.94$	0.03
LFC	Control	-1.98* ± 4.39		
Channel 17	Orienting	0.44* ± 3.60	$F_{1,18} = 6.0$	0.02
RPC	Control	-3.39* ± 3.39		
Channel 22	Orienting	1.01* ± 3.57	$F_{1,18} = 5.93$	0.02
RFC	Control	-4.65* ± 6.44		

RPC = right parietal cortex, RFC = right frontal cortex, LPC = left parietal cortex, LFC = left frontal cortex, C = middle left and right motor cortex.
* $p < 0.05$.

identified the optode locations with respect to their approximate scalp location from the international 10-20 system, taking the vertex as a reference. There was a total of twelve channels for each hemisphere.

The raw HbO data were filtered by a bandpass filter, with cutoff frequencies of 1 Hz and 0.01 Hz, to remove the signal noise caused by the cardiac and respiratory oscillations. The NIRS data were normalized by subtracting the average of 1 second (10 points) of the baseline activity, and dividing by the highest absolute value of this segment to obtain proportional changes relative to its own baseline.[14] Consequently, each channel was averaged to allow an individual channel response in each experimental condition (i.e., orienting and control). Finally, the mean was calculated for each age group. To make these filters and corrections, we used Python 2.7, which automates all calculations. For the analysis, the data were then divided into orienting and control conditions as follows:

- Total orienting time: 29 seconds (19.5 s orienting and 9.5 s black screen).
- Total control time: 29 seconds (18-22 s control and 7-11 s black screen).

Each condition starts at time zero, so that the time is relative to the duration of that condition. Both conditions together had a total duration of 58 seconds.

The cortical responses were assessed using the average of Hob concentrations in a 3-s sample,[15] from 17 s to 20 s after the stimulus appeared. In both, the orienting and control conditions the mean HbO concentrations were obtained for each participant.

Statistical analyses. For comparison between groups, mixed 2-way ANOVA were used. The between-subject factor was group-age (4 months, 8 months and 12 months), and the within-subject factor was condition (orienting and control). Since 24 channels per participant were included in the analysis, Turkey's honest significant test was used for post hoc analyses.

The Bioethics Committee of the Institute of Neurobiology approved the protocol, and the experiment was conducted according to Declaration of Helsinki. Informed written parental consent for participation in the study was obtained for each infant.

RESULTS

Initially, the whole period of the orienting attention condition (from zero to twenty seconds) was compared to the whole period of the control condition. No significant differences between conditions were observed. Later, we compared the mean values of HbO in a sample of three seconds of each condition from the 17 s to the 20 s (the last three seconds of each condition). *Table 1* shows the mean and SD values of the channels that were significant in the ANOVA test. It is interesting that at 4 and 8 months-old, only right channels showed statistically significant differences, while at 12 months of age there were also statistically significant differences in channels of the left hemisphere.

DISCUSSION

To our knowledge, this is the first study that measured the HbO concentration in the PC and FC during an orienting attention task in infants in the first year of life.

In our initial data analyses, in which the whole period of the orienting attention condition (from zero to twenty seconds) was compared to the whole period of the control condition, no statistically significant differences between conditions were found. This could be due to two reasons. On the one hand, the hemodynamic response takes some number of seconds to reflect the neural activity related to the increase in oxygen delivery to a cerebral region.[16,17] Therefore, in the first seconds both conditions may have similar demands for oxygen delivery in the PC and FC. However, at the end of the task, orienting attention probably demands more oxygen in these cortices.

On the other hand, brain activity in the FC and PC are recruited not only when subjects orient attention, but also when subjects expect to see moving stimuli.[3] In the first seconds of the control condition, the infants may have this expectancy. Some seconds after the control condition has started, the infant can see that the stimuli do not move in the control condition, so the delivery of oxygen is different between conditions.

Considering these initial results, we had a second hypothesis: the mean HbO concentration in the last three seconds of each condition would be higher in the orienting attention condition than in the control condition. We found statistically significant differences in HbO concentrations between conditions. The right FC showed higher HbO concentrations during the orienting condition than during the control condition, at 4 and 8 months-old. Surprisingly, a lower HbO concentration in the right PC was observed during the orienting condition; this phenomenon does not correspond to what has been described in adults, and we think future studies could further explore this finding. A different activation pattern was observed in 12-month-old infants. They showed a higher HbO concentration in the FC and PC in both hemispheres during the orienting condition than the control condition. These results are similar to those reported in adults,[1,2] and during development, as well.[18]

It has been suggested that the left frontal region is involved in regulation strategies such as those related to the expression of interest. The participation of the left PC and left FC in 12-month-old infants corresponded to the expected development at this age, when orienting attention already includes the suppression of competing information. Before this age, orienting attention is only toward salient information without suppressing competing information.[19] It has been reported that infants younger than one year of age who fail to show this basic orienting response, may lack sufficient cortical and subcortical development in brain areas, especially in the frontal eye fields and prefrontal cortex.[20,21]

We want to emphasize that the attention system plays a key role in other cognitive processes, such as learning and working memory.[22,23] Orienting attention also allows better emotional and behavioral control if we can orient our attention to particular events. Parents commonly orient the attention of their infants when they become upset.[24] It has been demonstrated that, infants of 3-month-old can quickly shift visual attention toward a particular location indicated by a parent.[22] This was confirmed in our research: 12-month-old infants more quickly oriented their attention to the stimuli than the younger infants.

Finally, it is important to mention that we could obtained all our data despite that the evaluation of awake infants during attention tasks is difficult. Babies do not hold still and are uncomfortable with the devices on their heads. We also need to acknowledge the limitations of this study: the small sample size, and that the NIRS technique considers the activity of only the cortex and not the subcortical structures involved in orienting attention. Furthermore, with NIRS is also difficult the precise localization of small areas of the cortex, for example, the functions of the areas of the lateral frontal cortex.

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