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Use of eye tracking technology in infancy research

Gisane Novaes Balam
Mackenzie Presbyterian University, SP, Brazil

Ana Alexandra Caldas Osório[1]
Mackenzie Presbyterian University, SP, Brazil

Abstract: Initially, eye tracking technology concerned more adults, however, over the last decades, it has shown great promise in infant research, with several studies demonstrating that its use can provide essential data on the emergence and development of cognitive, social and, emotional processes in childhood. This article aimed at systematizing information regarding the use of eye tracking in infants, including the types of trackers available, their advantages and disadvantages, as well as to present some recent studies. Although there are a significant amount and variety of studies with this approach worldwide, Brazilian research is still scarce. The present study analyses the usefulness of eye tracking technology in infant samples to assist researchers in their methodological decisions, and extend its applicability beyond existing studies.

Keywords: eye tracking; infants; children; development; assessment.

RASTREAMENTO OCULAR: POSSIBILIDADES E DESAFIOS DO USO DA TECNOLOGIA EM AMOSTRAS INFANTIS

Resumo: A técnica de rastreamento ocular foi inicialmente dirigida a adultos, no entanto, ao longo das últimas décadas, tem se mostrado muito promissora em pesquisa com bebês, com diversos estudos demonstrando que sua utilização pode fornecer dados importantes sobre o surgimento e o desenvolvimento de processos cognitivos, sociais e emocionais na infância. O objetivo deste trabalho é sistematizar informações relativas ao uso do rastreamento ocular em bebês, incluindo seu histórico, os tipos de rastreadores disponíveis e suas vantagens e desvantagens, além de citar exemplos de estudos recentes. Embora exista uma quantidade e variedade significativa de estudos com essa abordagem em âmbito internacional, as publicações nacionais são escassas. O presente estudo apresenta uma análise da utilidade do rastreamento ocular em amostras infantis, a fim de auxiliar os pesquisadores na tomada de decisões metodológicas e estender sua aplicabilidade para além dos estudos existentes.

Palavras-chave: rastreamento ocular; bebês; crianças; desenvolvimento; avaliação.

USO DE LA TÉCNICA DE RASTREO OCULAR EN LA INVESTIGACIÓN EN MUESTRAS INFANTILES

Resumen: La técnica de rastreo ocular fue inicialmente dirigida a adultos, pero a lo largo de las últimas décadas, se ha mostrado muy prometedora en investigación con bebés,

[1] **Mailing address**: Ana Alexandra Caldas Osório: Rua Piauí, 181, 10º andar. São Paulo, SP, Brazil. CEP: 01241-001. *E-mail*: ana.osorio@mackenzie.br

siendo que diversos estudios han demostrado que su utilización puede proporcionar hallazgos significativos sobre el surgimiento y desarrollo de aspectos cognitivos, sociales y sociales emocionales en la infancia. El objetivo de esta revisión teórica es sistematizar informaciones relativas al uso del rastreo ocular en bebés, incluyendo su historial, los tipos de rastreadores disponibles y sus ventajas y desventajas, además de citar algunos estudios actuales. Aunque existe una cantidad y variedad significativa de estudios con este enfoque a nivel internacional, las publicaciones nacionales son escasas. El presente estudio abordará un análisis general del rastreo ocular en los bebés, a fin de estimular el uso de la técnica, ayudar a los investigadores en la toma de decisiones metodológicas, y extender su aplicabilidad más allá de los estudios existentes.

Palabras clave: rastreo ocular; bebés; niños; desarrollo; evaluación.

Introduction

Looking is one of the very first behaviors to develop in the early childhood – even newborns direct gaze selectively at certain objects and events around them. Vision will quickly improve in the first months of life, with infants being increasingly attracted by objects and people moving within their visual field, especially biological motion and human faces (Simion, Regolin, & Bulf, 2008). Vision is important to detect, identify and understand what is happening around us. Indeed, gaze movements are involved in nearly everything we do for the time we remain awake, and so looking is an important access to the study of cognition – especially in infants who have not yet developed expressive language (Karatekin, 2007; Gredebäck, Johnson, & von Hofsten, 2009).

Thus, the emergence of eye tracking systems – capable of providing data on the processes infants and children use to extract information and to make inferences and predictions about events and stimuli – offers an extraordinary extension to conventional evaluation methods of child cognition, both in typical and atypical developmental samples. However, until recently, evaluating gaze movements was also one of the most difficult tasks to measure objectively. This difficulty is to be overcome with the development and improvement of equipment and software capable of analyzing gaze movements with accuracy and quality (Gredebäck, et al., 2009).

Currently, there are different systems and technologies capable of measuring eye movements for a wide range of purposes. In studies with infants, the corneal reflection system is the most indicated, and its presentation can occur remotely or mounted on the head, considering the objectives of the study and analyzing the benefits of each presentation. The main measures obtained with the technique are: fixations, saccades, smooth pursuit and pupillary dilatation, and from these variables it is possible to evaluate to where and for how long the subjects fixated their gaze on certain static or dynamic visual stimuli, along with estimates of recruitment of cognitive and emotional resources according to the demands of the task.

In this article we aim to systematize information related to the applicability of the eye tracking technique in infants and children, discussing the main measures used, the advantages and disadvantages and the main difficulties in the evaluation of

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infant samples. Additionally, remarkable studies will be presented in several areas of child development that have used eye tracking for the early characterization of typical and atypical development.

Method

Eye tracking technologies: equipment and techniques

The first equipment for measuring eye movements was built in 1908 by Edmund Huey. Since then, research has flourished over the ensuing decades, and since the 1970s equipment has been refined, becoming less invasive and more accurate, as well as being able to separate eye movements from head movements. Currently, most eye tracking systems are automated and easy to apply, and since the early 2000s there was a significant increase in research using eye tracking for several purposes (Aslin, 2012).

There are different systems and technologies capable of measuring eye movements, and the corneal reflection system is the most appropriate for use in infant samples. In this system, gaze data are derived by the reflexes generated from the projection of an infrared light into the eye and capture of the respective eye movements by means of a video camera (or by an optical sensor). It is a non-invasive method with wide and varied applications. Because it is the most used system in the different age groups – especially in infant samples – we will present its specificities in more detail.

Use of optical eye tracking systems in infant samples: pros / cons

The main benefit from using an eye tracking system is to obtain a constant flow of information in real time. In comparison with human observation, optical trackers offer an important improvement in the resolution (both spatial and temporal) of information regarding patterns of visual stimuli inspection. However, some specifications should be taken into consideration when it comes to studies with infants and young children. The fact that it is a non-invasive and painless technique, which is usually of short duration and easy to apply, are factors that support its use. Nevertheless, unlike cooperative adults, infants may not be able to respond to verbal requests (even simple ones), nor do they remain in a stable and controlled position during the task (Oakes, 2012) – important conditions for an adequate collection of eye movements.

Concerning the configuration of optical systems, there are two types available: head-mounted, where children need to use an accessory on their head; and remote, which are completely non-invasive and record gaze movements from a distance, which are integrated to a monitor.

One specific advantage of remote trackers is the fact that you do not need any accessory or device placed on the infant's head. Once the calibration has been successfully completed, the equipment is able to record gaze movements when the head is relatively still and stimulus-oriented. However, if the infant leans either forward or backward, or even sideways, or excessively moves their head, the tracker loses the spatial information of the pupil and data ceases to be recorded, something that does not occur in head-mounted trackers. If there is loss of pupil data for a few moments and right after the head returns to the mid-line, some remote trackers very efficient in immediately recovering the location of the pupil. However, there will be data loss and this may be a major problem in infant research. Indeed, infants and young children are more susceptible to distraction and have significant difficulty in maintaining their attention to a specific scene, which implies that researchers must establish clear rules and accurate limits for what data will be accepted/excluded in order to obtain reliable and valid analysis results (Oakes, 2010).

In turn, head-mounted equipment is designed to be small and lightweight, and therefore suitable for activities where it is convenient that the participant will have total freedom of movement, which certainly constitutes an advantage and allows more ecological evaluations. Thus, it is possible to evaluate gaze patterns in the environment where the person moves, rather than viewing stimuli on a computer screen. However, its use involves the positioning of an equipment on the head (e.g., the placement of glasses on the face), as well as transporting additional data record equipment (e.g. a smartphone or a notebook) – aspects that can be problematic in infants and young children.

With regard to sampling rates, remote systems are often superior to head-mounted systems as the former can currently reach up to 2000 Hz. This adds details and accuracy when recording information, in addition to enabling faster calibration, which is very important in infant research (Corbetta, Guan, & Williams, 2012).

Eye tracking measures

An important aspect to be considered in eye tracking research is that the equipment needs to be previously adjusted to the specifications of each participant through a process called calibration. Calibration is used to detect the exact location of the participant's gaze relative to the environment. At that specific moment the system records the center of the pupil and the cornea-reflex relation by reference to an X, Y coordinate on the monitor. Excessive head movement and possible misinterpretation by the analysis software are two major problems that may compromise the calibration process and consequently the set of data (Goldberg & Wichansky, 2002).

Basic measurements of gaze movements that may be measured by means of the eye tracking technique are: fixations, saccades, smooth pursuit and pupil dilatation.

- Fixations: Regard the moment in which the eyes are relatively fixed, assimilating or decoding information. In general, the fixation duration increases as the task difficulty increases and consequently the need to collect more information increases as well. In a reading task, for example, a higher frequency of fixations in a given word may indicate greater complexity in interpreting that particular word.
- Saccades: are defined as ballistic eye movements occurring in very short time scales (from 30 to 120 ms) between fixations whose main function is to bring objects to the foveal vision. A saccade usually coincides with a displacement of the spatial

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and visual attention towards the object and therefore, similar to fixations, saccades are also correlated with varying levels of cognitive load (Karatekin, 2007). The following image illustrates the two measures mentioned where: circles represent fixations, considering that the greater the diameter, the longer the time of each fixation; and lines between fixations represent the saccades.

Figure 1. Representation of eye measures: saccades and fixations

Source: Developed by the authors.

- Smooth pursuit: to track small objects that move relatively slow, we use eye skill/movement called pursuit. They are smooth, non-ballistic movements, which maintain the object within the foveal vision during a path where the speed of the gaze corresponds to the speed of the pursued target (Karatekin, 2007). While smooth pursuit develops in the first few months of life, head movements (that are usually needed to follow the movement path) develop in a much slower fashion, as there is a gap of months between both skills.
- Pupil dilatation: the main factor regulating pupil diameter is the amount of light; however, pupil size also varies depending on the recruitment of cognitive resources. The ability to infer the cognitive load of pupillary responses is known as pupillometry, a field of research that covers the effects of psychological influences, perceptive processes and mental activities on pupil size. In addition, pupillary dilatation can be used as an index of the emotional reaction to a visual stimulus. Pupil responses provide a continuous measure regardless of whether the participant is aware of such changes and is therefore one of the few direct measures of resource recruitment that is extremely sensitive to the underlying cognitive processes. Finally, since pupillary responses can be measured non-invasively, are present from birth and may occur in the absence of voluntary and conscious processes, they are a very promising tool for the study of pre-verbal (e.g., infants) or nonverbal individuals.

Challenges of the use of eye tracing in infants samples

As already mentioned, although the eye tracking technique is of relatively easy application in infant samples, there are some limitations and difficulties imposed by research with infants and toddlers, making it quite challenging. The first difficulty may precede data collection, and regards the preparation of the task to be presented. Due to the wide variety of paradigms found in the literature, when elaborating a task that meets the proposed objectives, the researcher may come across questions such as: For how long should a visual stimulus be presented? What is the ideal overall duration of the task? How many trials are needed? How do you get the participant's consistent attention through the task? In addition, in studies with pre-verbal infants and children, communication is limited, rendering unusable some resources that are widely used in adults, such as asking the participant to press a key in response to a given command or stimulus. In research with collaborative adults, maintaining the attentional focus and engagement in the task is already a challenge, and in the case of the child samples this challenge increases considerably. For example, if the task presented is not carefully adjusted to the child's level of cognitive development, the child may quickly ignore it and look away to any other event around him or her.

Another difficulty imposed regards the ideal positioning of children and especially of infants. Some authors cite the use of infant seats (Ellis, Borovsky, Elman, & Evans, 2015; Jones & Klin, 2013), while others indicate that the baby should sit on the mother's lap to feel more comfortable and secure (Telford et al., 2016). In fact, the infant's behavior tends to be more natural if they are in their mother's lap. However, freedom of movement is greater and this can compromise the necessary stability of trunk and head for the equipment to capture the eye data (in case of using remote systems). In both positions suggested by the literature, difficulties may arise in data capture, resulting in high data loss.

Some precautions should be taken when working with infants in order to minimize data loss, for example: the room where data collection is to take place should be free from visual or auditory stimuli that may compete with the attention focus to the target stimuli. Thus, ideally the data collection room should have little or no decoration (especially within the infant / child's field of vision during the presentation of stimuli), avoiding the circulation of people outside. In addition, the parent should be instructed to refrain from communicating with the infant and the researcher as much as possible during the task, since any stimulus may cause the infant to become distracted.

Eye tracking in children samples: main studies

Data from this technique in infant samples have already been used to elucidate a great variety of cognitive processes, such as: visual spatial attention (Richmond, Zhao, & Burns, 2015), memory processing (Richmond & Nelson, 2009), language (Ellis et al., 2015), motor action comprehension (Biro, 2013), face processing (Frank et al., 2014), in addition to social information processing (Telford et al., 2016) and social-emotional process analysis (Biro et al., 2014), among others.

In the following section we present some studies performed in the first years of life (birth to two years), in order to exemplify the amplitude of the use of eye tracking and

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its contribution in studies with typical and atypical samples (in the early detection of neurodevelopmental changes).

Jones and Klin (2013) used remote eye tracking (60Hz sampling rate) to perform a longitudinal assessment of infants from two months of age who were at high risk for developing ASD symptoms. The aim of the study was to investigate signs prior to the manifestation of clinical symptoms. For this, 110 babies were evaluated in 10 different moments (between 2 and 24 months of life). Babies were divided between high (n = 59) and low (n = 51) risk for ASD, the first group consisting of siblings of diagnosed children. During the task the infants viewed a video that contained scenes in natural surroundings where an actress simulated a context of play. In each video, four areas of interest were delimited: eyes, mouth and body of the actress and surrounding objects. The authors observed an increase in visual fixations in the eye region (compared to all other regions) in the low risk infants at 2 to 6 months. Furthermore, there was also a reduction in object (versus body) gaze throughout the first 24 months of life. However, among high-risk infants – specifically those later diagnosed with an ASD – the growth curves for visual social engagement followed a different course of development. From 2 to 24 months of age, visual fixation in the eye region decreased significantly. In addition, at 24 months, visual fixation to objects was twice the level found in typical controls. These results indicate that in the first months of life, the basic mechanism of adaptive social interaction is not immediately diminished; on the contrary, it begins at normative levels before declining. Based on the results, the authors suggest that there is a narrow window of development that offers a promising opportunity for early intervention.

In another study, Telford et al., (2016) compared premature infants with full-term infants from 6 to 10 months (N = 100) where the infants were presented three categories of social stimuli of increasing complexity. The first task consisted of tracking faces – faces of men and women with neutral facial expressions were presented. In the second task, five visual stimuli were simultaneously presented: a photo of a human face, a distorted image of that photo (where pixels were altered in order to make it unrecognizable) and three other non-social images (for instance: car, cellphone and bird). The last task, called visual social preference, was composed of two stimuli that occupied the whole screen, where on one side a social stimulus was presented (e.g. one or two children) and on the other side a non-social image (such as scenes and objects of daily life without human presence). The authors concluded that the premature infants, compared to their full-term counterparts, fixed their gaze for a shorter period in images with social content in the three requested tasks, concluding that the eye tracking technique provided early evidence of atypical social cognition in the premature group.

In the area of language, Ellis et al., (2015) also making use of a remote system (500Hz), evaluated 14 18-month-old infants with language delay and 14 infants with typical language development (paired in age and cognitive levels) in a task that examined the lexical processing of two new words (being both non-existent words, created for the experiment). In the test phase, the goal was to teach the infants the new words, and so they listened to one of the words while simultaneously being presented with the visual stimulus that represented that word. In this phase infants heard and saw each stimulus 14 times. In the test phase, infants heard one of the new words and two visual stimuli were presented (the target image and a distractor image). To consider that the word was effectively learned, researchers analyzed the latency of the first fixation towards the target image, and according to this criterion there was no significant difference between the evaluated groups. However, there was a group difference when total fixation times to target versus distractor images were compared, as infants from the typically developing group distinguished the target image at an earlier time point. These results indicate that the infants in the language delay group may have different emerging representations of new words than their typical counterparts.

Several studies have addressed pupillary dilatation as an indicator of children's emotional arousal in response to social stimuli (Nuske, Vivanti, & Dissanayake, 2015). In a study by Hepach, Vaish, and Tomasello (2012), pupillary dilatation of typically-developing two-year-olds was evaluated – while similar levels were found when the children themselves helped someone in need or when help came from third parties, different levels were observed when the person did not receive help from anyone. These results suggest that when young children engage in helping behaviors, they are not primarily motivated to get credit for their good deed, but to get that person the help they need.

Instructions / guidelines for future researches

Given the significant increase of studies using eye tracking equipment in infants and young children in the last decades, Oakes (2010) proposed a list of eight guidelines for researchers who intend to publish their data: a) *Describe in detail aspects concerning the presentation of stimuli* – for example, presenting data on the distance of infants in relation to the equipment (which must be kept constant), the size of the displayed images and the total visual angle of the viewing area; b) *Provide details on the eye tracking system used* – systems differ significantly in terms of very important variables, such as the sampling rate (an equipment that records data at a rate of 50Hz provides very distinct information from a 2000Hz equipment) or how the system resumes the lost record due to head movements, eye blink or other very common situations in evaluating children samples; c) *Describe the calibration procedure in detail* – for example, indicating the number of calibration points used, the type of stimulus used (e.g. a red ball, the drawing of a starfish) and its position; d) *Present procedures used to deal with missing data* – for example, applying filters to correct missing data due to blinking; e) *Presenting information about how gaze data was processed* – what type of filters were previously applied to analyses and at what time were they applied (e.g., at the time or after data collection); f) *Specify data reduction procedures and parameters* – given the great amount of resulting data, researchers must specify if they have resorted to any data-selection and reduction strategies; g) *Provide information on how the regions of interest were defined* – for example, if regions were manually drawn

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or defined according to the pixel grid, if they are either regular or irregular shapes, if they are the same for each stimulus; and h) *Provide detailed information on exclusion criteria* – for example, set out cases excluded by not reaching the minimum number of valid trials; the minimum fixation time/minimum number of saccades for a trial to be considered valid, etc.

Conclusions

Since the earliest studies aimed at eye tracking up to the present days, the evolution of the equipment and the technology is remarkable. Among the different types of eye trackers available, those using the corneal reflection technique are the most used as they are non-invasive and painless, as well as more accurate and automated, enabling good human-computer interface. Eye trackers used in infants may be either remote or head-mounted, and each modality has its pros and cons. The choice of equipment and method will depend on the purpose of the study, the target population and also its cost effectiveness. Considering that eye tracking studies with infants and children are scarce in Brazil, this survey sought to provide information to encourage and assist researchers in the methodological decision-making process, by pointing out important issues to be considered when conducting research in early infancy. We hope that our work will contribute to a wider and better use of the eye tracking technology by Brazilian researchers.

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