Behavioural Brain Research 285 (2015) 34–43

Contents lists available at ScienceDirect

Behavioural Brain Research

journal homepage: www.elsevier.com/locate/bbr

Research report

Infant visual attention and object recognition

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HIGHLIGHTS

- Infant visual attention and object recognition are closely related.
- The bulk of research on infant attention and recognition memory is based on preferential looking tasks.
- Infants demonstrate increased voluntary control of attention across infancy as well as major gains in recognition memory.
- The Nc and late slow ERP components serve as neural correlates of infant attention and object recognition.

ARTICLE INFO

Article history:
Received 2 June 2014
Received in revised form 6 January 2015
Accepted 8 January 2015
Available online 14 January 2015

Keywords:
Infancy
Object recognition
Visual attention
Event-related potentials

ABSTRACT

This paper explores the role visual attention plays in the recognition of objects in infancy. Research and theory on the development of infant attention and recognition memory are reviewed in three major sections. The first section reviews some of the major findings and theory emerging from a rich tradition of behavioral research utilizing preferential looking tasks to examine visual attention and recognition memory in infancy. The second section examines research utilizing neural measures of attention and object recognition in infancy as well as research on brain–behavior relations in the early development of attention and recognition memory. The third section addresses potential areas of the brain involved in infant object recognition and visual attention. An integrated synthesis of some of the existing models of the development of visual attention is presented which may account for the observed changes in behavioral and neural measures of visual attention and object recognition that occur across infancy.

1. Infant visual attention and object recognition

The ability to selectively attend to objects or events in the environment shows significant development in infancy. This ability is a critical component of early cognitive functioning for the human infant and remains so throughout the lifespan. Attention is strongly related to recognition memory, another core cognitive function which is present at birth in the human infant but shows significant development throughout the infancy period [1–3]. Together these two functions account for the human infant's responsiveness to novelty which researchers have capitalized on for decades to gain a window into the perceptual and cognitive capabilities of the non-verbal human infant. In the current paper, some of the major findings and theory on infant attention and memory which emerged from this line of research are reviewed, followed by a review of research on neural correlates of attention and object recognition in infancy, and theory on brain–behavior relations in the development of attention and recognition memory. The influence of individual differences in infant visual attention on object recognition is also discussed. The neuroanatomical basis of recognition memory is then explored followed by a section describing the development of attention systems in the brain [4–6]. These attention systems are associated with significant changes in stimulus processing which occur with increasing age and strongly influence recognition memory for objects and events.

2. Preferential looking, visual attention, and recognition memory in infancy

Developmental scientists have historically been interested in infant looking behavior because it provides a window into the perceptual and cognitive world of the non-verbal human infant. Being among the most altricial species, the human infant is generally incapable of complex behavior and is highly limited in range of responsiveness to environmental events. However, even in the newborn period, infants are capable of demonstrating selective attention and preferential looking for very brief periods [3,7,8]; and infants experience rapid gains in the voluntary control and

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http://dx.doi.org/10.1016/j.bbr.2015.01.015
0166-4328/

maintenance of visual attention across the first postnatal year (for reviews, [4,9]). Much of the research on preferential looking has focused on responsiveness to novelty, a defining feature of infant recognition memory [3]. The use of novelty preferences as an index of recognition memory in infant participants grew out of Fantz's revolutionary studies using a preferential looking task first with chimpanzee infants [10] and later with human infants [11].

In his groundbreaking study published in 1964, Fantz presented 2- to 6-month-old infants with repeated pairings of photographs from magazines. One photograph was shown repeatedly to the infant for 10 presentations, but for each of the 10 presentations, this "constant" stimulus was paired with a novel photograph. Fantz found that with repeated presentations, the infants looked progressively longer toward the novel stimuli relative to the familiar (i.e., constant) stimulus. Based on this finding, he concluded that visual experience can be retained for at least a very brief period of time for infants over 2 months of age. This approach of presenting infants with a simultaneous pairing of two visual stimuli to the left and right of midline and measuring their preferential looking was modified by Fagan [12] to include an initial familiarization phase, and is now referred to as the visual paired comparison (VPC) procedure. The majority of what we know about recognition memory in infancy has come from research utilizing some variant of this procedure.

The use of preferential looking as a measure of recognition memory requires a certain set of inferences to be made regarding what each of the possible preferences (novelty, familiarity, null) represents. The most common assumption made regarding these visual preferences is based on Sokolov's [13] comparator model in which he proposed that during looking, infants are actively constructing a mental representation (i.e., engram) of the fixated stimulus. If the stimulus matches an existing engram, then further looking or encoding is unnecessary and the infant will shift fixation to a different stimulus. A novelty preference is thus assumed to reflect recognition of a fully processed familiar stimulus. Longer looking toward the familiar stimulus (i.e., a familiarity preference) is assumed to reflect further encoding of stimulus that has not been fully processed. Null preferences (equal looking to each stimulus) are believed to reflect a lack of prior processing of either stimulus or equivalent levels of processing of each stimulus. Hunter and Ames [14] proposed that infant visual preferences are influenced by multiple factors, including: the age of the infant, the amount of previous exposure to the stimuli, and task difficulty. Similar to Sokolov's [13] model, the infant would be expected to look longer toward a repeated (i.e., familiar) stimulus compared to novel stimuli until he/she has completely processed the familiar stimulus. Once the infant has no new information to extract from the familiar stimulus, the familiarity preference would be expected to shift to a novelty preference.

Studies in which length of familiarization was manipulated across and within age groups provide support for these inferences (e.g., [15,16]). For example, Rose et al. [16] found that with 30 s of familiarization with an object, 3.5-month-old infants demonstrated preferences for the familiar object during the VPC task. However, 4.5- and 6.5-month-olds showed novelty preferences with 30 s of exposure during familiarization. Furthermore, 6.5-month-olds allowed to accumulate 5 s of looking during familiarization with an object, subsequently demonstrated familiarity preferences in a VPC task; however, infants of the same age allowed to accumulate 15 s or longer of looking during familiarization demonstrated novelty preferences. These findings and others (e.g., [15–19]) demonstrate that longer familiarization leads to greater evidence of object recognition in infants; and with increasing age, infants require less exposure during familiarization to subsequently recognize an object. Additionally, Diamond [20] found that with increasing age infants demonstrate evidence of recognition memory following longer delays between familiarization and testing. Four-month-old infants recognize stimuli with up to 10 s delays between testing, whereas 6-month-olds and 9-month-olds show evidence of recognition with up to 1 and 10 min of delays, respectively.

It should be clear based on this review of behavioral work in the area that visual attention and recognition memory are tightly, perhaps inseparably, coupled in research utilizing visual preference tasks with infant participants. Recognition memory is inferred based on the distribution of infant visual attention during testing. Two forms of attention, selective attention and sustained attention, are clearly involved in recognition memory tasks. Selective attention involves the selection of a specific object or spatial location as the focus of attention. This process is influenced by both external and internal factors, such as stimulus salience and the child's goals, respectively [21]. Sustained attention refers to the extended selective engagement of a behavioral or neural system that primarily enhances information processing in that system (e.g., [19,22]). For example, novel objects often elicit stimulus orienting (i.e., selective attention) followed by sustained attention as the infant continues to maintain visual attention toward the stimulus. Areas of the brain controlling arousal and state are involved in sustained attention

Table 1
Table 1 provides a summary of developmental findings related to infant visual attention and recognition memory on behavioral [16,17,58,89] and ERP tasks [27,33,39,41,43–45,98]. The potential onset of areas of the brain involved in these tasks is also shown [5,6,9,21,65,88].

Age	Behavioral findings	ERP findings	Brain areas involved in attention and recogniton memory
Birth–3 months	Visual attention is reflexively drawn to salient features of environment: areas of high contrast, borders of stimuli, motion. Infants may display long looks, but visual scanning and information processing are immature and inefficient. Infants require up to 60 s of prior exposure to subsequently recognize stimuli	Latency to peak Nc: 800–1200 ms. By 3 months, infants display differential Nc amplitude to oddball and standard stimuli	Reflexive system: superior colliculus, lateral geniculate nucleus, primary visual areas Object recognition: medial temporal lobe structures, area TE
3–6 months	Look duration decreases significantly as infants gain voluntary control of visual fixation and scanning. Infants begin to focus attention on relevant features of objects, people, and events; and require less exposure (approximately 20 s) to subsequently recognize stimuli	Latency to peak Nc: 450–750 ms. Nc increases in amplitude, and infants show greater amplitude to novel stimuli, unless familiar is mother's face or favorite toy. Differential LSW responding occurs based on familiarity and novelty	Posterior orienting system: frontal eye-fields, posterior parietal cortex Selective attention network: pulvinar, anterior cingulate, dorsolateral prefrontal cortex
6 months–on	Infants begin to develop higher level attention, and are better able to inhibit attention to distracters and maintain sustain attention when called for. Look duration remains low to basic stimuli and increases to more complex stimuli	Latency to peak Nc: 350–650 ms. Nc amplitude continues to increase up to 1 year and then begins to decrease. Infants are more likely to demonstrate differential LSW responses based on frequency of presentation of familiar stimuli	Anterior attention system: dorsolateral prefrontal cortex, orbitofrontal cortex, anterior cingulate Object recognition: increasing involvement of area TE and increased dependence on hippocampus