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Do infants have the horizontal bias?

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ABSTRACT

A robust set of studies show that adults make more horizontal than vertical and oblique saccades, while scanning real-world scenes. In this paper we study the horizontal bias in infants. The directions of eye movements were calculated for 41 infants (M = 8.40 months, SD = 3.74, range = 3.48–15.47) and 47 adults (M = 21.74 years, SD = 4.54, range = 17.89–39.84) while viewing 28 real-world scenes. Saccade directions were binned to study the proportion of saccades in the horizontal, vertical and oblique directions. In addition, saccade directions were also modeled using a mixture of Von Mises distributions, to account for the relatively large amount of variance in infants data. Horizontal bias was replicated in adults and also found in infants, using both the binning and Von Mises approach. Moreover, a developmental pattern was observed in which older infants are more precise in targeting their saccades than younger infants. That infants have a horizontal bias is important in understanding infants' eye movements. Future studies should account for the horizontal bias in their designs and analyses.

1. Introduction

Eye movements are frequently used to study infant cognition (Wass, Forssman, & Leppänen, 2014) in both experimental and free-viewing paradigms. Traditionally, looking time measures have been extremely important in studying infant cognitive development (Aslin, 2007) and new eye tracking techniques can further enhance our knowledge in this area (Aslin, 2012). Understanding infant cognitive development starts with knowing what information is available for infants to process. Especially in free-viewing paradigms, infant eye movements reflect natural exploration behavior and provide a relative unbiased measure of attention. Understanding what guides infant eye movements is therefore of key importance to study infant cognitive development.

Adult eye movements are series of short fixations and rapid saccades. Approximately three fixations and saccades are made every second (Rayner, 2009). Saccades are targeted at salient regions (Itti & Koch, 2000; Itti, Koch, & Niebur, 1998) influencing eye movements in a bottom-up way, but top-down processes (e.g. knowledge) also influence where we fixate (Henderson, 2003). Apart from these bottom-up and top-down influences, general biases also play an important role in

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guiding eye movements (Tatler & Vincent, 2008, 2009). Most early fixations fall in the center of the scene (Clarke & Tatler, 2014) and saccades are predominantly targeted in the horizontal direction (Foulsham, Kingstone, & Underwood, 2008; Gilchrist & Harvey, 2006; Tatler & Vincent, 2008). In this paper we examine the possibility of a horizontal bias in infants.

At birth, eye movements are less efficient than in adults, because the first few weeks of postnatal life infants have relatively little control over their eye movements (Atkinson, 1992). However, the visual system develops rapidly and 1- to 2-month-old infants start to fixate visual stimuli (Bronson, 1994; Hunnius & Geuze, 2004). These fixations are often long (>500 ms), as infants may have trouble shifting their gaze. At 3- to 4-month of age fixations become shorter (<500 ms, Bronson, 1994) and control over eye movements is more stabilized (Hunnius & Geuze, 2004). The fixation systems continue to develop until adolescence (Luna, Velanova, & Geier, 2008) and fixation durations are known to decrease until at least 10 years of age (Helo, Pannasch, Sirri, & Rämä, 2014).

Also for infants there is evidence of top-down and bottom-up processes guiding eye movements. Three-month-old infants have a preference for looking at own-group faces versus other-group faces, whereas this preference is not present at birth (Kelly et al., 2005) and 3- to 4-month-old infants have a preference for faces of the gender of their primary caregiver (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002). These findings indicate that top-down processes influence eye movements. There is also evidence of bottom-up processes guiding infants' eye movements, while watching a Charlie Brown video clip, 3-month-old infants' fixations were best predicted using saliency, whereas 6- and 9-month-old infants' fixations were best predicted by the location of faces in the video (Frank, Vul, & Johnson, 2009). The influence of bottom-up factors on eye movements continues to decrease until adolescence (Açık, Sarwary, Schultze-Kraft, Onat, & König, 2010; Helo et al., 2014).

Although the development of top-down and bottom-up visual processes in infancy has been investigated in some detail, the early development of many general biases remains largely unexamined. Tatler and Vincent (2009) showed that models accounting for general biases gave a better description of where adult fixations are located than models based on top-down and bottom-up processes alone. As these general biases play an important role in guiding adult eye movements (Tatler & Vincent, 2008), it is likely infant eye movements are also guided by these general biases.

To our knowledge, the horizontal bias has yet to be examined in infants. Studying the horizontal bias in infants is important to gain a better understanding of what guides infants' eye movements. If the horizontal bias is present in infants, future studies can improve models to explain infant looking behavior and can account for the bias in experimental studies. For example, before concluding infants have a preference for some stimuli or object in a scene, it must be ruled out that this preference is due to general biases.

1.1. Horizontal bias in adults

In the adult literature there is overwhelming evidence of the horizontal bias (e.g., Foulsham et al., 2008; Gilchrist & Harvey, 2006; Tatler & Vincent, 2008). Although the origin of the bias remains unclear, there are some factors that may contribute to it. First, biomechanical factors may partially drive the bias. Horizontal saccades require only the use of one pair of muscles (the lateral and medial rectus), whereas saccades in the other directions requires more than one pair of muscles (Viviani, Berthoz, & Tracey, 1977). For instance, oblique saccades require coordinated horizontal and vertical muscle activity (Becker & Jürgens, 1990) and even vertical saccades require extraocular muscle activity (Henn & Cohen, 1973). Second, physiological factors may guide the bias. The spatial density of rods and cones in the retina is higher along the horizontal direction than the vertical direction (Curcio, Sloan, Kalina, & Hendrickson, 1990). Najemnik and Geisler (2008) found that an ideal observer model based on this asymmetry produced a distribution of saccade directions with a horizontal bias. Third and lastly, the distribution of objects in the environment may contribute to the bias. We may learn that interesting objects are often located along the horizon. In order to maximize our information uptake in the shortest timeframe, therefore, we start to move our eyes along the horizon.

1.2. Current study

The horizontal bias is a well established phenomenon in adults and an important factor in the guidance of eye movements as saccades are made more often in the horizontal directions, than in the vertical and oblique directions. To fully understand adult eye movements it is important to consider bottom-up and top-down factors, but also more general eye movement biases (Tatler & Vincent, 2009), such as the horizontal bias. The research question of this paper is: "Do infants exhibit the horizontal bias in saccade direction, while scanning real-world scenes?" Furthermore, the bias may be different for older than younger infants. To answer the question if the bias changes with age, we observed a wide age range (3- to 15-month-olds). This enabled us to test if the horizontal bias develops with age. Answering these questions will help us to understand what guides infants' eye movements and thus enable us to learn more about infant cognitive development.

1.3. Analytical approach

The direction of eye movements is usually analyzed by a binning approach (e.g., Foulsham & Kingstone, 2010; Foulsham et al., 2008), in which saccade directions are binned in pre-defined categories (i.e. horizontal, vertical, oblique). However, this may introduce a confound in this study as the pre-defined ranges of the binning approach may not be applicable to infants. Infants' eye movements are likely to be noisy compared to adult eye movements. Therefore, saccade directions