Infant Behavior & Development 33 (2010) 663–671

Contents lists available at ScienceDirect

Infant Behavior and Development

Infants' representations of three-dimensional occluded objects

Rebecca J. Woods[a,*], Teresa Wilcox[b], Jennifer Armstrong[b], Gerianne Alexander[b]

[a] North Dakota State University, Child Development & Family Science, P.O. Box 6050, Dept. 2615, Fargo, ND 58108-6050, United States
[b] Texas A&M University, United States

ARTICLE INFO

Article history:
Received 30 June 2009
Received in revised form 16 April 2010
Accepted 1 September 2010

Keywords:
Object representation
Infants
Eye-tracking

ABSTRACT

Infants' ability to represent objects has received significant attention from the developmental research community. With the advent of eye-tracking technology, detailed analysis of infants' looking patterns during object occlusion have revealed much about the nature of infants' representations. The current study continues this research by analyzing infants' looking patterns in a novel manner and by comparing infants' looking at a simple display in which a single three-dimensional (3D) object moves along a continuous trajectory to a more complex display in which two 3D objects undergo trajectories that are interrupted behind an occluder. Six-month-old infants saw an occlusion sequence in which a ball moved along a linear path, disappeared behind a rectangular screen, and then a ball (ball–ball event) or a box (ball–box event) emerged at the other edge. An eye-tracking system recorded infants' eye-movements during the event sequence. Results from examination of infants' attention to the occluder indicate that during the occlusion interval infants looked longer to the side of the occluder behind which the moving occluded object was located, shifting gaze from one side of the occluder to the other as the object(s) moved behind the screen. Furthermore, when events included two objects, infants attended to the spatiotemporal coordinates of the objects longer than when a single object was involved. These results provide clear evidence that infants' visual tracking is different in response to a one-object display than to a two-object display. Furthermore, this finding suggests that infants may require more focused attention to the hidden position of objects in more complex multiple-object displays and provides additional evidence that infants represent the spatial location of moving occluded objects.

1. Infants' representations of three-dimensional occluded objects

Scientists have long puzzled over the nature of the naïve human mind prior to extensive experience in the physical world. There is now substantial evidence that young infants represent the existence and physical properties of objects (e.g., Aguiar & Baillargeon, 2002; Baillargeon, 1987, 2004; Baillargeon & DeVos, 1991; Clifton, Rochat, Litovsky, & Perris, 1991; Hood & Willatts, 1986; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Wilcox, Nadel, & Rosser, 1996). One capacity that has received a great deal of attention is that of representing object motion during occlusion. With improvements in technology, the use of eye-tracking has converged with other methods to provide evidence of infants' representational capacities and has provided new insights into the nuances of infants' tracking abilities. These studies have demonstrated that infants are relatively good at tracking occluded objects and making predictions about where objects will next appear. For example, when viewing an object moving along a linear or curvilinear path that is partially occluded, infants aged 4–12 months

* Corresponding author. Tel.: +1 701 231 9791; fax: +1 701 231 9645.
E-mail address: rebecca.woods@ndsu.edu (R.J. Woods).

0163-6383/$ – see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.infbeh.2010.09.002

predict where an object will next become visible (Gredebäck & von Hofsten, 2004; Gredebäck, von Hofsten, & Boudreau, 2002; Gredebäck, von Hofsten, Karlsson, & Aus, 2005; Johnson, Amso, & Slemmer, 2003; Kochukhova & Gredebäck, 2007; McMurray & Aslin, 2004; Rosander & von Hofsten, 2004; von Hofsten, Kochukhova, & Rosander, 2007), shifting their gaze during the occlusion interval to the appropriate edge of the occluder. Infants demonstrate predictive looking across a wide range of occluder widths and occlusion intervals and scale the latency of their gaze across the occluder to the duration of the occlusion interval (Gredebäck & von Hofsten, 2004; Gredebäck et al., 2002; von Hofsten et al., 2007).

These and other studies have also revealed that infants base their anticipation of emergences of moving occluded objects upon a number of different factors. One source of information infants draw on is their physical knowledge. Even very young infants possess basic expectations about how physical objects move and interact and use this information to predict the outcome of occlusion events (Aguiar & Baillargeon, 2002; Spelke et al., 1992; Spelke, Katz, Purcell, & Ehrlich, 1994; Spelke, Kestenbaum, Simons, & Wein, 1995). For example, infants extrapolate when and where a moving occluded object will next appear on the basis of pre-occlusion motion (Gredebäck & von Hofsten, 2004; Gredebäck et al., 2002; von Hofsten et al., 2007) and the expectation that objects move on continuous paths even when occluded (Kochukhova & Gredebäck, 2007). Infants can also predict the trajectory of a moving occluded object on the basis of its physical characteristics (e.g., the red square moves left) and anticipate the final orientation of an object as it rotates during the occlusion interval (Hespos & Rochat, 1997; McMurray & Aslin, 2004). At the same time, infants are able to adapt their anticipatory looking on the basis of recent experience (Kochukhova & Gredebäck, 2007). For example, when presented with fixed but non-linear paths (e.g., an object changes its direction of motion when occluded), initially infants fail to correctly predict where the object will next appear, typically looking to the edge of the screen at which the object would appear if it had followed a linear path. However, infants quickly learn non-linear but fixed paths and after two or three presentations of the occlusion sequence can accurately predict the point of emergence (Kochukhova & Gredebäck, 2007). These and related findings (Johnson et al., 2003; Wilcox, 2003) indicate that recent experiences can influence infant's interpretation of occluded motion and trial-related changes in behavior can be observed.

2. New directions

In sum, much has been learned about infants' capacity to represent objects as they move behind an occluder by means of detailed analysis of infants' visual behaviors. These investigations of infants' ability to track briefly occluded objects using an eye tracker typically measure predictive or anticipatory looking. While this measure has been informative, other looking behaviors may provide additional and potentially more detailed evidence of the representations infants' maintain concerning object motion and therefore warrant investigation.

What's more, assessment of infants' representations of complex occlusion events using eye tracking has been relatively understudied. The spatiotemporal parameters of occlusion events involving a single object moving along an unobstructed path are rather simple. In the physical world, however, occlusion events are often more complex. Paths of motion are sometimes obstructed and occlusion events can involve multiple objects. To what extent can infants represent these more complex events? There is evidence that infants expect a moving occluded object to stop or alter its path of motion after hitting an impenetrable barrier (Spelke et al., 1992, 1994) or to cause a stationary object to move upon contact (Kotovsky & Baillargeon, 1994, 2000). In addition, infants recognize when the spatiotemporal or featural properties of an event require the presence of more than a single object (Aguiar & Baillargeon, 2002; Spelke et al., 1995; Wilcox & Schweinle, 2002, 2003). It is possible that using an assessment measure as sensitive as eye-tracking will reveal looking patterns other than anticipatory looks that provide information about the nature of infants' object representations in complex occlusion events. The present research investigated infants' response to events involving one object as compared to two objects.

Finally, eye-tracking studies assessing infants' ability to track moving objects during an occlusion sequence have made use primarily of two-dimensional displays. The present research sought to build on these findings by using three-dimensional displays.

3. The present research

Given these gaps in current studies of infants' ability to track objects as they undergo occlusion, the purpose of the current research was to investigate infants' capacity to represent simple and complex occlusion sequences within a three-dimensional display. Infants looking patterns to multiple areas of the display were assessed using an eye-tracking system. Infants aged 6 months saw one of two events, ball–box or ball–ball (Fig. 1) and a corneal reflection eye tracker was used to assess looking patterns. Previous research indicates that infants 4.5 months and older interpret a ball–box event as involving two separate and distinct objects and a ball–ball event as involving a single object (McCurry, Wilcox, Woods, & Armstrong, 2009; Wilcox & Baillargeon, 1998a, 1998b; Wilcox & Chapa, 2002; Wilcox & Schweinle, 2002). However, 4.5 month olds' perception of depth is limited. It is not until around 5 or 6 months that infants' visual capacities and experiences have given them an understanding of the significance of depth (Birch, 1993; Brown & Miracle, 2003; Fox, Aslin, Shea, & Dumais, 1980; Gordon & Yonas, 1976; Kavšek, 2003), therefore infants in the current study were tested at about 6 months.

We hypothesized that if infants represent occluded paths of motion and if infants were given sufficient time to examine the display during occlusion, they should evidence three types of looking patterns that are consistent with the objects' path of motion. First, the infants in both conditions should demonstrate anticipatory looking. This outcome would build and extend