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Three-month-old infants' object recognition across changes in viewpoint using an operant learning procedure

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Abstract

Object knowledge refers to the understanding that all objects share certain properties. Various components of object knowledge (e.g., object occlusion, object causality) have been examined in human infants to determine its developmental origins. Viewpoint invariance—the understanding that an object viewed from different viewpoints is still the same object—is one area of object knowledge, however, that has received less attention. To this end, infants' capacity for viewpoint-invariant perception of multi-part objects was investigated. Three-month-old infants were tested for generalization to an object displayed on a mobile that differed only in orientation (i.e., viewpoint) from a training object. Infants were given experience with a wide range of object views (Experiment 1) or a more restricted range during training (Experiment 2). The results showed that infants generalized between a horizontal and vertical viewpoint (Experiment 1) that they could clearly discriminate between in other contexts (i.e., with restricted view experience, Experiment 2). Overall, the outcome shows that training experience with multiple viewpoints plays an important role in infants' ability to develop a general percept of an object's 3D structure and promotes viewpoint-invariant perception of multi-part objects; in contrast, restricting training experience impedes viewpoint-invariant recognition of multi-part objects.

Keywords: Human infants; Viewpoint invariance; Object perception; Object knowledge; Operant learning; Visual perception

Object knowledge plays an important role in perceptual abilities and refers to the understanding that all objects share certain properties. For example, adults understand that objects exist even without direct perception of them (object permanence). From a developmental perspective, an interesting question arises—How does object knowledge develop? To answer this question, various components of object knowledge have been examined in human infants: object occlusion (i.e., Johnson, Bremmer, Slater, Mason, & Foster, 2002), object permanence (i.e., Cashon & Cohen, 2000), object causality (i.e., Spelke, Breinlinger, Macomber, & Jacobson, 1992) and physical reasoning (Kannass, Oakes, & Wiese, 1999; Kim & Spelke, 1999; Rivera, Wakeley, & Langer, 1999). One area of object knowledge, however, that has received less attention in the developmental literature is the issue of perceiving 3D object shape. One particular issue in this area is the question of viewpoint invariance. Viewpoint invariance is defined as the understanding that an object viewed from different viewpoints is still the same object. Hence, viewing a chair from the side, back, or top does not impede identification of that object as a chair. The object is still recognized even though the viewpoint has changed. The purpose of the current study is to investigate this ability in infants.

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It is important to note that the concept of viewpoint invariance differs from the related issue of shape constancy. Shape constancy refers to the ability to map, at the perceptual level (as opposed to the level of a memory representation), the distal stimulus from the proximal stimulus. That is, the visual system perceives a distal shape (the real object) despite changes that occur in the proximal stimulus (i.e., changes in size or shape of the retinal images). For example, a glass might be presented with the (round) top at various angles, relative to an observer, such that the top will produce multiple elliptical retinal projections. The observer will combine each of these varying elliptical projections with depth information from various sources and will perceive a circle in each instance. That is, the visual system takes into account the tilt of the glass to produce a constant percept (a circular top) of the distal object. Thus, the primary point of interest in shape constancy is the ability to map a single distal stimulus from multiple proximal stimuli (i.e., perceive a circle despite a retinal image of an ellipse). Shape constancy has been shown in infants as young as 8 weeks of age (Bower, 1966; Cook & Birch, 1984).

Viewpoint invariance, on the other hand, refers to the ability to perceive that the retinal projection of an object seen from one viewpoint maps onto the same distal stimulus as the retinal projection produced by observing the object from a different viewpoint, despite clearly perceptible differences (accretion and deletion of vertices, edges, or even whole parts) between the two retinal projections. For example, when a coffee mug is rotated, the handle might be attached on the left in one view, but on the right in another view. The visual system can map both projections onto the same representation. Thus, what is being studied in viewpoint invariance is the ability to understand that two *perceptibly different* proximal/distal stimulus pairings refer to the same object representation. The capacity for shape constancy is likely to be an important precursor to viewpoint invariance because the ability to perceive a constant distal shape by combining retinal projections with depth information is needed to construct an initial description of 3D shape, independent of a memory representation.

Viewpoint invariance, in contrast to shape constancy, deals with issues more directly related to the representation of an object's real-world shape, and is presumed to occur at a cognitively higher level. For example, viewpoint invariance addresses questions such as: How sensitive are infants to variations in object viewpoint? Can infants discriminate a change in viewpoint in one context yet recognize that the stimulus is the same despite a change in viewpoint in another context? Adults are clearly capable of discriminating differences in object viewpoint while appreciating the fact that the object itself has not changed (i.e., they can generalize across views). Do infants possess this dual ability to both discriminate and generalize across changes in viewpoint? What mechanisms underlie viewpoint invariance early in development? Does viewpoint invariance involve the ability to link, in memory, different representations of an object (i.e., different viewpoints)? Addressing questions such as these will be beneficial in understanding the development of object knowledge because they will help reveal what information infants use to represent objects. Understanding of how infants represent objects, in turn, will provide insight into how perceptual and cognitive processes develop. It is important to note, however, that not all object recognition is viewpoint-invariant. The adult literature on object recognition acknowledges that object recognition is likely controlled by both viewpoint-invariant and viewpoint-dependent processes (Hummel & Stankiewicz, 1996; Logothetis & Sheinberg, 1996; Palmeri & Gauthier, 2004).

The most relevant study with regard to viewpoint invariance in infants was conducted by Bornstein, Krinsky, and Benasich (1986). Bornstein et al. explicitly questioned whether 4-month-old infants could show the same dual ability in object recognition typically seen in adult performance: The ability to discriminate between different viewpoints, along with the ability to recognize that those viewpoints represent the same object. To test this, one group of infants was habituated to one viewpoint of an object while a second group of infants was habituated to multiple viewpoints of that object. Both groups were then tested for transfer of habituation to a novel viewpoint of the object. Bornstein et al. predicted that if infants could discriminate between viewpoints, then infants presented multiple viewpoints during habituation should habituate slower than those infants presented only one viewpoint. At the same time, to demonstrate that infants recognize that the different viewpoints represent the same object, Bornstein et al. predicted that only infants habituated to multiple viewpoints would generalize (i.e., not dishabituate) to a novel viewpoint of the object at test. Bornstein et al.'s results supported these predictions.

Despite some methodological (two-dimensional irregular shapes served as the stimuli) and statistical (unequal habituation levels prior to testing) concerns with Bornstein et al.'s (1986) study, their approach to examining viewpoint invariance was well-designed. They recognized that a functional object representation in infants would include the ability to both generalize and discriminate across viewpoints. Otherwise, a finding of generalization across viewpoints in the absence of showing discrimination across viewpoints would merely indicate a perceptual deficit—an inability