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The elusive illusion: Do children (*Homo sapiens*) and capuchin monkeys (*Cebus apella*) see the Solitaire illusion?

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ABSTRACT

One approach to gaining a better understanding of how we perceive the world is to assess the errors that human and nonhuman animals make in perceptual processing. Developmental and comparative perspectives can contribute to identifying the mechanisms that underlie systematic perceptual errors often referred to as perceptual illusions. In the visual domain, some illusions appear to remain constant across the lifespan, whereas others change with age. From a comparative perspective, many of the illusions observed in humans appear to be shared with nonhuman primates. Numerosity illusions are a subset of visual illusions and occur when the spatial arrangement of stimuli within a set influences the perception of quantity. Previous research has found one such illusion that readily occurs in human adults, the Solitaire illusion. This illusion appears to be less robust in two monkey species, rhesus macaques and capuchin monkeys. We attempted to clarify the ontogeny of this illusion from a developmental and comparative perspective by testing human children and task-naïve capuchin monkeys in a computerized quantity judgment task. The overall performance of the monkeys suggested that they perceived the numerosity illusion, although there were large differences among individuals. Younger children performed similarly to the monkeys, whereas older children more consistently perceived the illusion. These findings suggest that human-unique

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perceptual experiences with the world might play an important role in the emergence of the Solitaire illusion in human adults, although other factors also may contribute.

Introduction

There has been long-standing theoretical interest in how children perceive the world. This area of psychological research ranges from studying how children perceive basic elements of objects (e.g., color, shape, size) to more complex properties of their environments (e.g., temporal patterns, spatial orientation) (Baldwin, 1955; Gibson & Gibson, 1955; Piaget & Inhelder, 1969; Wohlwill, 1960). One key approach to studying the ontogeny of perception is to use visual illusions to establish when and why information is misperceived and, critically, how these misperceptions change across the lifespan (for a review, see Wohlwill, 1960). Much like the approach of studying biases to understand heuristics in decision-making research, visual illusions can be considered a tool to uncover how the perceptual system typically operates and the circumstances under which errors emerge (e.g., Eagleman, 2001; Gori & Stubbs, 2014). Importantly, several investigations of the emergence and progression of visual illusions have shown that susceptibility to some illusions increases throughout adolescence (e.g., size–weight illusion: Ohwaki, 1953; Rey, 1930), whereas susceptibility to other illusions decreases into adulthood (e.g., Delboeuf illusion: Giering, 1905; Piaget, Lambercier, Boesch, & Von Albertini, 1942; horizontal–vertical illusion: Walters, 1942; Müller–Lyer illusion: Binet, 1895; Piaget & Von Albertini, 1950).

A phylogenetic approach also is informative in understanding children's perception (and adult humans' perception) because many features of the visual system are shared with our closest living relatives, the primates, ranging from the anatomical structure of the eye to how information is processed in the brain (e.g., De Valois & De Valois, 1988; Essock, 1977; Fobes & King, 1982; Matsuzawa, 1990; for a review, see Matsuno & Fujita, 2009). Visual illusions provide a useful means for comparative research because they can reveal critical information on the organization and functioning of perception among different species. Thus, the comparative study of visual illusions among nonhuman animals, and particularly among closely related primate species, has emerged as a growing subfield within comparative cognition. We and other primates often misperceive our environment in similar ways, as evidenced by continuity across species in visual illusion perception (e.g., Agrillo, Parrish, & Beran, 2014b; Benhar & Samuel, 1982; Fujita, 1996, 1997, 2001; Parrish & Beran, 2014; Suganuma, Pessoa, Monge-Fuentes, Castro, & Tavares, 2007; for a review, see Wasserman, 2012). Despite research into the development of some visual illusions among human children and separate research on visual illusion emergence in nonhuman primates, very few studies have combined these areas of inquiry by directly comparing data from human children with data from nonhuman animals.

Our recent comparative work has focused on a subset of illusions known as numerosity illusions. We are particularly interested in these illusions because nonhuman primates share many of the same hallmark characteristics with humans for encoding and representing number and quantity information (for a review, see Beran, Parrish, & Evans, 2014). Specifically, we are interested in the circumstances under which quantitative cognition can be disrupted by certain perceptual stimulus aspects such as item size, density, and movement. Numerosity illusions, therefore, provide a valuable window into investigating the mechanisms that underlie quantity representation. These illusions emerge when the perceived quantity or numerousness of a set of stimuli is disrupted by the spatial arrangement of items within a set. For example, like human adults (Ginsburg, 1976, 1980), rhesus macaques overestimate the quantity of dots in a regularly arranged pattern versus the same number of dots in a randomly arranged pattern (Beran, 2006). Similarly, like human adults (Chesney & Gelman, 2012), rhesus macaques underestimate arrays when sets contain circles that are placed inside one another (nested) versus sets that contain discrete non-nested circles (Beran & Parrish, 2013).