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The foundations of object permanence: Does perceived cohesion determine infants' appreciation of the continuous existence of material objects?

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ABSTRACT

One of the most fundamental achievements in infants' cognitive development is their appreciation that material objects exist permanently in space and time. Recent findings suggest that infants fail to identify fragmented material objects as continuously existing items. Four experiments assessed 8–12-month-old infants' ability to further represent an object that was fragmented into two or more parts. Results suggest that infants successfully trace the spatiotemporal displacement of fragmented objects, but that their processing of size/quantity-related property information may be affected. This suggests that, contrary to recent claims, 8- to 12-month-old infants can and do appreciate the continuity of fragmented objects.

1. Introduction

One of the most fundamental achievements in infants' cognitive development is their appreciation that material objects continuously exist in time and space – even beyond direct perception. Piaget (1954) considered *object permanence* to be the hallmark of representational skills, enabling the infant to learn and reason about the objects in its environment. Continuity (i.e., the understanding that objects travel on spatiotemporally continuous paths) is a necessary condition for recognizing an object as the same individual item at different points in time (Scholl, 2007) and thus a precondition for categorizing and structuring elements of one's surroundings in meaningful ways. In recent decades, research has corroborated the view that inferring objects' continuity is a core pillar of human cognitive architecture. Infants as young as 2.5 months of age were found to expect the further existence of hidden objects (e.g., Wang, Baillargeon, & Paterson, 2005). It was thus proposed that the notion of continuity might be part of an innate cognitive core that helps infants to interpret the undivided visual input, in order to perceive a world of discrete, continuously existing objects (Spelke, 1994; Spelke, Breinlinger & Macomber, 1992).

1.1. Cohesion and continuity are linked in basic processing

Recent findings have revealed that infants' continuity inferences appear most closely connected to whether a given entity is perceived as being a connected, bounded unit (Cheries, Mitroff, Wynn, & Scholl, 2008; Chiang & Wynn, 2000; Huntley-Fenner, Carey, & Solimando, 2002). These findings support the core principles view, that suggests that in basic perceptual and cognitive processing, the core principles of *continuity* and *cohesion* operate together to define which perceptual features count as "objects" and are thus continuously existing items (Spelke, 1994). According to this view, the principles of cohesion and continuity are linked in basic processing: First, only features that move as cohesive, bounded wholes are identified as *permanent* objects. In contrast to this, non-cohesive patterns are not addressed as objects and thus not traced

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through space and time. Second, entities identified as continuously existing objects are supposed to move as cohesive, stable units. Put simply: Cohesive entities are supposed to be continuous, while continuous entities are supposed to remain cohesive. Previous research has largely corroborated this view. Infants indeed expect solid objects to move as distinct, cohesive wholes (e.g., Needham, Cantlon, & Ormsbee Holley, 2006; Needham, Dueker, & Lockhead, 2005; Spelke, 1990). Further, there is evidence that infants fail to appreciate the continuous existence of non-cohesive entities (Cheries et al., 2008; Chiang & Wynn, 2000; Huntley-Fenner et al., 2002; Rosenberg & Carey, 2009). For example, Huntley-Fenner et al. (2002) reported that infants fail to appreciate the continuous existence of a non-cohesive substance. They suggest that, due to its non-cohesive structure and behaviour, infants interpret sand as being a non-object entity and thus fail to view it as continuously existing. Likewise, infants failed to appreciate the continuous existence of entities that were initially represented as solid objects, but whose structural connection was later cancelled by way of *cohesion manipulation*.[1] For example, 8-month-olds failed to further represent a Lego tower that was broken up into its individual parts and hidden behind a screen (Chiang & Wynn, 2000). Most remarkably, 12-month-olds even failed to track a graham cracker if it was split into two halves (and thus failed to move as a connected whole) before being placed into a cup (Cheries et al., 2008). Using a crawling paradigm they presented 10–12 months-old infants with two conditions where either pieces of undamaged (no-split condition) or fragmented crackers (split condition) were hidden. In the no-split condition, infants saw one cracker being lowered into a cup and two crackers placed into another cup. They consistently selected the cup with the greater amount of cracker. However, if infants were first presented with a single big cracker that was split into two halves before placing it into the cup, infants failed to have an above-chance preference for either cup, even though the quantities to compare were exactly the same in both conditions. These findings were interpreted as demonstrations of how object-based representations may be destroyed in the face of cohesion manipulations (i.e., if the represented entity was manipulated in such a way as to affect object cohesion). Similar but less deleterious effects were observed in adult attentive tracking (Cheries, Mitroff, Wynn, & Scholl, 2009; Mitroff, Scholl, & Wynn, 2004) and non-human primate cognition (Cacchione & Call, 2010; Cacchione, Hrubesch, & Call, submitted for publication; Mahajan, Barnes, Blanco, & Santos, 2009).

[1] In the developmental literature, object transformations that decrease the cohesion of an object (e.g., by breaking it by applying force) are usually addressed as "*cohesion violations*". However, the term 'cohesion violation' can be misleading if it is interpreted as referring to events that *violate the physical law of cohesion*. We think it is important to clearly distinguish between events that violate the *physical law* of cohesion (where objects spontaneously break apart *without* the application of external force, e.g., when a mug moves and its handle stays behind) and events that violate the *psychological principle* of cohesion (where objects are broken by the application of force, e.g., when a person deliberately breaks off the handle of a mug). We decided to use the term 'cohesion manipulations' throughout this manuscript to refer to the latter case (to events that constitute an object transformation, manipulating the apparent cohesion of the object without violating the physical law of cohesion).

1.2. Do cohesion manipulations destroy infants' object representations?

Cohesion manipulations, such as the breaking up of solid objects, are of special interest because they examine the impact of cohesion on already established object representations. That is, infants are not presented with non-solid substances that are fundamentally *non-object* entities, but with solid, cohesive objects that are later fragmented. Cohesion manipulations are challenging, because they affect the spatiotemporal path of objects, producing ambiguity in at least two ways (Scholl, 2007). First of all, cohesion manipulations bring about ambiguity regarding the objects' identity. What happens to the original object if its unconnected parts suddenly move in different directions? Which of the parts should now be addressed as the object? Does the object cease to exist or must it be re-represented as a non-object entity? Second, they bring about spatial ambiguity, compromising infants' ability to further track the trajectory of the object (due to the inability to address multiple spatial locations with a single object file; see e.g., Kahnemann, Treisman, & Gibbs, 1992). At present it is not known what exactly happens to infants' representations in the face of cohesion manipulations. Suggestions range from very severe effects including a full breakdown of representations (i.e., adding up to a lack of object permanence) to milder forms of impairment compromising infants' ability to engage in comparative judgments (e.g., quantifying amounts of graham crackers). One explanation implying severe effects is derived from the core principles view and suggests that infants' continuity inferences are restricted to cohesive, bound objects. According to this view infants are fundamentally unable to appreciate the continuity of non-cohesive entities, because they lack "object status" (i.e., fragmented objects, collections, non-solid substances). A second strong explanation for infants' failure to track fragmented objects is derived from studies on object-based visual attention processes (Kahnemann et al., 1992; Pylyshyn & Storm, 1988; Sears & Pylyshyn, 2000). These studies suggest that *indexes* containing primarily spatiotemporal information (e.g., object files) are allocated to discrete objects in the visual field. These indexes serve as pointers for the selected objects and allow them to be traced through space and time, thereby making the objects available for higher-level cognitive processes. According to this view, infants fail to track fragmented objects because they fail to assign the pre-existing object file to multiple resulting parts, and also fail to construct new distinct object files for each of them. Without an object file indexing the location of these parts, infants fail to further trace them through time and space. Thus, both of these strong explanations claim that cohesion manipulations leave the child without a representation of the resulting parts – without which these parts no longer exist in the infant's mind. In contrast to this, a weaker explanation claims that cohesion manipulation does not destroy infants' object representation, but affects it in such a way that it no longer supports quantification (e.g., because some information was lost when the open object file was copied and reallocated to remaining parts). Thus, the child is left with a downgraded representation that only