Cognition 134 (2015) 128–139

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Manual action, fitting, and spatial planning: Relating objects by young children

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ARTICLE INFO

Article history:
Received 3 January 2014
Revised 2 September 2014
Accepted 11 September 2014

Keywords:
Object manipulation
Planning
Spatial ability
Fitting
Mental rotation

ABSTRACT

This study uses motion tracking technology to provide a new way of addressing the development of the ability to prospectively orient objects with respect to one another. A group of toddlers between 16 and 33 months of age ($N = 30$) were studied in an object fitting task while they wore reflective markers on their hands to track spatial adjustments in three dimensions. Manual displacements of the handheld object were separated into translations and rotations. Results revealed that younger children largely used a two-step approach in which they initially translate an object to a target and subsequently attempt to rotate the object to match the target. In contrast, older children evidence more advanced spatial planning and integrate translational and rotational components throughout the entire period when they are transporting the object to the target. Additionally, at the oldest ages, children show even further improvements in coordinating translations and rotations by using relatively shorter translations (i.e., covering less distance) and by avoiding unnecessary rotations of the object. More broadly, the results offer insights into how manual problem solving becomes more efficient and planful during the toddler years.

1. Introduction

Many problem solving and tool use tasks require individuals to relate the orientation of an object to that of another stimulus, such as an object or aperture. For example, placing a flat head screwdriver into a screw depends upon appropriate alignment of the tip of the screwdriver with the indentation of the head of the screw. Plugging in an electronic device calls for orienting a plug relative to the holes of an electrical outlet. The ability to perform these kinds of manual tasks efficiently underlies many forms of adaptive behavior and requires anticipatory adjustments when relating objects to other stimuli.

In the present study, we investigate the development of object fitting and more generally, the problem of aligning objects in relation to one another. In this work, we advance a spatial analysis to understand the development of object fitting. Specifically, we consider the kinds of spatial displacements that must be combined when transporting and aligning an object with an aperture. We describe this process as entailing spatial displacements where translations and rotations of the object need to be coordinated. During translations, the object's center of mass moves from one location to another. In rotations, only the orientation of the object changes (Landau & Spelke, 1988). Adults integrate translations and rotations effortlessly when fitting objects into apertures, typically aligning the object with the aperture by the time the object first contacts the aperture. In contrast, coordinating translations and rotations of objects presents challenges for young children, who often fail to initially align a handheld object with an aperture when attempting fitting. Indeed, it is typically not until the end of the second year that young children orient a handheld object to match the orientation of an aperture

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http://dx.doi.org/10.1016/j.cognition.2014.09.004
0010-0277/

prior to contacting the aperture (Meyer, 1940; Örnkloo & von Hofsten, 2007; Shutts, Örnkloo, von Hofsten, Keen, & Spelke, 2009; Street, James, Jones, & Smith, 2011).

1.1. Visuomotor coordination in reaching and grasping tasks

Well before young children preorient handheld objects in the context of fitting tasks, they gain experience with a formally similar, yet simpler manual task: grasping objects in different orientations. When grasping objects in different orientations, individuals must bring the hand to a target location (translation) and they must align the hand with the shape or orientation of the object (rotation). By the beginning of the second half year, infants show improvements in translational movements, bringing their hands smoothly and efficiently to the location of a target (Berthier & Keen, 2006; von Hofsten, 1991). Soon afterwards, they show improvements in rotational displacements that can be considered prospective: they align their hands with the longitudinal axis of a horizontally or vertically oriented object before they contact it (Lockman, Ashmead, & Bushnell, 1984; McCarty, Clifton, Ashmead, Lee, & Goubet, 2001; von Hofsten & Fazel-Zandy, 1984; Wenthworth, Benson, & Haith, 2000; Witherington, 2005).

Around the same time, infants also display the ability to prospectively align their hands with the orientation of an aperture. By 10 months, infants take into account aperture orientation when reaching through an aperture (McKenzie, Slater, Tremellen, & McAlpin, 1993) and by 16–18 months, toddlers are clearly successful at aligning their hands with a horizontally or vertically oriented slot (Street et al., 2011). Taken together, these studies indicate that by the time infants bring the hand to an object or aperture, they behave prospectively: infants match the orientation of the hand to that of the target. In spatial terms, before the end of the first year, infants have successfully combined translational and rotational displacements within these reaching contexts.

1.2. Visuomotor coordination in fitting tasks

Although infants under one year preorient their hands when reaching to an object or aperture, it is not until more than a year later that they preorient a handheld object when fitting it into an aperture (Meyer, 1940; Örnkloo & von Hofsten, 2007; Shutts et al., 2009; Street et al., 2011). The reason for this asynchrony is not well understood (Lockman & Ashmead, 1983; Street et al., 2011). Based on the foundational work of Perenin and Vighetto (1988) and Milner and Goodale (1995) on the separate roles of the dorsal and ventral visual streams, investigators have explained this dissociation in terms of developmental differences in the maturation of these two visual streams (e.g., see Street et al., 2011). These and other researchers (Johnson, Mareschal, & Csibra, 2001) have suggested that vision for object recognition (i.e., the ventral stream) is more developed in toddlers than vision for action (i.e., the dorsal stream), such that difficulties in fitting reflect relative immaturity of the dorsal stream.

Nevertheless, there are limitations in using the dorsal/ventral pathway distinction to account for the developmental dissociation between reaching for objects in different orientations and aligning objects with other stimuli. First, both reaching for objects in different orientations and aligning objects with apertures presumably involve dorsal function or vision for action. In fact, both kinds of abilities (aligning one's hand with an aperture and fitting an object into an aperture) are compromised due to dorsal stream deficits (Atkinson et al., 1997; Dilks, Hoffman, & Landau, 2008; Perenin & Vighetto, 1988). There is no reason why immaturity of the dorsal stream should be unique to situations in which infants hold objects in their hands. Further, it is not clear whether the inability to align an object with another stimulus would reflect immaturity of the dorsal pathway alone and/or a lack of functional integration between the two pathways.

1.3. The current study

We suggest that before ascribing the manual changes in prospective object alignment to underlying neural development, it is important to understand the behavioral changes that underlie developmental advances in fitting. In much of the prior developmental literature on object fitting, the focus has been on whether the object is aligned with the aperture when the object initially contacts it (Meyer, 1940; Örnkloo & von Hofsten, 2007; Street et al., 2011). This focus, however, neglects full consideration of the process by which an individual integrates rotations and translations during the transport phase of the task. In work with adults on the neural bases of object prehension, researchers have divided the action into two separate components: reaching and grasping (Jeannerod, 1984). Bringing the hand to a target object and appropriately preshaping the hand relative to that object are two neurally distinct processes (Grafton, 2010), which require integrated coordination and planning. In a similar vein, we suggest that object fitting tasks also involve a transport phase in which two separable components must be combined: bringing the handheld object to the aperture and aligning the handheld object with the aperture. By examining fitting tasks throughout the entire transport phase – that is, from picking up an object to transporting it to the aperture – we can gain insights into how children attempt to combine translational and rotational displacements and age related changes in this overall ability. Whereas researchers have analyzed the ontogeny of object search (Landau & Spelke, 1988) and object perception (Eizenman & Bertenthal, 1998) tasks in terms of their underlying translational and rotational components, this type of approach has not been used in work on development of object alignment.

To address how young children engage in visuomotor planning and coordinate rotations and displacements when fitting objects, we adapted motion capture technology so that we could continuously track the spatial adjustments that children made during the transport phase of the task. Motion tracking systems can be used to quantify precisely changes in location and orientation of the handheld object, the two parameters relevant for considering