How Motor and Visual Experiences Shape Infants' Visual Processing of Objects and Faces

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ABSTRACT—***Infants' impressive achievements in processing objects and faces during the 1st year of life lead to questions about the factors driving that development. In this article, I review and discuss how infants' experiences that are related to their emerging motor skills and their development of face expertise lead to such crucial developmental agents. During the 1st year of life, infants' visual processing of objects is primarily associated with their object exploration and crawling experiences. Infants' development of face processing is influenced by their increasing experience with face categories that they encounter most frequently. A link also exists between infants' processing of faces, on one hand, and their exploration of objects and their experience with sitting, on the other. Thus, experiences that result from acquiring motor skills seem to facilitate infants' visual processing across domains.***

KEYWORDS—*object processing; face processing; motor development; perception-action coupling; infancy*

From birth, infants are fascinated by seeing objects and faces in their environment. Especially during the 1st year, infants become increasingly proficient in recognizing objects and faces across varying points of view, light conditions, and distances. Such skills enable them to deal with a visual world that is changing constantly.

Infants' impressive achievements in processing objects and faces lead to questions about the underlying factors driving those changes. Developmental psychologists agree that perceptual development is driven by biological maturation in close interaction with experiential effects. Although we can do little to investigate biological maturation, we *can* explore the effect of experience on infants' perceptual development. Experience can affect perceptual development to facilitate further perceptual development or attune the perceptual system to the affordances of the environment (Gottlieb, 1981). Although experience constitutes a vital force in infants' perceptual development, it is unclear at which age specific types of experience link to corresponding perceptual skills. In this article, I address which motor and visual experiences facilitate and attune infants' visual perception of objects and of faces, and whether the effects of such experiences are domain general in nature.

HOW ARE INFANTS' MOTOR EXPERIENCES LINKED TO PROCESSING OBJECTS?

Developmental psychology has a long history of linking achievements in infants' motor skills with improvements in perceptual abilities. Although infants' motor development by itself is also prone to experiential factors (Vierhaus et al., 2011), sensorimotor experiences are thought to be linked to infants' understanding of objects (Piaget, 1952). Piaget argued that infants' object understanding is based on acquired information about objects through sensorimotor experiences or actions. Other researchers (e.g., Adolph, Eppler, & Gibson, 1993; Gibson, 1988) proposed that infants' action systems tune their perceptual systems, allowing them to gain information about objects. Interactions with objects fine-tune infants' perceptual systems to the association between characteristics of objects and the actions the objects afford. For example, 9-month-olds rely initially on touch and then vision to match their motor responses to objects (Corbetta & Snapp-Childs, 2009).

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The publication of this article was supported in part by a grant from the Collaborative Research Center SFB/TRR 135/1 2014 at the German Research Foundation.

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DOI: 10.1111/cdep.12093

Child Development Perspectives

However, which type of developing motor skill is linked to infants' visual processing of objects? When focusing on the first 9 months of life, infants' skills in exploring objects seem to constitute a crucial developmental influence. A link between manual action and visual processing of objects was found in newborns who demonstrated a cross-modal transfer between touched and seen information about objects (Streri & Gentaz, 2004). Moreover, a training of 3.5-month-old infants' exploration of objects led to an enhanced understanding of segregation of objects (Needham, 2000). In other words, infants' active experience exploring objects is relevant for their later understanding of objects (see also Libertus & Needham, 2010). In addition, 6-month-olds integrated different object dimensions such as size, texture, and shape into their visual perception of whole objects only when they had the opportunity to explore objects manually and visually (Jovanovic, Duemmler, & Schwarzer, 2008). When analyzing the specific type of infants' object manipulations, rotating, transferring, and fingering objects predicted most strongly infants' performance on a visual 3D object completion task (Soska, Adolph, & Johnson, 2010). In another study, rotating, transferring, and fingering objects were also related to infants' understanding of rotating objects (Schwarzer, Freitag, & Schum, 2013); however, the study used an age-held constant paradigm that prevents conclusions of causality (this topic will be covered in more detail later in the article).

For older infants (those between 9 and 12 months), the onset of self-produced locomotion, like crawling, is another developmental force underlying infants' visual processing of objects. Locomotion allows infants to explore their environment visually in a new, self-initiated manner. Crawling infants can view objects dynamically from different perspectives, learn to anticipate new positions of objects, and experience the invariant properties of objects. Infants' crawling ability is apparently related to a variety of enhanced abilities of visually processing objects: searching for hidden objects (Clearfield, 2004; Kermoian & Campos, 1988), integrating different object dimensions (Schwarzer, Jovanovic, Schum, & Duemmler, 2009), and mentally rotating objects (Schwarzer, Freitag, Buckel, & Lofruthe, 2013; Schwarzer, Freitag, & Schum, 2013). The latter studies suggest that effects of crawling and manually exploring objects are interchangeable. This finding seems plausible, since both motor experiences provide infants with the opportunity to view objects from different perspectives.

All of the studies just described used an age-held constant paradigm in which infants were classified into two groups—crawling and noncrawling. In such a paradigm, a third factor could contribute to the relation: Perhaps crawling infants are generally more advanced and mature than noncrawling infants. However, training studies indicate that locomotion and not a third factor leads to change in infants' visual perception (Dahl et al., 2013; Uchiyama et al., 2008). Infants who had not yet begun to crawl or walk were assigned randomly to a locomotive training (via a powered mobility device) group and a control group. Only infants in the locomotive training group increased in the dependent variables, such as responses to peripheral optic flow and cardiac responses of wariness of heights.

In summary, experiences gained when younger infants explore objects manually and when older infants crawl are associated with advanced visual processing of objects. The developing motor skills allow them to gain experiences that facilitate and drive this processing. Of course, the effects of infants' motor experiences act in combination with their biological maturation.

HOW ARE INFANTS' VISUAL EXPERIENCES LINKED TO PROCESSING FACES?

Faces form a special kind of visual stimulus. They possess several types of visual information, such as facial expression, direction of eye gaze, and speech cues, that are available in no other objects. As a result, special visual mechanisms process such information. Faces and other objects also share many general characteristics—both are multidimensional in nature and represent the main stimuli of daily life, but research also suggests differences in how they are processed. For example, newborns look longer at schematic stimuli with face-like arrangements than at stimuli of similar complexity that lack face-like configurations (e.g., Goren, Sarty, & Wu, 1975). In addition, like adults, infants process faces differently than objects; they use a configural processing mode and an analytical one (e.g., Schwarzer, Zauner, & Jovanovic, 2007), and face-selective event-related potentials exist even at that age (e.g., De Haan, 2001). Finally, learning is easier when faces, not objects, are used as stimuli; 6-month-olds anticipated a temporal sequence with faces more proficiently than with objects (Teubert et al., 2012).

Visual experience is a crucial determinant of face processing. Processing faces depends on the visual system receiving informative visual input at the beginning of life. Studies with bilateral cataract patients deprived of early visual experience suggest that visual experience during the first weeks and months of life is critical for normal development of some aspects of face processing (Mondloch, Le Grand, & Maurer, 2010). When 6-week-olds had congenital cataracts removed, their face preferences were similar to that of newborns, suggesting that postnatal face preference requires little early visual input (Mondloch, Lewis, Levin, & Maurer, 2013). However, early visual deprivation from congenital cataracts was associated with permanent deficits in later development of face processing, including holistic face processing (Le Grand, Mondloch, Maurer, & Brent, 2004) and processing of second-order relations in faces (Le Grand, Mondloch, Maurer, & Brent, 2001). In contrast, the development of processing facial features was not impaired (Le Grand et al., 2001).

The role of visual experience in the development of face processing is also evident when exploring how experience with certain face categories affects preference and recognition of faces in children with normal early visual experience, which is reflected in studies on the so-called other-race effect (ORE). The ORE suggests that children have difficulty discriminating between and recognizing faces from other-race categories compared to faces of their own-race category. Facial input received during the first 3 months is sufficient to drive a visual preference for own-race faces in infants (Bar-Haim, Ziv, Lamy, & Hodes, 2006; Kelly et al., 2007). Such preference coincides with 1- to 3-month-olds' natural daily exposure to faces documented from their own first-person perspective (Sugden, Mohamed-Ali, & Moulson, 2014). Infants at that age are exposed predominantly to own-race faces, particularly to female and adult faces of their own race. This early preference may be the starting point for ORE development, mainly ranging from 3 to 9 months (Heron-Delaney et al., 2011). Whereas Caucasian 3-month-olds discriminated between faces within four ethnic groups, Caucasian 6-month-olds discriminated faces within only two, and Caucasian 9-month-olds did so only within Caucasian faces (Kelly et al., 2007). A similar developmental course was found for Chinese infants when they were presented with faces from different ethnic categories (Kelly et al., 2009). The ORE was also observed when infants learned a temporal sequence of Caucasian and African faces within a visual expectation paradigm, indicating the robustness of the ORE across different tasks (Fassbender et al., 2012). However, when infants encounter people from other ethnic groups, they can discriminate faces from those groups. Caucasian infants who had perceptual training with Chinese faces or who had contact with African faces between 3 and 6 months discriminated those faces at 9 months. In contrast, Caucasian 9-month-olds who had not experienced Chinese and African faces could not discriminate them (Heron-Delaney et al., 2011; Spangler et al., 2012). Based on the concept of perceptual narrowing (Nelson, 2001), experience with faces of other races seems to slow or modify perceptual fine-tuning toward faces of one's own race.

The accumulated experiences with own-race faces associated with the onset of the ORE cause infants to change the processing mode of their own-and other-race faces. They start to narrow their holistic face processing only to own-race faces but not to other-race faces (Ferguson, Kulkofsky, Cashon, & Casasola, 2009). They also look at faces differently; 9-month-old Caucasian infants fixated more on the eyes of Caucasian faces and more on the mouth of African faces (Xiao, Xiao, Quinn, Anzures, & Lee, 2013).

In summary, after birth, structural visual information makes up the relevant experiences that build the neuronal architecture needed for developing the face-processing system. With increasing age, specific experience with face categories leads infants to fine-tune their face-processing system to those faces that are most relevant in their environment; infants become experts in processing faces they encounter most frequently. Such a process of perceptual narrowing occurs not only with faces as a type of stimulus class but also with language and music stimuli (Scott, Pascalis, & Nelson, 2007).

ARE RELEVANT EXPERIENCE EFFECTS DOMAIN GENERAL?

Although objects and faces are both visual in nature, the studies reported earlier suggest that object and face perception during infancy is determined by different types of experience. While visual processing of objects seems to be driven by experiences involving exploring objects and by locomotion, face processing depends on structured visual information, such as the face information of the infant's own race. This assignment fits nicely with the different affordances of objects and faces. Typically, objects are processed visually so individuals can act on them, underlining the relevance of advanced motor skills. In contrast, faces are processed visually for later recognition, emphasizing the relevance of processing and representing pure visual face information.

This assignment fits with the model of two visual systems (Milner & Goodale, 1995), in which the visual brain is divided into anatomically and functionally distinct pathways: a dorsal pathway for processing visual information of objects to guide motor actions and a ventral pathway for processing visual information for recognizing stimuli. In other words, motor skill acquisition may drive visual object processing via the dorsal pathway and specific visual experience may drive face processing via the ventral pathway (Figure 1).

However, do the effects of motor and visual experiences operate only within the corresponding domain or do they also act outside that domain? That is, can motor skills affect processing of faces, and can visual experience with a visual category affect infants' visual processing of objects?

Two studies suggest a cross-domain link between infants' motor skills and the processing of faces. In one, 3-month-olds were trained for 2 weeks in skills of manual object exploration and afterward, their spontaneous orientation to faces or objects was tested (Libertus & Needham, 2011). Exploratory skills increased infants' spontaneous orientation to faces over objects. Infants' general experience to act on objects may change their understanding of the social affordances offered by faces or people and open opportunities for triadic engagement with others. The other study revealed a U-shaped relation between 5- and 7-month-olds' sitting stage (nonsitters, near sitters, expert sitters)

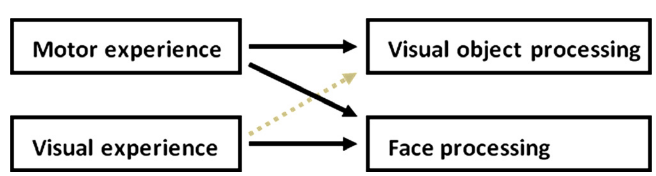

Figure 1. Proposed relation between motor/visual experience and object/face processing in infancy. Motor experience is related to visual object processing and face processing, whereas visual experience is related mainly to face processing. Research on the relation between visual experience and visual object processing is scarce.

and their holistic processing of upright faces (Cashon, Ha, Allen, & Barna, 2013). Nonsitters and expert sitters processed faces holistically, but nonexpert sitters failed to do so even when age was considered (Cashon et al., 2013). Learning to sit independently may contribute to infants' learning about the importance of upright faces; such learning temporarily causes the face-processing system to become overloaded until it incorporates the newly acquired information on the meaning of upright faces, suggesting that infants' face processing is associated with their acquisition of motor skills.

However, the types of motor behavior linked to processing faces and objects apparently differ in nature. It is not motor behavior linked to face processing that is associated with an active search for information, but rather the position from which infants view objects and their general experience of being effective in their environment. In contrast, motor behavior linked to object processing implies manual object exploration and mobility of the infant. Infants actively acquire object information, which they then use when processing objects visually.

Can an analog influence be observed between infants' visual expertise with a certain object class and their visual processing of those objects (see Figure 1)? To the best of our knowledge, no studies have reported an influence of infant expertise with a certain visual object category on their visual processing of those objects. One reason may be that infants rarely become experts of a visual object class without acting on the objects. Instead, infants' visual processing of objects is usually coupled with their motor activities. For example, when infants move independently, their vision helps them navigate through the world, perceive the properties of objects and surfaces, and stay upright (Schmuckler, 1993). Moreover, especially for small distances, infants need to grasp objects and explore them to learn about the visual properties of the objects. However, the resulting visual expertise with the visual object category is rooted in infants' motor experiences and not in their pure visual experience. Apparently, faces are the best example of a visual object in which infants nearly become visual experts without acting on the faces. This is because infants usually encode faces visually, recognize them, and learn to exchange emotional expressions with other faces without directly touching them. Therefore, and as already mentioned, such visual experiences constitute the driving force of face processing.

Researchers should test whether a link between nonaction-related visual expertise with objects and the visual processing of those objects exists in infancy. For example, infants could be trained to become familiar with a visual stimulus class without acting on it and then be tested on how they process and understand those objects that they have only seen.

CONCLUSIONS

The experience infants gain by exploring objects manually and by crawling apparently shapes how they process objects, and expertise with face categories shapes how they process faces. Moreover, motor skills not only drive visual processing of objects but are also apparently related to face processing. Consequently, the forces that drive face processing can be considered to be broad and general in nature, and they seem to be rooted in visual face expertise and motor inputs. This conclusion seems biologically reasonable because it ensures that such a vital function as face recognition operates as early and accurately as possible. We do not know whether the forces driving infants' visual processing of objects are related not only to infants' motor experiences but also to their visual expertise with objects; research is needed to address this question. All in all, motor experiences can be understood as a facilitator affecting processing across domains and can be ascribed a prominent role in infants' understanding of the visual world.

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