On the use of visual information in infant reaching actions
van Wermeskerken, M.M.

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Chapter 1

General Introduction
As adults we are experts in manipulating objects surrounding us. We know whether an object can be grasped or whether they are out of reach, and whether it is more appropriate to use one or two hands. Moreover, the reach and grasp movements themselves are mostly performed fluently and efficiently. Indeed, our perception of what an object affords for action, (e.g., its reachableness or graspableness), the selection of an appropriate action mode (e.g., reaching for it with one or two hands), and the control of the movement (e.g., the evolving arm speed or hand aperture) are perfectly adjusted to the object’s properties like its distance, size, weight, and shape. Considering that we were trying to reach and grasp objects ever since we were three months of age (or even earlier), it is not surprising that we are that skillful and barely make mistakes. Of course, infants this young are not as proficient as children or adults and, hence, their initially seemingly random and erratic reaching movements become increasingly more adaptive throughout the first year of life (Figure 1.1). This improvement is marked by an increased ability to perceive what an object affords for action, more adaptive action mode selection, and improved movement control (e.g., more smooth movement path towards the object).

![Figure 1.1](image_url) Infants performing reaching movements in the presented experiments (i.e., Chapter 4, 5, and 6, resp.).

In adults, there is a dominant paradigm that suggests that the use of visual information for the perception of objects, events, and situations, including what they afford for action, and the subsequent movement control is dissociated (Goodale & Milner, 1992; Milner & Goodale, 1995, 2008). More specifically, it is argued that perceiving what the environment affords for action and the subsequent movement execution of that action rely upon different sources of visual information and engage separate cortical areas (Haffenden & Goodale, 2000; Michaels, 2000; Milner & Goodale, 2008; van der Kamp, Savelsbergh, & Rosengren, 2001). This raises the issue
to what degree the use of visual information for these processes is already dissociated shortly after birth and how they develop (see also van der Kamp & Savelsbergh, 2000).

So far, the early development of these processes and their reliance on visual information has received only scant attention and it has remained unclear whether the use of visual information for these processes is dissociated in early infancy when reaching emerges, that is, the first few months after birth or (shortly) thereafter. Therefore, the main aim of the present thesis is to shed light upon the development of the use of visual information for perception (i.e., including affordance perception and action mode selection; see below p. 7) and movement control.

The ecological approach and the two-visual systems model

As will be evident from Chapter 2, the current thesis’ theoretical framework is provided by the ecological approach to perception and action, forwarded by James Gibson (1979/1986), and by the two-visual systems model, as proposed by Milner and Goodale (1995, 2008). As such, visual perception is defined as a process of picking up visual information from the optic array to directly guide goal-directed movements and/or to perceive the affordances (i.e., action possibilities) of the environment. Yet, the type of information exploited for movement control and visual perception (i.e., obtaining knowledge about objects, events, and situations, including their affordances) may be different given the different functional requirements of movement control and visual perception. Indeed, this differentiation in information use is in line with the two-visual systems model. According to this model, the human visual system is divided into two functionally dissociated and neuro-anatomically separate, but interacting, visual systems: vision for movement and vision for perception. These systems engage different cortical areas (see Figure 1.2) and can be distinguished on a behavioral level based on several attributes, such as the type of visual information that is exploited and the time span over which the information is retained and used (e.g., van der Kamp, Oudejans, & Savelsbergh, 2003; Westwood & Goodale, 2003). On the one hand, vision for movement, which is concerned with the online control of movements, mainly exploits egocentric (i.e., viewpoint dependent and context independent) sources of information that specify object properties (e.g., size) relative to the action system. This information is used instantaneously and decays quickly thereafter. Vision for perception, on the other hand, is engaged in obtaining knowledge about objects, events, and situations and primarily relies upon allocentric (i.e., viewpoint independent
and context-dependent) sources of information that specify objects relative to each other. This information can be exploited over longer time intervals. Importantly, the vision for perception system can also contribute to certain aspects of action. In particular, the perception of what an object affords for action (i.e., whether it is within or beyond reach) and the selection of an adaptive action mode (i.e., reaching with one or two hands) do engage vision for perception (Milner & Goodale, 2008). For instance, it has been shown that selecting one or two hands depending on object size relies on allocentric information (van Doorn, van der Kamp, & Savelsbergh, 2007). Also, if the online pick-up of visual information for movement control is perturbed (e.g., by occluding vision before movement onset), contributions of vision for perception are thought to become more dominant or perhaps even replace vision for movement (Westwood & Goodale, 2003; Westwood, Mceachern, & Roy, 2001).

Besides a thorough outline of the theoretical framework, Chapter 2 also provides a review of the literature with respect to the use of visual information for perception and movement control during early infancy. More specifically, it is reviewed to what degree the current literature supports the notion of an early dissociation in information usage for perception and movement control, as is observed in adults. Keeping in mind that most empirical evidence is indirect, the findings indeed may speak to, or at least do not rule out, a dissociation in information usage during early infancy, which suggests that the developments of vision for perception and vision for movement may follow their own developmental trajectories. Hence, the aim of the subsequent chapters is to

Figure 1.2 Depiction of the two visual streams. The ventral vision for perception stream (lower arrow) projects from the primary visual cortex to the inferior temporal cortex. The dorsal vision for movement stream (upper arrow) projects from the primary visual cortex to the posterior and superior parietal cortex.
explore more directly whether vision for perception and vision for movement processes are dissociated during early infancy and rely upon different sources of information. Yet, it should be noted here that the current thesis only includes behavioral data and thus remains suggestive with respect to the underlying neuronal circuitry. Therefore, phrases as 'vision for perception' and 'vision for movement' are used to refer to the detection and use of visual information to guide visual perception and movement control, respectively.

Outline of this thesis

In Chapter 3 we assess infants' reaching for moving objects in occlusion situations. Motivated by the two-visual systems model and based on findings in adults it is hypothesized that occlusion duration is the primary constraint on infants' control of reaching in occlusion situations. After all, it is in these situations (i.e., when online pick-up of visual information is perturbed) that vision for perception processes contribute to movement control (Hu, Eagleson, & Goodale, 1999; Westwood & Goodale, 2003; Westwood et al., 2001). Age-related effects, then, may reflect a change in interaction between the two systems.

The remaining three chapters (Chapters 4, 5, and 6) focus on infants' action mode selection or affordance perception and the subsequent movement control. More specifically, Chapter 4 is concerned with exploring the development of infants' action mode selection (i.e., one- or two-handed reaching) and control of reaching (i.e., scaling of bimanual hand aperture) for different-sized objects. It assesses whether these processes are dissociated and whether they are mutually constraining during early development. That is, whether adaptive action mode selection relative to object size also implies adaptive movement control, and vice versa. From the two-visual systems perspective, it is hypothesized that these processes are dissociated and may follow their own developmental trajectory (van der Kamp & Savelsbergh, 2000).

A subsequent issue is the type of information that is involved for affordance perception, action mode selection, and movement control. The two-visual systems model holds that affordance perception and action mode selection both mainly rely upon allocentric sources of information, whereas movement control primarily exploits egocentric sources of information (Michaels, 2000; Milner & Goodale, 2008; van der Kamp et al., 2001). The question whether such differentiation in information-use already exists in young infants is addressed in Chapter 5 and Chapter 6. That is,
in Chapter 5, we explore infants’ reaching for moving objects against a stationary or moving background. The background motion results in changes in allocentric information about the object’s velocity relative to its background, while leaving egocentric information about the object’s velocity relative to the infant unaltered. In line with the two-visual systems model, it is hypothesized that infants’ use of visual information is dissociated for action mode selection (i.e., reaching with the ipsi- or contralateral hand) and movement control (i.e., reaching kinematics), implying that background motion (i.e., allocentric information) should only affect infants’ action mode selection and have no effects on movement control.

The aim of Chapter 6 is comparable to the former chapter, but focuses on affordance perception rather than on action mode selection. That is, infants’ preferential reaching (i.e., reaching for one or the other object) is assessed whilst presented with stationary equidistant objects against an illusory Ponzo-like background. The texture gradient provided by this background makes objects appear to be located at different distances. Previous observations indicate that infants aged 5 months use this pictorial distance information (i.e., allocentric information) to guide their preferential reaching. More specifically, infants reach more often for the object that appears to be closer (and more strongly affords reaching) as compared to the object that appears to be more distant (Granrud & Yonas, 1984; Kavsek, Granrud, & Yonas, 2009; Yonas, Elieff, & Arterberry, 2002). As such, infants’ preferential reaching is considered to reflect their affordance perception (i.e., reaching for the object that more strongly affords reaching), which seems to be constrained by relative distance information provided by the illusory background. In this chapter, we try to replicate these findings with a Ponzo-like background, but also assess whether infants use this pictorial, allocentric information to control their reaching movements. In line with abovementioned observations, it is predicted that infants will reach more often for the perceptually closer object and, hence, that preferential reaching is constrained by allocentric, background information. Yet, movement control is hypothesized to be more reliant upon egocentric rather than allocentric sources of information and, thus, changes in allocentric information (i.e., relative distance) should not affect movement control. If so, this might suggest that indeed the use of visual information for affordance perception (i.e., as indicated by preferential reaching) and movement control are dissociated during early infancy. Consequently, in terms of the two-visual systems model this would point to an early dissociation between the two visual systems.
Finally, *Chapter 7* will summarize the main findings and discuss the theoretical implications. In addition, it will provide directions for future research.