Chapter 6

Getting the closer object? An information-based dissociation between vision for perception and vision for movement in early infancy

Accepted as:
Abstract

In human adults two functionally and neuro-anatomically separate systems exist for the use of visual information in perception and the use of visual information to control movements (Milner & Goodale, 1995, 2008). We investigated whether this separation is already functioning in the early stages of the development of reaching. To this end, six- and seven-month-old infants were presented with two identical objects at identical distances in front of an illusory Ponzo-like background that made them appear to be located at different distances. In two further conditions without the illusory background, the two objects were presented at physically different distances. Preferential reaching outcomes indicated that the allocentric distance information contained in the illusory background affected the perception of object distance. Yet, infants’ reaching kinematics were only affected by the objects’ physical distance and not by the perceptual distance manipulation. These findings were taken as evidence for the two-visual systems, as proposed by Milner & Goodale (2008), being functional in early infancy. We discuss the wider implications of this early dissociation.
Introduction

Over the last two decades, adult research has provided progressively more evidence that the human visual system is organized into two functionally dissociated and neuro-anatomically separate visual systems: vision for movement and vision for perception (Bridgeman, Gemmer, Forsman, & Huemer, 2000; Goodale & Milner, 1992, 2004b; Milner & Goodale, 1995, 2008; Rossetti & Pisella, 2002).\(^1\) The vision for movement system engages in the online control of goal-directed movements and projects from the primary visual cortex to the superior parietal cortex (i.e., dorsal stream). The vision for perception system is involved in the perception of objects, events and places, and in particular what actions they afford (e.g., avoiding versus intercepting, or one-handed versus two-handed grasping). This system projects from the primary visual cortex to the inferior temporal cortex (i.e., ventral stream). One attribute that distinguishes the two systems is the type of visual information that they preferably exploit (Haffenden & Goodale, 2000; Michaels, 2000; Milner & Goodale, 2008; van der Kamp, Oudejans, & Savelsbergh, 2003; van der Kamp, Savelsbergh, & Rosengren, 2001). The vision for movement system mainly detects egocentric (i.e., context-independent and viewpoint-dependent) information to control movements, whereas the vision for perception system primarily uses allocentric (i.e., context-dependent and viewpoint-independent) information to perceive what the situation offers for action.

An important line of evidence for this dissociation in information-usage, although still somewhat controversial (cf. Franz, Hesse, & Kollath, 2009; Smeets & Brenner, 2006), stems from visual illusions (e.g., Aglioti, DeSouza, & Goodale, 1995; Ganel, Tanzer, & Goodale, 2008). For instance, presenting an object embedded in the Müller-Lyer illusion affects the perception of its properties (e.g., length) or its affordances (e.g., one- or two-handed grasp), underlining that vision for perception uses context-dependent, allocentric information (i.e., the tails of the illusion). By contrast, the control of hand

\(^1\) Originally, the dorsal stream was referred to as “vision for action” (Goodale & Milner, 1992) rather than “vision for movement”. However, it is our contention that the term “movement” more directly speaks to the function of the dorsal stream than does the term “action”, which for example also includes the selection of an appropriate mode of action (see Goodale & Milner, 2008; van Doorn et al., 2007). In addition, it should be noted that the current study only includes behavioral data. That is, no brain-imaging techniques are used to validate activations in the ventral or dorsal stream. Therefore, the claims made in this paper are purely restricted to the behavioral level and are only suggestive with respect to the underlying neuronal circuitry. Hence, we use phrases as ‘vision for perception’ and ‘vision for movement’ to refer to the detection and use of visual information to guide visual perception and movement control, respectively.
aperture is scaled to the physical size of the object and remains largely immune to the illusion, demonstrating that vision for movement primarily exploits context-independent, egocentric information rather than allocentric information (Otto-de Haart, Carey, & Milne, 1999; van Doorn, van der Kamp, & Savelsbergh, 2007).

Whether the dissociation between vision for perception and vision for movement is present in early infancy when reaching develops, or whether it emerges thereafter has not been tested so far. Indeed, recently several authors have alluded to an early dissociation (or different developmental trajectories) of visual perception and movement control (Atkinson, 2000; Babinsky, Braddick, & Atkinson, 2012; Bertenthal, 1996; DeLoache, Uttal, & Rosengren, 2004; Newman, Atkinson, & Braddick, 2001; Street, James, Jones, & Smith, 2011; see also van der Kamp & Savelsbergh, 2000; van Wermeskerken, van der Kamp, & Savelsbergh, 2010). Yet, a direct investigation as to whether the use of information is dissociated according to these functions is still lacking. Hence, we aimed to assess whether 6- and 7-month-old infants’ use of visual information is dissociated for visual perception and movement control. To this end, we manipulated allocentric information by using a Ponzo-like illusion (i.e., a texture gradient that creates an illusion of size and distance), which would differentially affect affordance perception and movement control if indeed the information-usage is dissociated (see Gonzalez, Ganel, Whitwell, Morrissey, & Goodale, 2008).

Habituation and preference looking methods have demonstrated that infants from 5- to 6-month-olds discriminate between displays that vary in their pictorial depth information (e.g., line junctions, texture gradients, shading, relative size) (e.g., Kavsek, Yonas, & Granrud, 2012). In addition, when presented with equidistant objects against a background that creates an illusion of depth (such as the Ponzo illusion), 5- to 6-month-old infants reach more frequently for an object that appears closer (as specified by allocentric information) as compared to an object that appears more distant (i.e., preferential reaching), albeit under monocular conditions only (e.g., Granrud & Yonas, 1984; Kavsek, Granrud, & Yonas, 2009; Yonas, Elieff, & Arterberry, 2002). In other words, the object that appears closer affords reaching more strongly. In this respect, we assume that infants’ preferential reaching engages vision for perception similar as has been shown for affordance perception in adults. For example, objects afford one-handed or two-handed grasping dependent on their perceived size. Accordingly, van Doorn et al. (2007) showed that the choice to grasp an object with one or with two hands was affected by visual illusions (i.e., allocentric information).
and, hence, entailed vision for perception. The subsequent grasping movement, however, was largely immune to the illusion, pointing to the engagement of vision for movement (see also Aglioti et al., 1995; Ganel et al., 2008; Milner & Goodale, 2008). In a similar vein, preferential reaching is not considered to be part of the movement execution itself, but rather is considered to reflect affordance perception (and actually precedes the execution of the reach). As such, the reported effects of pictorial depth information on infants’ preferential reaching are consistent with the proposition that affordance perception involves the exploitation of allocentric information through the vision for perception system (Milner & Goodale, 2008; van der Kamp et al., 2003; van der Kamp, Rivas, van Doorn, & Savelsbergh, 2008). The preferential reaching studies, however, do not speak to the issue whether allocentric information (or egocentric information for that matter) is exploited to control the unfolding reaching movement, nor is there any other study that examined the contribution of allocentric information on young infants’ reaching (for an overview see van Wermeskerken et al., 2010). The current study, therefore, is the first to directly compare the purported differential use of allocentric and egocentric sources of information in affordance perception (i.e., preferential reaching) and the control of movement during early infancy.

The current experiment used and extended a paradigm that was introduced and validated by Yonas and colleagues (e.g., Yonas et al., 2002). We investigated 6- and 7-month-old infants’ preferential reaching for same-sized objects presented at the same distance against a Ponzo-like background that induces an illusion of depth (Figure 6.1a and b). In line with previous observations, we expected that the illusory background would result in a higher frequency of reaches directed at the perceptually close object as compared to the perceptually distant object (e.g., Kavsek et al., 2009). In addition, and in order to explore contributions of allocentric information sources during movement control, we compared infants’ reaching kinematics for reaches directed at the perceptually close with reaches directed at the perceptually distant object. A control condition in which identical objects were presented against a non-illusory background (Figure 6.1c) but at different physical distances (i.e., the objects were equidistant, only the distance of the infant to the display was varied) served to reveal adjustments in reach kinematics as a function of distance. Though previous findings suggest that the end position of an infant’s reaching movement is adjusted to the position of the object by 4 months of age (Fetters & Todd, 1987; Field, 1976a, 1976b; von Hofsten, 1977; Yonas & Hartman, 1993), less is known about how infants’ reaching kinematics
vary with respect to manipulation of distance. Findings of Fetters and Todd (1987) point to an increase in the number of movement units with distance. Moreover, based on prior observations in older children and adults, we also anticipated that a larger distance would result in an increase in movement time, a higher peak velocity, and a shorter relative acceleration time (i.e., relative time to peak velocity) than a smaller distance (e.g., Chieffi & Gentilucci, 1993; Jakobson & Goodale, 1991; Jeannerod, 1984; Kudoh, Hattori, Numata, & Maruyama, 1997; Paulignan, Frak, Toni, & Jeannerod, 1997; Zoia et al., 2006). Critically, we predicted that if the use of information for affordance perception and movement control is dissociated at 6 to 7 months, no effects of the perceptual distance manipulation (i.e., reach to the perceptually close versus perceptually distant object in the illusory conditions) on infants’ reaching kinematics would occur. By contrast, if there is no such dissociation, and infants (also) rely on allocentric information in the control of reaching, similar adjustments in reaching kinematics were expected in response to the perceptual distance manipulation as for the physical distance manipulation.

**Methods**

**Participants**

Sixteen 6-month-old ($M = 6.05$ months, $SD = 0.14$) and twelve 7-month-old ($M = 7.37$ months, $SD = 0.11$) healthy full-term infants participated in the study after their parents gave written informed consent. Six additional infants (three 6-month-olds and three 7-month-olds) were tested but excluded from the analysis because of fussing, crying or not reaching. The experiment was approved by the Ethical Committee of the Medical Faculty at Uppsala University and conducted in accordance with the standards specified in the 1964 Declaration of Helsinki.

**Apparatus**

Infants sat in front of a whiteboard (60 cm x 92 cm) on which one of two patterned backgrounds was affixed using magnets (see Figure 6.1). The backgrounds measured 30 cm x 96 cm and almost covered the infants’ entire field of view. A black cloth (1.5 m x 1.8 m) occluded the surroundings of the display to prevent infants getting distracted. In front of the backgrounds two identical objects were attached to the display with magnets. The objects afforded one-handed grasping (diameter of 3 to 4 cm) and were
always presented on the same horizontal level 7.7 cm from the center of the background. One background consisted of the Ponzo-like illusion and was presented at a distance of 25 cm from the infant. The texture gradients in the Ponzo-like illusions result in an illusion of distance: an object presented in front of the large squares (i.e., 5 cm side) appears perceptually closer in comparison to an object presented in front of the small squares (i.e., 2 cm side). The illusory background was presented in two orientations with the perceptually close object either to the right or left (cf. Figure 6.1a, b) to control for possible reaching preferences to the right or left side. The non-illusory background (Figure 6.1c) only contained squares of equal size (i.e., 3 cm). This background was presented at distances of 20 cm (physically close) and 30 cm (physically distant) from the infant.

Infants were seated in an infant chair with adjustable supports such that the infants had their trunk straight, head upright, and limbs free to move. The entire experiment was conducted under monocular viewing (see e.g., Yonas et al., 2002), using an eye-patch to cover one eye of the infant. The eye that was covered was varied randomly across infants.

Reaching behavior was recorded using a three-camera ProReflex system (Qualisys Inc., Sweden) with a sampling frequency of 200 Hz. Infants wore bracelets with two reflective markers on both wrists to monitor the reaching movements. Another reflective marker was attached to the back of the chair to monitor the distance of the

![Figure 6.1](image)

**Figure 6.1** Stimulus conditions of the present study. (a) The illusory background with the right object being perceptually close (and the left object being perceptually distant) and (b) with the right object being perceptually distant (and the left object being perceptually close). (c) The non-illusory background presented at two different physical distances.
infant from the display across conditions.\textsuperscript{2} A video camera (Logitech) was placed above the experimental setting to record the whole trial with a sampling frequency of 15 Hz. The camera and motion capturing system were synchronized.

**Procedure**

Infants were positioned in front of the display with their body midline aligned to the center of the display to enable reaching to the left and the right object with both hands. A trial started by moving the infant toward the display so that the objects came within reach. A trial lasted for 60 seconds after which the infant was withdrawn from the display. When the infant touched or grasped one or both objects, he or she was also moved backwards, and a new pair of objects was attached to the display and the procedure was repeated. Hence, during one trial several reaches could be performed. After completion of the trial the background was replaced and a new trial started. In between trials infants were allowed to play with the objects.

The experiment started by presenting one pair of objects without background to familiarize the infant with the experimental setting. Thereafter, the four conditions (i.e., the two non-illusory conditions [physically close, physically distant] and the two illusory conditions [perceptually close to the right, perceptually distant to the right]) were presented in blocks of four trials in which each condition was presented once in random order. The experiment was terminated when the infant reached a maximum of 12 trials with one or multiple reaches or consistently refused to reach, got fuzzed, or cried. The experiment took about 20 minutes.

**Data analysis**

*Preferential reaching.* A reach was defined as an arm movement of the infant directed at one of the objects with the hand approaching the object within a fist-size distance and with the gaze directed at this object. Using the video recordings, infants’ *preferential reaching* was derived by determining the object that was first contacted by either hand. A second independent observer analyzed about 15% of the trials to assess inter-rater reliability. Cohen’s kappa was .91.

For each infant and each background condition (i.e., the data of the two non-

\textsuperscript{2} To facilitate the analysis, the positions of the objects were recorded prior to testing by attaching two reflective markers at both object positions. These object positions were used for movement segmentation only.
illusory conditions were merged), the proportion of reaches directed to the right side of the display was computed, and submitted to a repeated measures ANOVA with background (non-illusory, perceptually close at the right side and perceptually distant at the right side\(^3\); Figure 6.1a, b resp.) as a within-subject factor and age (6, 7 months) as a between-subjects factor. This and the subsequent dependent variables were distributed normally and had equal variances. Moreover, for this and subsequent analyses of variance, we report Hyun-Feldt adjustments of the p values in cases where the sphericity assumption was violated (i.e., epsilon's > 1.0). All post hoc comparisons were conducted using the Bonferroni adjustment (\(p < .05\)).

**Reaching kinematics.** The position data obtained by the Qualisys motion analysis system were identified using MATLAB (version 7.4.0, Release R2007a). Before analyzing the data, each trial of 60 seconds was divided into reaches. Subsequently, reach onset (i.e., the moment at which the hand started to move towards the object) and the end of the reach (i.e., the moment at which the hand contacted the object or refrained from the object in cases of no contact) were determined using the multiple sources of information method (Schot, Brenner, & Smeets, 2010). This method entails several functions being formulated that together compute the likeliness that a certain instant is the onset or end of a movement. The moment with the highest likelihood is taken to be movement onset or end (for a detailed description of the objective functions we refer to van Wermeskerken, van der Kamp, & Savelsbergh, 2011a). In cases where after movement segmentation position data was incomplete, a least squares approach for interpolation was used if the missing data did not exceed 100 ms, otherwise the reach was excluded from further analysis. Subsequently, the position data were filtered with a second-order recursive Butterworth low-pass filter with a cutoff frequency of 10Hz. Finally, infants’ reaching kinematics were analyzed. That is, for each infant and each reach we computed (1) the duration of the reach, (2) peak velocity, (3) relative moment of peak velocity (i.e., acceleration phase), and (4) number of movement units. A movement unit was defined as consisting of an acceleration and a deceleration phase which lasted at least 100 ms, yielded a maximum velocity of at least 10 cm/s, and in which the difference between both velocity minima and the velocity maximum exceeded 2 cm/s (Thelen, Corbetta, & Spencer, 1996; von Hofsten, 1991; von Hofsten & Rönnqvist, 1993). For each infant and each of the four conditions,

\(^3\) We only report the proportion of reaches to the right object as our measure for reaching preference. Notice however that this is fully complementary to the proportion of reaches directed at the left object, and hence, the statistical results for this measure are identical.
averages of these kinematic variables were computed. We first examined which of these variables differentiated between the physical close and distant conditions (i.e., the conditions with non-illusory background) and then assessed differences for these variables for reaches toward the perceptually close and perceptually distant object in the illusory conditions. Hence, first reach duration, peak velocity, relative time to peak velocity, and the number of movement units were submitted to a repeated measures MANOVA with physical distance (close, distant) as within-subject factor and age (6, 7 months) as between-subjects factor. Subsequently, the variables that were significantly affected by physical distance were submitted to a repeated measures MANOVA with perceptual distance (close, distant) as within-subject factor and age (6, 7 months) as between-subjects factor.

Results

Preferential reaching

Twenty-three out of 28 infants performed reaches in all four conditions. On average these infants performed 27-28 reaches, resulting in a total of 631 reaches.

We assessed whether the illusory background influenced infants’ preference to reach for the right or left object. To this end, we first established for each infant the proportion of reaches for the right and left object in the two non-illusory conditions (i.e., physically close and physically distant), and then determined whether the illusory background changes these proportions toward more or less reaches for the illusory close or distant object respectively. For instance, if in the non-illusory conditions an infant prefers to reach to the right object (this would be indicated by a higher proportion of reaches to the right object, see footnote 3), then for the illusory background condition we expect this preference to be more pronounced when the perceptual close object is presented on the right (this would be indicated by an even higher proportion of reaches toward the right) or to be reduced or reversed when the perceptual distant object is on the right (as would be indicated by a decrease in the proportion of reaches toward the right).

Figure 6.2 shows that in the non-illusory background conditions the infants had a preference to reach for the right object (i.e., proportion of reaches directed to the right object was more than .5). In addition, the reaching preference was altered in the illusory background conditions, in particular when the right object was perceptually
distant. A RM-ANOVA on the proportion of reaches directed to the right object with background (non-illusory, perceptual close on the right, perceptually distant on the right) as within-subject factor and age (6, 7 months) as between-subjects factor indeed revealed a significant effect for background ($F(2,42) = 8.0, p < .01, \eta_p^2 = .28$). Post hoc comparisons revealed that infants had significantly lower proportion of reaches to the right object when the illusory background made it appear more distant as compared to the non-illusory background condition or when the illusory background made it appear closer (both $p$’s < .01). Yet, infants did not reach more frequently to the right object when it was presented in front of an illusory background that made it appear closer as compared to the non-illusory condition ($p > .1$). There was neither a significant effect of age, nor a significant interaction effect between age and condition.

Finally, we explored on an individual basis whether infants responded to the illusion. That is, infants who directed more than 50% of their reaches towards the perceptually close object (irrespective of the side at which it was presented) were coded as responders to the illusory background, while the remaining infants were coded as non-responders. Note that all infants were included in this analysis ($n = 28$), since they all performed reaches in the illusory conditions. Overall, this revealed that 19 out of 28
infants (i.e., 68%) responded to the illusion. Indeed, the majority of the 6-month-olds, i.e., 13 out of 16 (81%) responded to the illusion, whereas only half of the 7-month-olds (i.e., 6 out of 12) were classified as responders.

In sum, the findings replicate previous observations that infants’ reaching preferences are affected by illusory distance information. Perusal of the individual data suggests that more than half of the infants responded to the illusory information.

Table 6.1 Mean values and standard deviations of kinematic parameters with respect to object distance for each age group.

<table>
<thead>
<tr>
<th>Kinematic parameter</th>
<th>Physically Close</th>
<th>Physically Distant</th>
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<tbody>
<tr>
<td>Movement time (s)</td>
<td></td>
<td></td>
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<tr>
<td>6 months</td>
<td>1.91 ± 0.35</td>
<td>1.80 ± 0.46</td>
</tr>
<tr>
<td>7 months</td>
<td>1.49 ± 0.26</td>
<td>1.86 ± 0.32</td>
</tr>
<tr>
<td>Peak velocity (cm/s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 months</td>
<td>42.7 ± 9.9</td>
<td>60.2 ± 19.1</td>
</tr>
<tr>
<td>7 months</td>
<td>54.3 ± 6.5</td>
<td>65.8 ± 5.6</td>
</tr>
<tr>
<td>Time to peak velocity (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 months</td>
<td>27.1 ± 15.7</td>
<td>37.9 ± 17.4</td>
</tr>
<tr>
<td>7 months</td>
<td>34.5 ± 21.3</td>
<td>37.1 ± 9.2</td>
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<tr>
<td>Number of movement units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 months</td>
<td>3.8 ± 0.7</td>
<td>4.6 ± 1.2</td>
</tr>
<tr>
<td>7 months</td>
<td>3.2 ± 1.1</td>
<td>5.1 ± 0.8</td>
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</table>

Reaching kinematics

To examine whether the illusory background not only influenced preferential reaching but also affected movement control, we first assessed what kinematic variables systematically vary as a function of physical distance. In a subsequent step, we compared these kinematic variables for reaches directed towards the perceptually close object with reaches that were directed towards the perceptually distant object. Note that in doing so, we do not have to take the side at which the object is presented into account as was done for preferential reaching.

Effects of physical distance on reaching kinematics.

Of the 23 infants who performed reaches in all conditions, 2 were excluded from subsequent analyses due to too much missing data. Of the remaining 21 infants a total of 204 reaches was included (97 reaches in the physically close and 107 in the physically distant condition).

An overview of infants’ reaching kinematics per age group is provided in Table 6.1. A MANOVA with repeated measures with the kinematic variables as dependent
variables revealed a main effect of distance (Wilks $\Lambda = .351$, $F(4,16) = 7.4$, $p < .01$, $\eta_p^2 = .65$) and a marginal interaction effect of Age x Distance (Wilks $\Lambda = .603$, $F(4,16) = 2.6$, $p = .073$, $\eta_p^2 = .40$). There was no main effect of age ($p > .1$). Separate univariate analyses of variance indicated that with longer distances infants moved their hands faster to the object (i.e., higher peak velocities; $F(1,19) = 23.7$, $p < .001$, $\eta_p^2 = .56$) and performed more movement units ($F(1,19) = 17.8$, $p < .001$, $\eta_p^2 = .48$). Moreover, an interaction effect of Age x Distance was revealed for reach duration ($F(1,19) = 5.4$, $p < .05$, $\eta_p^2 = .22$). Post hoc comparisons showed that this effect was due to an increase in reach duration for the 7-month-olds with distance ($p < .05$), but not for the 6-month-olds ($p > .1$).

**Table 6.2** Mean values and standard deviations of kinematic parameters with respect to perceptual object distance for each age group.

<table>
<thead>
<tr>
<th>Kinematic parameter</th>
<th>Perceptually Close</th>
<th>Perceptually Distant</th>
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<tbody>
<tr>
<td>Movement time (s)</td>
<td></td>
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</tr>
<tr>
<td>6 months</td>
<td>1.77 ± 0.38</td>
<td>2.0 ± 0.58</td>
</tr>
<tr>
<td>7 months</td>
<td>1.55 ± 0.24</td>
<td>1.68 ± 0.49</td>
</tr>
<tr>
<td>Peak velocity (cm/s)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 months</td>
<td>48.9 ± 10.6</td>
<td>49.2 ± 11.3</td>
</tr>
<tr>
<td>7 months</td>
<td>52.8 ± 15.8</td>
<td>56.8 ± 10.2</td>
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<tr>
<td>Number of movement units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 months</td>
<td>4.3 ± 1.4</td>
<td>4.7 ± 1.4</td>
</tr>
<tr>
<td>7 months</td>
<td>4.3 ± 1.1</td>
<td>4.4 ± 1.2</td>
</tr>
</tbody>
</table>

*Effects of perceptual distance on reaching kinematics.*

Although all infants performed reaches in these illusory conditions, two infants only reached for the perceptually close object and were therefore excluded from the analyses. Of the remaining 26 infants a total of 335 reaches was included (175 to the perceptually close and 160 to the perceptually distant object).

The kinematical variables that were significantly affected by physical distance (i.e., reach duration, peak velocity, and number of movement units) were taken as dependent variables in the MANOVA with repeated measures. This did not reveal a main effect of distance, age or interaction effect between age and distance (all $p$’s > .1; see Table 6.2). Together, these findings indicate that infants’ reaching kinematics were not significantly affected by perceptual distance information.

Subsequently, we assessed whether infants who responded to the illusion showed different reaching kinematics than infants who did not respond to the illusion. This was explored by submitting reach duration, peak velocity, and the number of
movement units as dependent variables into a MANOVA with repeated measures with distance (perceptually close, perceptually distant) as within-subject variable and group (responders, non-responders) as between-subjects factor. This analysis did not reveal any significant main or interaction effects (all $p$’s > .1). Hence, irrespective of whether infants responded to the perceptual distance information (i.e., reaching more frequently for the object that was perceptually close), reaching kinematics remained unaffected by the illusory information.

Finally, we examined whether infants who were categorized as responding to the illusion adapted their reaching kinematics to the objects’ perceptual distance. This was done by assessing whether the responsiveness to the illusion (as indicated by the proportion of reaches towards the perceptually close object) was correlated to the difference in peak velocity for reaches directed at the perceptually distant and close object. We hypothesized a positive correlation if infants relied on the same illusory distance information for perceiving action opportunities and for the control of movement. A Pearson product correlation, however, did not reveal such a relation ($r(18) = -.22, p > .1$). We repeated this procedure for the number of movement units and reach duration, but, again, no significant positive correlations were observed ($r(18) = -.25, p > .1$ and $r(18) = -.1, p > .1$, resp.). Hence, the degree to which infants responded to the illusory background information did not relate to any adjustments in reaching kinematics.

**Discussion**

There is well-established evidence that in human adults the use of visual information for vision for perception and vision for movement is dissociated (e.g., Bruno, Bernardis, & Gentilucci, 2008; Ganel et al., 2008; Milner & Goodale, 2008). Although recently, findings demonstrated a similar dissociation in toddlers as young as 16 to 18 months (Street et al., 2011), it remains indecisive whether this dissociation in information usage is already functional during early infancy when goal-directed reaching emerges or whether it develops thereafter. The aim of the present paper, therefore, was to address this issue by investigating 6- and 7-month-old infants’ use of visual information for the perception of affordances of the environment (i.e., as reflected by preferential reaching) and movement control (i.e., as reflected in the reaching kinematics). To this end, we varied allocentric information sources by presenting objects in front of a Ponzo-like background, which creates an illusion of depth (and size). This manipulation affected
preferential reaching (i.e., infants showed an enhanced preference for the perceptually closer object), indicating that infants exploited allocentric information for affordance perception. However, the manipulation did not influence the subsequent reaching movement, even though the infants clearly adapted the kinematics of the reach to the physical distance of the object. These findings support the conjecture that already in infants as young as six months there exists a dissociation between the use of visual information for perception and for the control of movements. Before returning to the wider implications of this dissociation, we first discuss the implications of the current findings for the young infants’ use of information for perception and movement control in their own right.

Infants' use of allocentric information in affordance perception

The present findings replicate previous observations of Yonas and colleagues (e.g., Yonas, Cleaves, & Pettersen, 1978; Yonas et al., 2002) that infants’ preference to reach for one or the other object is modulated by monocular pictorial depth information. Pictorial depth information is an allocentric source of information, because it specifies object distance relative to other objects. Therefore, the observed reaching preferences indicate that 6- and 7-month-old infants exploit allocentric sources of information to perceive the objects’ affordances. Yet, the individual analysis also reveals that not all infants used monocular pictorial depth information for preferential reaching. Indeed, the individual differences are pertinent for understanding when reliance on pictorial depth information emerges (see also Yonas et al., 2002). That is, some studies reported that infants increasingly used pictorial depth information between 5 to 7 months of age (e.g., Arterberry, Yonas, & Bensen, 1989; Yonas et al., 2002; Yonas et al., 1978), while others failed to show any developmental changes (e.g., Arterberry, 2008). Instead of the infants coming to rely progressively more on pictorial information for distance perception, the present study points to the emergence of sensitivity for pictorial depth information around 6 months of age, but with some individual onset differences (Yonas et al., 2002). Hence, prior reported age-differences based on group averages might actually reflect that a larger proportion of infants start to exploit pictorial depth information, rather than infants gradually becoming more sensitive to these information sources.

Nevertheless, the observation that not every individual infant’s reaching preference was affected by pictorial depth information does not necessarily imply that
these infants had not yet developed sensitivity to pictorial depth information. That is, an infant’s reaching preference is likely dependent upon other factors than perceived distance alone. For instance, previous work of Yonas and colleagues point to more pronounced influence of pictorial depth information on preferential reaching when the objects are presented at a critical distance beyond which the objects are out of reach (Yonas, Granrud, Arterberry, & Hanson, 1986; Yonas et al., 2002). In addition, an infant’s reaching preference may also be modulated by an inclination to reach with the left or right hand (e.g., Corbetta & Thelen, 1999; Fagard & Lockman, 2005), or to reach for larger rather than smaller objects. Newman et al. (2001), for example, suggested that infants aged between 5 and 8.5 months display a preference to look and reach for the larger of two objects when presented at the same distance. In fact, in the present study, the pictorial information contained in the illusory background also results in the perceptually closer object to appear smaller relative to the perceptually distant object (i.e., it occludes less background texture). Accordingly, an influence of pictorial size information on infants’ preference to reach for the larger object may potentially neutralize the effect of pictorial depth information to reach for the closer object. Although this leads to an underestimation of the role of pictorial depth information in the present study, it would still substantiate the crucial role for allocentric information in preferential reaching and, hence, affordance perception.

**Infants’ use of egocentric information in movement control**

The current study is the first to examine the kinematics of reaching as a function of distance in early reaching. It is generally believed that 6- to 7-month-olds’ reaching is under visual guidance rather than being ballistic or pre-programmed (Bushnell, 1985; see also e.g., Lockman, Ashmead, & Bushnell, 1984; van Wermeskerken et al., 2011a; von Hofsten & Fazel-Zandy, 1984; von Hofsten & Rönnqvist, 1988). The current observation that infants as young as six months adapt reaching kinematics to variations in distance is consistent with this contention, especially with respect to the increase in movement units with distance. In fact, to some extent, the reaching kinematics are reminiscent of child- and adult-like visually guided reaching, in which the largest adjustments also occur during the final part of the reach (i.e., deceleration phase; e.g., Glover & Dixon, 2001; Jeannerod, 1984; Marteniuk, Leavitt, MacKenzie, & Athenes, 1990; but see Jakobson & Goodale, 1991). More specifically, like in children and adults, the 6- and 7-month-olds showed higher peak velocities and longer reach
durations with an increase in object distance, although the latter only reliably occurred among the 7-month-olds (e.g., Chieffi & Gentilucci, 1993; Jakobson & Goodale, 1991; Kuhtz-Buschbeck, Stolze, Johnk, Boczek-Funcke, & Illert, 1998; Zoia et al., 2006). Moreover, the infants produced reaches that consisted of more movement units (i.e., corrective movements) with an increase in distance (see also Fetters & Todd, 1987). A closer look revealed that this increase mainly occurred during the last part of the reach (i.e., after peak velocity)\(^4\), which points to a larger degree of visual control towards the end of the reach, as is also observed in older children and adults.

Infants are most likely to visually guide their reaching movements on basis of egocentric sources of information, in line with the proposal of Milner and Goodale (1995, 2008). After all, infants’ reaching kinematics were not affected by allocentric depth information made available by the Ponzo-like background, not even for infants who clearly exploited allocentric depth information to select the nearer of two objects. This is not to say, however, that reliance on allocentric information sources other than relative distance can be entirely ruled out. By isolating egocentric sources of information (e.g., presenting glowing objects in the dark, see Robin, Berthier, & Clifton, 1996), future studies should uncover to what extent allocentric information contributes to movement control (for a detailed argument see van Wermeskerken et al., 2010).

**Dissociation in information usage between vision for perception and vision for movement**

The current findings indicate that a dissociation in information usage for affordance perception and movement control exists in infants as young as 6 months. In terms of the two-visual systems model proposed by Milner and Goodale (1995, 2008), this suggests that the dissociation between vision for perception and vision for movement is functional at this age. This functional dissociation early in the development of visual perception and action sheds light on previous seemingly contradictory findings. For

\(^4\) That is, the mean number of movement units after peak velocity was submitted to a RM-ANOVA with distance (close, distant) as within-subject factor and age (6, 7 months) as between-subjects factor. This revealed that infants performed significantly more movement units with an increase in distance \(F(1,19) = 11.89, p < .01, \eta_p^2 = .39\). In addition, there was a marginal interaction effect between age and distance \(F(1,19) = 4.21, p = .054, \eta_p^2 = .18\), which indicated that the increase in movement units was larger in 7-month-olds \(p < .01\) than in 6-month-olds \(p > .1\). A similar analysis performed on the number of movement units with perceptual distance as within-subject factor and age as between-subjects factor did not reveal any significant effects (all \(p\)'s > .1).
instance, whereas 4- to 10-month-old infants' visual perception of moving objects (as indicated by means of habituation) does not abide by principles of inertia (Spelke, Katz, Purcell, Ehrlich, & Breinlinger, 1994), 6- to 7-month-olds' arm, head, and eye movements toward moving objects do conform to this principle (Bertenthal, Longo, & Kenny, 2007; von Hofsten, Vishton, Spelke, Feng, & Rosander, 1998). This discrepancy can be resolved if the use of information for perception and the use of information for movement control are distinct and follow their own developmental trajectories (e.g., van der Kamp & Savelsbergh, 2000, 2002; van Wermeskerken et al., 2010, 2011a). This raises the issue of the dependency between vision for perception and vision for movement on the developmental time scale. It has been argued that the development of vision for perception necessarily precedes the development of vision for movement (e.g., Atkinson, 2000; Atkinson et al., 2003), although the example above questions the generalizability of such a claim. Yet, although the present study provides evidence that the two systems are dissociated with respect to information usage in real time, this does not preclude that they interact on longer time scales. Indeed, recent findings point to mutual influences after brief periods of learning. For instance, Rakison and Krogh (2011; see also van Hof, van der Kamp, & Savelsbergh, 2008) demonstrated that experiencing the causal effects of one's movements (i.e., infants wore red sticky mittens that allowed them to displace green balls) enhanced 4.5-month-old infants' ability to visually discriminate between causal and non-causal events (i.e., a stationary green ball started to move after it was contacted by a moving red ball). Likewise, 4-month-old infants performed more anticipatory eye movements after watching a series of related visual events (Johnson & Shuwairi, 2009). These findings suggest that on time scales beyond real time, vision for perception and vision for movement can induce adaptive changes onto each other. Clearly, future efforts should be directed at portraying infants’ performance in visual perception and movement control tasks over a longer time span (i.e., learning and development) to see how the two systems mutually constrain each other.

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