Perception, 2013, volume 42, pages 828–834

doi:10.1068/p7460

Infants see illusory motion in static figures

So Kanazawa[1], Akiyoshi Kitaoka[2], Masami K Yamaguchi[3]
[1] Department of Psychology, Japan Women's University, 1-1-1 Nishiikuta, Kawasaki City, Kanagawa 214-0037, Japan; e-mail: kanazawas@fc.jwu.ac.jp; [2] Department of Psychology, Ritsumeikan University, 56-1 Toji-in Kitamachi, Kita-ku, Kyoto 603-8577, Japan; [3] Department of Psychology, Chuo University, 742-1 Higashinakano Hachioji-shi, Tokyo 192-0393, Japan
Received 2 February 2013, in revised form 21 July 2013

Abstract. We investigated illusory motion perception in 6-to-8-month-old infants using a static figure which produces strong illusory motion. In experiment 1 we prepared a control figure, which was physically similar to the illusory motion figure but which did not produce illusory motion. We presented the illusory figure and the control figure side-by-side, and measured infants' looking time at the target illusory figure. Results showed that the infants' looking time at the illusory figure was significantly longer than that for the control. In experiment 2 we made another set of stimuli consisting of the same local pattern used in experiment 1, but which did not produce illusory motion. The results showed that no preferences were observed in experiment 2. These results suggest that 6-to-8-month-old infants perceive illusory motion in static figures.

Keywords: infants, visual illusion, illusory motion, preferential looking

1 Introduction

A static figure called "rotating snakes" (http://www.ritsumei.ac.jp/~akitaoka/index-e.html) (target area of figure 1a) produces a large amount of illusory motion. This stimulus was invented by Kitaoka (2003) and was recently investigated psychophysically (Backus and Oruc 2005; Beer et al 2008; Hisakata and Murakami 2008; Murakami et al 2006) and neurophysiologically (Conway et al 2005). The illusory motion comes from the local arrangement of yellow, blue, white, and black regions. Kitaoka and Ashida (2003) showed that the illusion depends on the fact that black and white are higher contrast than blue and yellow and produce faster responses. Conway et al (2005) showed that these responses occur in the neurons in V1 and MT of macaque brains. Kuriki et al (2008) found using fMRI that the visual cortex in the human brain also responds to this illusion.

Previous research into perceptual development has demonstrated that infants can see illusory patterns such as subjective contour (Ghim 1990; Kavsek 2002; Otsuka and Yamaguchi 2003) or modal and amodal completion behind the occluders (Johnson and Aslin 1995; Kellman and Spelke 1983; Otsuka et al 2006). However, no infant research, especially on illusory motion perception in static figures, has been reported. Here we report studies on the development of local and global motion mechanisms in infants using a static figure called rotating snakes. In order to investigate the development of motion perception, we used this figure because it has much more illusory motion than any other static figure. We observed infants' preferential looking behavior at this figure on the basis of the hypothesis that infants will prefer to look at illusory motion information.

Previous research on infant visual development has shown that a sensitivity to basic relative motion emerges at around 2 to 3 months of age (Shirai et al 2004a, 2004b; Wattam-Bell 1992, 1994). However, a perception of more complex motion such as motion segregation or transparent motion develops from 3 to 5 months (Banton et al 2001; Kanazawa et al 2006, 2007; Wattam-Bell 2010). These results suggest that motion information processed by the dorsal stream—including V1, MT, or MST—develops at 5 months. Compared with motion

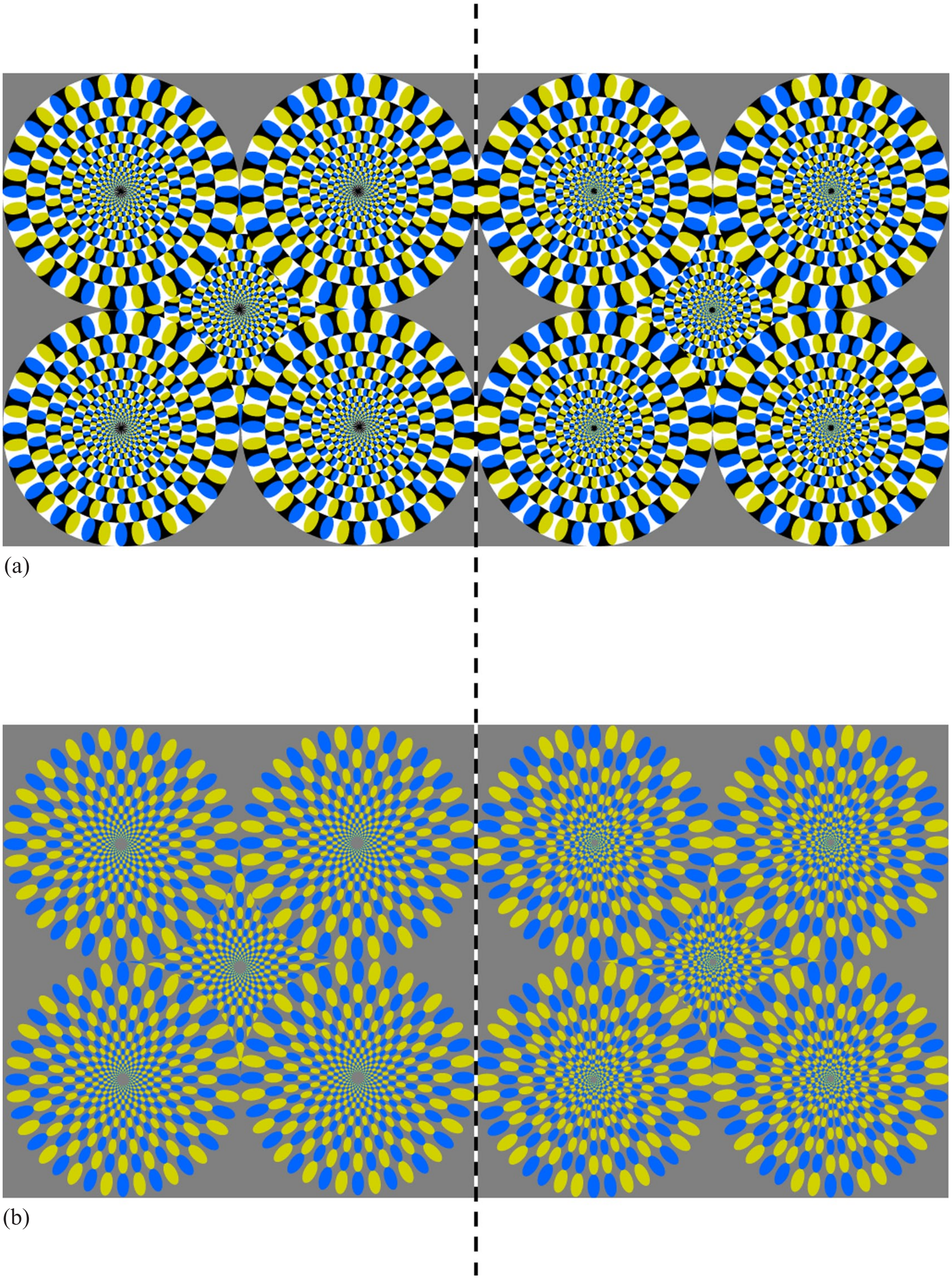

Figure 1. [In color online, see http://dx.doi.org/10.1068/p7460] Stimulus examples used in (a) experiment 1 and (b) experiment 2. In both stimulus examples the right side of the display was the target area and the left side was the nontarget one. Each target and nontarget area consisted of five disks. In (a) disks of the target area produce illusory rotating movement but disks of the other side do not. These stimuli were used in experiment 1. In (b) arrangements of blue and yellow regions were same as those of (a) except white and black regions. In this case both target and nontarget areas produce no illusory motion. We used these stimuli in experiment 2.

information, previous research has shown that sensitivity to static global patterns which might be processed by the ventral stream develops relatively slowly (Atkinson 2000; Braddick et al 2003). For example, previous research showed that perception of subjective contours develops at 5 months of age (Otsuka et al 2004, 2006). These results suggest that the ventral stream develops more slowly than the dorsal stream (Braddick and Atkinson 2011; Braddick et al 2003).

If infants can perceive illusory motion information in a static figure such as the rotating snake, they can process static figure and motion information. We conducted experiments on illusory motion perception in 6-to-8-month-old infants because previous research has shown that the ventral and dorsal stream develop at more than 5 months of age. For example, sensitivity to transparent motion develops at around 5 months (Kanazawa et al 2006, 2007), and moving square completion behind occluders (McDermott et al 2001) also develops at 5 months (Otsuka et al 2009). We hypothesized that infants of more than 5 months can process higher motion and static figure information and so can perceive illusory motion in static figures.

2 Experiment 1

In order to investigate illusory motion perception in infants, we used the forced-choice preferential looking (Teller 1979) method. In the first experiment we prepared a control figure which did not produce any illusory motion (nontarget area of figure 1a). In this stimulus the sequential order of the units was (1) yellow, white, yellow, black, blue, white, blue, and black or (2) yellow, black, yellow, white, blue, black, blue, and white. We arranged these units in a circular shape because previous research has used this arrangement to activate human brain areas such as MT+ (Ashida et al 2012; Kuriki et al 2008). As can be seen, the global appearance of the control figure is very similar to the illusory one. Using these illusory and control figures, we observed infants' preferential looking behavior at the illusory figure, on the basis of the hypothesis that infants will prefer to look at the illusory moving figure than at the static one.

2.1 *Method*

2.1.1 *Participants.* Twenty-three 6-to-8-month-old infants (mean age = 215.0 days, SD = 25.66 days) participated in experiment 1. The infants were recruited through newspaper advertisements. This study was approved by the ethical committee of the Japan Women's University, and written informed consent was obtained from the parents of the infant participants. The experiments were conducted according to the Declaration of Helsinki.

2.1.2 *Stimuli.* We used a control figure (nontarget area of figure 1a) as a nontarget stimulus and the illusory figure (target area of figure 1a) as a target stimulus. We made a disk composed of units. We placed four adjacent disks with one disk placed centrally behind the other four. These arrangements may promote eye movement and increase the amount of illusion because of eye drift during fixation (Beer et al 2008; Murakami et al 2006).

We presented five disks composed of illusory units and another five disks composed of no-motion units side-by-side, with a gray background. We defined the illusory motion area as a target area and the no-motion area as a nontarget area (figure 1a). The target and nontarget areas were adjacent, and the size of each area was a 28.5 deg by 28.5 deg square. Both target and nontarget were composed of four local black (CIE $x = 0.287$, $y = 0.367$, luminance = 0.64 cd m^{-2}), white (CIE $x = 0.307$, $y = 0.343$, luminance = 122 cd m^{-2}), blue (CIE $x = 0.163$, $y = 0.136$, luminance = 21.2 cd m^{-2}), and yellow (CIE $x = 0.401$, $y = 0.505$, luminance = 74.9 cd m^{-2}) units. Only the arrangement of orders was different.

2.1.3 *Procedure.* The preferential looking method was used to measure each infant's response. The infant sat on his or her parent's lap in front of the CRT monitor. The infant's viewing distance from the CRT monitor was approximately 40 cm. There were two loudspeakers, one on either side of the CRT monitor. There was a CCD camera just below the monitor screen. Throughout the experiment the infant's behavior was videotaped through this camera. The experimenter could observe the infant's behavior via a television monitor connected to the CCD camera. Before the experimental session started the parent was instructed not to look at the CRT monitor during trials so that their looking behavior would not affect the data coding.

One of the target or nontarget areas was presented at the right side of the display, and the other was presented at the left side. We recorded infants' looking behavior at the target or nontarget stimulus area through a video camera. An observer who did not know the target side judged whether infants looked at the left or the nontarget side on the basis of off-line video images. The target stimulus contained illusory motion information. If infants can perceive illusory motion, they will look at the target rather than at the nontarget. Because we predict that a moving figure is more attractive to infants than a static one (Aslin and Shea 1990), we can hypothesize that infants will prefer to look at the target figure if they can perceive illusory motion in the target stimulus. We presented the stimuli for 15 s in each trial. We conducted 4 trials for each infant, and the target side was randomized from trial to trial.

2.2 *Results and discussion*

An observer, unaware of the target position, measured infants' looking time for each stimulus on the basis of video recordings showing only looking behavior of infants. We also calculated the percentage of time spent looking at the target area. Results showed that the average looking time ratio at the target area was 58.97% ($n = 23$, SE = 2.13). A sample t-test relative to chance level (50%) showed that infants significantly preferred to look at the target area ($t_{22} = 4.21$, $p < 0.01$). This result suggests that 5-to-8-month-old infants might perceive some kind of attractive information in the illusory figure.

3 Experiment 2

However, another hypothesis could explain infants' preferences to the target area. Infants might prefer to look at the target area due to the local arrangement of four color regions rather than due to illusory motion information. In order to eliminate this possibility, we conducted a second experiment using different control stimuli. In experiment 2 we removed all black and white local regions from the target and nontarget areas used in experiment 1. Then the units in the target area were composed of gray, blue, gray, and yellow regions and the units of the nontarget area were composed of yellow, gray, yellow, gray, blue, gray, blue, and gray (figure 1b). The sequential orders of the blue and yellow regions used in experiment 2 were the same as those in experiment 1, although the units produced no illusory motion—shown by previous neuroimaging research (Kuriki et al 2008).

3.1 *Method*

We presented the stimuli and observed the target looking time of twenty-four 6-to-8-month-old infants (mean age = 208.6 days, SD = 26.68 days). Other experimental parameters such as the presentation time of stimuli or number of trials were the same as those used in experiment 1.

3.2 *Results and discussion*

We also calculated the looking time ratio at the target and averaged the percentage data for the twenty-four infants. The average percentage value was 48.29% ($n = 24$, SE = 1.89), and a t-test against chance (50%) showed that this value was not significantly different from chance ($t_{23} = 0.91$, $p = 0.187$). This means that the target preference observed in experiment 1 disappeared in experiment 2. We can conclude that the infants' preferential looking at the illusory figure disappeared when the local black and white regions were replaced by the background gray colors.

Comparison between the results obtained in experiments 1 and 2 (figure 2) demonstrated that the preference to the illusory figure in experiment 1 came not from the local static information but from the illusory motion information. These results suggest that 6-to-8-month-old infants perceive illusory motion information in static figures made by contrast difference information.

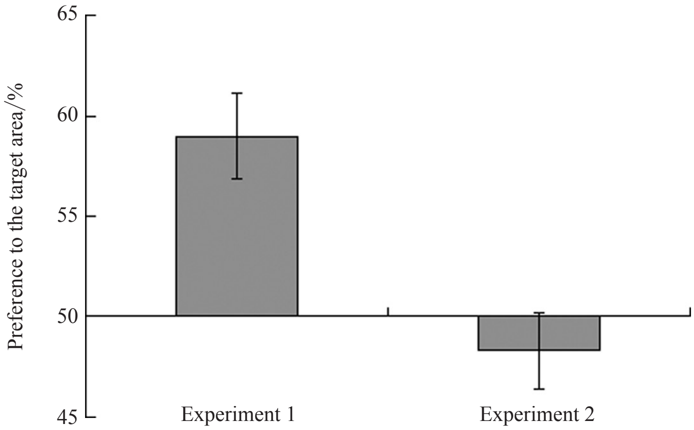

Figure 2. Results of experiment 1 and experiment 2. The horizontal axis is the experimental condition, and the vertical axis is the percentage of the preferential looking time at the target areas in experiments 1 and 2. Vertical lines added to the bars represent standard errors. Statistical analysis showed that the values of experiment 1 were significantly different from those of experiment 2 ($t_{45} = 3.76$, $p < 0.01$).

4 General discussion

In this research we showed that 6-to-8-month-old infants preferred to look at the target rotating snake figure rather than at the control figure (experiment 1). This preference disappeared when we replaced the local white and black regions with a gray color (experiment 2). These results suggested that the preference observed in experiment 1 did not depend on the local arrangement of blue and yellow regions, but on the global feature of the illusory figure. Indeed, we do not know whether the preference came from illusory motion perception or not. However, we could conclude that infants perceived some kind of attractive information in this static figure, and the strongest candidate might be the motion information which adult subjects perceive.

Previous research explained this illusory motion by the contrast-dependent latency difference in adjacent pairs of four local color regions (Conway et al 2005; Kitaoka and Ashida 2003). Kitaoka and Ashida (2003) explained that illusory motion depends on the fact that black and white regions are higher contrast than blue and yellow regions. Faster neural responses to the high-contrast regions and slower responses to low-contrast regions create illusory motion information from higher to lower regions.

Global circular arrangements also facilitated the illusory motion. Murakami et al (2006) suggested that the illusion was the by-product of a mechanism which stabilizes a visual field during eye movement and fixation. Global features such as the circular arrangement of color patches or the four global circles might facilitate eye movement and produced more illusory motion than a simple arrangement of local patches.

Conway et al (2005) showed that MT and V1 neurons in the macaque brain responded faster to white or black regions than to light gray (yellow) or dark gray (blue) regions.

And they also showed that the directional selective neurons in MT and V1 responded to the local units of the rotating snake figure. And the directional configurations of white–black and blue–yellow regions were consistent with the real motion direction. This means that neurons which represent motion information also respond to the unit of illusion. Conway et al (2005) concluded that the illusory motion in the rotating snake figure was represented in MT and V1 neurons. Human brain imaging studies also have shown the relationship between MT+ and V1 in recognizing the rotating snake figures (Ashida et al 2012; Kuriki et al 2008). They used the same figures as we used here, and showed that MT+ in the human brain responded only to the rotating snake figure and not to the control figure. V1 did not respond to either figure.

In previous research we found that the function of the higher visual cortex such as MT or MST might develop at 5 months, using transparent motion stimuli (Kanazawa et al 2006, 2007). Previous studies have also shown that the perception of higher motion such as motion segregation is developed by 5 months of age (Banton et al 2001; Wattam-Bell 1992, 1994). These studies suggested that sensitivity to higher motion such as transparent motion or motion segregation might reflect the development of MT or MST. If infants perceived illusory motion in the static figure, we suspect that some kind of neural connections between MT+ and V1 might have developed by around 6 months of age. However, we have to be careful before reaching conclusions. In this paper we did not test whether younger infants, such as 3 month olds, can see illusory motion. So we can conclude the illusory motion processing mechanisms might develop at least before 8 months of age.

Studies on eye movement have demonstrated that the amount of illusion in this rotating snake figure depends on the extent of micro eye drift during fixation (Beer et al 2008; Murakami et al 2006). They measured the amount of individual eye drift during fixation and found a positive correlation with the subjective amount of motion illusion. They suggested that this illusion was the by-product of stabilizing a visual field during eye movement and fixation. As imaging studies have shown (Ashida et al 2012; Kuriki et al 2008), some kinds of information about eye movement and static image data might be processed in the higher visual cortex, such as human MT+, when we view illusions. Data obtained here suggested that this mechanism for processing illusory motion might develop before 6 to 8 months of age at least. We need to conduct further experiments with younger infants in order to know exactly at what age this mechanism develops.

Acknowledgments. We thank Y Otsuka, N Shirai, T Imura, H Okamura, and E Nakato for their support with data collection. MKY was supported by the RISTEX Japan Science Technology Agency, a Grant-in-Aid for scientific research from JSPS, and a Chuo University Joint Research Grant.

References

Ashida H, Kuriki I, Murakami I, Hisakata R, Kitaoka A, 2012 "Direction-specific fMRI adaptation reveals the visual cortical network underlying the 'Rotating Snakes' illusion" *NeuroImage* **61** 1143–1152

Aslin R N, Shea S L, 1990 "Velocity thresholds in human infants: Implications for the perception of motion" *Developmental Psychology* **26** 589–598

Atkinson J, 2000 *The Developing Visual Brain* (Oxford: Oxford University Press)

Backus B T, Oruc I, 2005 "Illusory motion from change over time in the response to contrast and luminance" *Journal of Vision* **5**(11):10, 1055–1069

Banton T, Dobkins K, Bertenthal B I, 2001 "Infant direction discrimination thresholds" *Vision Research* **41** 1049–1056

Beer A L, Heckel A H, Greenlee M W, 2008 "A motion illusion reveals mechanisms of perceptual stabilization" *PLoS ONE* **3**(7):e2741

Braddick O, Atkinson J, 2011 "Development of human visual function" *Vision Research* **51** 1588–1609

Braddick O, Atkinson J, Wattam-Bell J, 2003 "Normal and anomalous development of visual motion processing: motion coherence and 'dorsal-stream vulnerability' " *Neuropsychologia* **41** 1769–1784

Conway B R, Kitaoka A, Yazdanbakhsh A, Pack C C, Livingstone M S, 2005 "Neural basis for a powerful static motion illusion" *Journal of Neuroscience* **25** 5651–5656

Ghim H R, 1990 "Evidence for perceptual organization in infants: perception of subjective contours by young infants" *Infant Behavior and Development* **13** 221–248

Hisakata R, Murakami I, 2008 "The effects of eccentricity and retinal illuminance on the illusory motion seen in a stationary luminance gradient" *Vision Research* **48** 1940–1948

Johnson S P, Aslin R N, 1995 "Perception of object unity in 2-month-old infants" *Developmental Psychology* **31** 739–745

Kanazawa S, Shirai N, Otsuka Y, Yamaguchi M K, 2006 "Perception of opposite-moving dots in 3- to 5-month-old infants" *Vision Research* **46** 346–356

Kanazawa S, Shirai N, Otsuka Y, Yamaguchi M K, 2007 "Perception of motion transparency in 5-month-old infants" *Perception* **36** 145–156

Kavsek M J, 2002 "The perception of static subjective contours in infancy" *Child Development* **73** 331–334

Kellman P J, Spelke E S, 1983 "Perception of partly occluded objects in infancy" *Cognitive Psychology* **15** 483–524

Kitaoka A, 2003 "Rotating snakes", http://www.ritsumei.ac.jp/~akitaoka/

Kitaoka A, Ashida H, 2003 "Phenomenal characteristics of the peripheral drift illusion" *Vision* **15** 261–262

Kuriki I, Ashida H, Murakami I, Kitaoka A, 2008 "Functional brain imaging of the Rotating Snakes illusion by fMRI" *Journal of Vision* **8**(10):16, 1–10

McDermott J, Weiss Y, Adelson E H, 2001 "Beyond junctions: nonlocal form constraints on motion interpretation" *Perception* **30** 905–923

Murakami I, Kitaoka A, Ashida H, 2006 "A positive correlation between fixation instability and the strength of illusory motion in a static display" *Vision Research* **46** 2421–2431

Otsuka Y, Kanazawa S, Yamaguchi M K, 2004 "The effect of support ratio on infants' perception of illusory contours" *Perception* **33** 807–816

Otsuka Y, Kanazawa S, Yamaguchi M K, 2006 "Development of modal and amodal completion in infants" *Perception* **35** 1251–1264

Otsuka Y, Konishi Y, Kanazawa S, Yamaguchi M K, 2009 "The effect of occlusion on motion integration in infants" *Journal of Experimental Psychology: Human Perception and Performance* **35** 72–82

Otsuka Y, Yamaguchi M K, 2003 "Infants' perception of illusory contours in static and moving figures" *Journal of Experimental Child Psychology* **86** 244–251

Shirai N, Kanazawa S, Yamaguchi M K, 2004a "Sensitivity to linear-speed-gradient of radial expansion flow in infancy" *Vision Research* **44** 3111–3118

Shirai N, Kanazawa S, Yamaguchi M K, 2004b "Asymmetry for the perception of expansion/contraction in infancy" *Infant Behavior and Development* **27** 315–322

Teller D Y, 1979 "The forced-choice preferential looking procedure: A psychophysical technique for use with human infants" *Infant Behavior & Development* **2** 135–158

Wattam-Bell J, 1992 "The development of maximum displacement limits for discrimination of motion direction in infancy" *Vision Research* **32** 621–630

Wattam-Bell J, 1994 "Coherence thresholds for discrimination of motion direction in infants" *Vision Research* **34** 877–883

Wattam-Bell J, 2010 "Reorganization of global form and motion processing during human visual development" *Current Biology* **20** 411–415