

Perceptual and Motor Skills

Disappearance of Biased Visual Attention in Young Infants: Remediation of Tonic Neck Reflex or Maturation of Visual Asymmetry?

Journal:	<i>Perceptual and Motor Skills</i>
Manuscript ID	PMS-17-0419.R3
Manuscript Type:	Review
Keywords:	Visual asymmetry, Visual neglect, Depth perception development, Infant reaching, Dynamic Systems Theory
Abstract:	<p>Typically, infants younger than four months fail to attend to the left side of their spatial field, most likely because of an innate asymmetrical tonic neck reflex (ATNR). In a critical transition, by four months of age, infants begin to reach and develop depth perception; and, by five months of age, they tend to monitor the entire spatial field. However, this developmental transition can be delayed. Moreover, there always is a residual right sided spatial bias under cognitive load, a phenomenon that may occur as well among adult stroke patients. While causative factors of biased visual attention in both infants and brain-injured adults may vary, mechanisms of remediation may be similar. This literature review addresses whether the infant's emergence of attention toward a full visual spatial field and the associated shift from monocular to binocular vision occurs because of (a) increased left side reaching loosens the rarely mentioned high muscle tension ATNR, or (b) maturational resolution of a visual asymmetry in motion perception. More research is needed to investigate the origins of the infants' visual control system and factors involved in its development, especially because Alzheimer and dementia patients may also show primitive two-dimensional vision and deficits in perceiving objects-in-motion that seem to mirror earlier infant visual perception.</p>

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Disappearance of Biased Visual Attention in Young Infants:

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Typically, infants younger than four months fail to attend to the left side of their spatial field, most likely because of an innate asymmetrical tonic neck reflex (ATNR). In a critical transition, by four months of age, infants begin to reach and develop depth perception; and, by five months of age, they tend to monitor the entire spatial field. However, this developmental transition can be delayed. Moreover, there always is a residual right sided spatial bias under cognitive load, a phenomenon that may occur as well among adult stroke patients. While causative factors of biased visual attention in both infants and brain-injured adults may vary, mechanisms of remediation may be similar. This literature review addresses whether the infant's emergence of attention toward a full visual spatial field and the associated shift from monocular to binocular vision occurs because of (a) increased left side reaching loosens the rarely mentioned high muscle tension ATNR, or (b) maturational resolution of a visual asymmetry in motion perception. More research is needed to investigate the origins of the infants' visual control system and factors involved in its development, especially because Alzheimer and dementia patients may also show primitive two-dimensional vision and deficits in perceiving objects-in-motion that seem to mirror earlier infant visual perception.

Keywords: Visual asymmetry; Visual neglect; Depth perception development; Infant reaching; Dynamic Systems Theory

BIASED VISUAL ATTENTION AND REACHING 2

Disappearance of Biased Visual Attention in Young Infants:**Remediation of Tonic Neck Reflex or Maturation of Visual Asymmetry?**

This review examines the importance of the asymmetric tonic neck reflex (ATNR) in early infancy for the development of attentional control based on the theoretical approach of the Dynamic Systems Theory (DST) (Thelen & Smith, 1994) asserting that different domains interact in development. An early developmentalist, Gesell (1938) attributed great functional significance to the tonic neck reflex as an indicator of delayed or deviant development, though there has been minimal subsequent research. This review focuses particularly on the relevance of the ATNR in the remediation of infant visual neglect (IVN) of the left spatial field. Particular attention is warranted for two alternative explanatory hypotheses concerning the development of evenly distributed visual attention across the full spatial field: (a) Hypothesis 1: The onset of infant reaching loosens the ATNR that previously led to biased right-sided visual attention, or (b) Hypothesis 2: Maturation of the infant's visual system leads to a shift away from this visual asymmetry. Hopefully, this overview will stimulate new questions and research activities.

As Dynamic Systems Theory (DST) focuses on interactive developmental domains, this theory may be especially relevant to development in the first year of life when the innate reflex system gradually makes way for more controlled behavior. It is unclear whether early infant reflexes disappear for ever, or whether they are subdued and remain in place beneath cognitive controls that enable the development of higher order processes. The DST clearly predicts that development as early as in the first year of life leads to a layered model of functioning in which both lower and higher processes operate. DST studies have shown that reflexes can reappear under certain circumstances, for instance, the walking reflex re-emerges when the infant's down-weighting postnatal weight gain is relieved by placing the lower part of the baby's body underwater (Thelen, Fisher, & Ridley-Johnson, 1984, 2002).

BIASED VISUAL ATTENTION AND REACHING 3

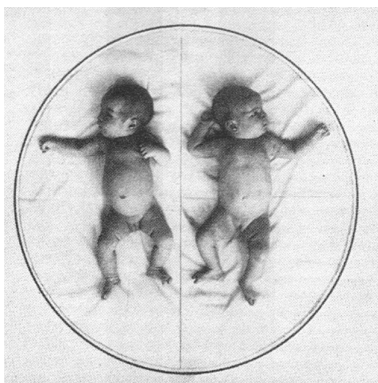
DST assumptions about the control of the early reflex system have wide reaching implications for post-infancy development. DST predicts that if the development of a higher control system is compromised, a reflex may persist (delay) or reappear (regression), implying that symptoms of some neuropsychological disorders may result from the re-emergence of earlier uncontrolled reflex-like behavior.

Accordingly, in the current review, we hypothesize that infant visual neglect (IVN) due to ATNR normally disappears with the onset of reaching in the same way that visual neglect in adult stroke patients is improved by rehabilitation strategies consisting of directed motor practice. Even though the causes of biased visual attention are different in these two populations, the mechanism of motor training may be similar. Therefore, this literature review aims to extend beyond a recap of developmental psychology and to identify a general basic mechanism in the human development of perceptual and motor skills. This review begins with the scant research literature that has investigated ATNR as a basis for infants' right sided spatial field attention bias and a description of a similar (possibly regressive) phenomenon in adult stroke patients. First, developmental studies addressing selective looking and reaching and those addressing handedness and grasp are relevant and described. Then, in the following section, we discuss asymmetry in motion perception in animals and infants and the transition from monocular to binocular depth perception with regards to its impact on spatial field perception and visual neglect. We explain important aspects of approach and receding object movements in relation to the infant in both visual asymmetry with attention to looming studies. Finally, we present an outlook on future research, listing the factors that require measurement and control in order to give a satisfactory account of visual attention bias and its mediation factors, possibly impacting on both developmental neuropsychology and rehabilitation.

BIASED VISUAL ATTENTION AND REACHING 4

The Asymmetric Tonic Neck Reflex (ATNR)

Frequent asymmetric right arm moments have been observed in utero and are thought to be predictive of brain lateralization (McCartney & Hepper, 1999). In the first weeks of life, an innate reflex for selective attention towards the (mostly) right side of the spatial field has been called the asymmetric tonic neck reflex (ATNR), and this reflex has usually disappeared by five months of age at the latest (Forfar & McIntosh, 2008). Spatial asymmetric biases exist in many species (Malashichev & Rogers, 2002; Rogers, 2000). Most newborns already turn their heads, even in the first hour after birth, toward their right side (Hopkins, Lems, Janssen, & Butterworth, 1987). The head and right arm are turned to the right side, while the left part of the body is relaxed (Gesell & Amatruda, 1947). In premature newborns this has been observed as early as the 35th to the 39th week of gestation (Gardner, Lewkowicz, & Turkewitz, 1977). In this review, we do not regard the ATNR as the infant's right sided preference because this view assumes too much intentionality on the part of the infant. Instead, we conceptualize the ATNR as an infantile visual neglect (IVN) that is not actually modality-bound; the same asymmetry is evident in auditory perception (Dehaene-Lambertz, 2000; Lange-Küttner, 2010; see also adult stroke patients, Zimmer, Lewald, & Karnath,



2003).

Figure 1 Asymmetric tonic neck reflex (ATNR) (Gesell, Ilg, Bullis, & Getman, 1998)

BIASED VISUAL ATTENTION AND REACHING 5

Some research highlighted the eye-hand correspondence that occurs during the tonic neck reflex (Coryell & Henderson, 1979). Others have suggested that the ATNR may be a precursor for handedness that establishes itself more clearly only months later (Butterworth & Hopkins, 1993). However, the tonic neck reflex also has other far-reaching implications. For example, parenting behavior corresponds to the tonic neck reflex in infants, as seen by the cradling bias (Turnbull & Lucas, 2000). Independent of culture and age, about 75% of mothers prefer to carry their infant on the left side. Among possible explanations, one is that mothers want to carry the infant closer to their heart, another is that they are interested in emotional communication, or, more practically, they want to use the non-dominant left arm for carrying the infant so as to free the dominant right arm and hand for other activities (Van der Meer & Husby, 2006). When Matheson and Turnbull (1998) covered a potential caretaker's left eye with an eye patch, young women's leftward cradling bias hardly changed. In contrast, young men showed a 71% left side cradling bias when the right eye was patched which shifted to a 75% right side cradling bias with a left side eye patch. The authors concluded that the men changed their cradling direction in order to observe the infant regardless of the side of their visual field. However, when becoming fathers, men also appear to settle on the left-side cradling bias (De Chateau, 1983). This research established a link between vision and cradling bias, lending support for the idea that a tonic neck reflex to the right and a cradling bias to the left seem to complement each other for establishing and facilitating primal social communication, with the infant predisposed to a position enabling gazing at the mother (caregiver) versus the environment. In our current understanding, we do not necessarily assume that these early reflexes just drop-out and disappear. For instance, Gill (2017) pointed out on the US consumer health information web site *Healthline* that "...babies are born with many reflexes that fade in the months after birth. Some reflexes are

BIASED VISUAL ATTENTION AND REACHING 6

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4 present in infancy and last into adulthood. If an adult experiences a brain injury, they may
5 exhibit infant reflexes again.” According to *Healthline*, the tonic neck reflex is supposed to
6 fade away.
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11 There are also some reflex-like automatic reactions involving the infant’s arms that are
12 not innate and that emerge during the early months, including the protective arm extension
13 reaction: When a fall is mimicked with infants by holding the infant and tilting it towards the
14 floor, the 6-month old (but not the 3-month old) infants stretch out both arms (Martin, 2006).
15 Of note, among premature newborns, those slow to develop or with developmental delays,
16 and those with more severe handicaps due to perinatal stroke, cerebral palsy (CP), or genetic
17 disorders, this protective arm extension reaction is absent. The absence of this arm extension
18 reaction may also lead to other gross motor delays, as infants frequently fall when learning to
19 walk and they may avoid attempting to walk in order to avoid these falls if they are less
20 confident without this self-protection mechanism; training this reflex, if it is absent, is
21 essential to prevent cascading developmental delays (Martin, 2006). In this way, the
22 outstretched arm of the tonic neck reflex may ultimately develop into a useful automatic self-
23 protective motor pattern that, in turn, sets the stage for other motor skills development. For
24 instance, Martin (2006, p. 20) described how a persistent ATNR may hinder functional
25 activities such as rolling, bringing the hands together, or bringing a hand to the mouth.
26 Hence, reflexes need practiced motor control and skilful adaptation for progression to occur.
27 The reflex system may be disrupted, not only by severe perinatal strokes or genetic disorders,
28 but also by too fixed or singular a sleeping position, sometimes leading neurotypical infants
29 to show motor delays and/or a permanently incorrect body posture (Vaivre-Douret, Santos,
30 Charlemaine, & Cabrol, 2005) with later consequences for eye-hand coordination (Vaivre-
31 Douret & Burnod, 2001).
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BIASED VISUAL ATTENTION AND REACHING 7

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4 Trehub, Corter and Shosenberg (1983) could find no systematic difference in infant
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6 attention towards the right spatial field. Bishop (1990, p. 56/57) explained this by noting that,
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8 in this study, researchers had adjusted the head position during the infants' sleep towards the
9
10 left side, and, once they were awake, they had rotated the infants through the air in various
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12 spatial planes. On further inspection of the data in this study, when infants with a clear visual
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14 neglect were excluded, 16 of 20 infants in the remaining sample still showed an attention bias
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16 towards the right side, although not in a deterministic form in each and every trial. Thus,
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18 Trehub et al. (1983) also demonstrated some effectiveness of a motor-based intervention for
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20 early visual attention bias.
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23 There is a similar need for movement rehabilitation when assisting infants after stroke (Anderson, Northam, I
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25 than cortical damage from a stroke after year one (Ferro, Martins, & Tavora, 1984; Kolb &
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27 Whishaw, 1996; Thompson, Ewing-Cobbs, Fletcher, Miner, & Levin, 1991; Trauner, 2003).
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29 Early lesions have been found to reduce intelligence further than later lesions (Riva &
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31 Cazzaniga, 1986), making early diagnosis of cortical damage particularly urgent as a means
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33 of eliciting early interventions (Ferro et al., 1984). Yet, a perinatal stroke is often difficult to
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35 detect as early signs of stroke are very subtle. Newborns with low Apgar scores at birth tend
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37 to show no reflexes on the right side of the body (Prechtl, 1977; Turkewitz, Moreau, & Birch,
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39 1968). Fidgety movements may be absent on only one side of the body, there may be only
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41 unilateral kicking, and even unilateral reaching with the hand before four months may be
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43 misinterpreted as early handedness, rather than stroke (Stiles, Reilly, Levine, Trauner, &
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45 Nass, 2012). Infants and children with perinatal stroke and cerebral palsy may show different
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47 types of reflexes in addition to an absent or persistent tonic neck reflex, that is, a tonic
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49 labyrinthine reflex and a symmetrical tonic neck reflex as well as a hypersensitive startle
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51 reflex (Martin, 2006). Injured infants may not always show a paresis and neglect of the right
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BIASED VISUAL ATTENTION AND REACHING 8

side of the spatial field, because these neurophysiological symptoms are dependent on the size of the lesion (Stiles et al., 2012).

A selective attention bias towards the right spatial field can also occur under cognitive load among neurotypical school children (Wilding, 2003; Wilding, Munir, & Cornish, 2001) and adults (Bruce & Tsotsos, 2005; Yund, 1997). When under significant performance pressure, renewed neglect-like behavior is evident in paper and pencil tasks such as the line cancellation test (Manly, Cornish, Grant, Dobler, & Hollis, 2005). This is an indicator that a right spatial field bias lingers throughout the life-span and may re-emerge when the attentional system is challenged. A bias towards the right spatial field can also be observed in adults following a stroke. Neglect of the left spatial field is one of the most common deficits associated with right hemisphere brain lesions (Karnath, 2003, 2006). Patients with neglect behave as if one side of the external space has ceased to exist. Objects in the left side of visual-spatial field are ignored by such patients. Patients with visual neglect do not neglect objects or people on the left side because they cannot see them, but because they turn to the right side to search for them. In the acute stage of visual neglect both the patient's head and eyes are clearly oriented towards the side of the brain lesion, which, in most cases, is the right side (Becker & Karnath, 2010; Frühmann-Berger & Karnath, 2005). However, adult stroke patients with hemianopsia really cannot see what is on the left hand side and thus their condition is more likely to be a result of visual perception than of an attentional bias (Birnbaum, Hackley, & Johnson, 2015; Tamietto & Morrone, 2016). This is the case because in homonymous hemianopsia, the visual cortex or the subcortical lateral geniculate nuclei visual pathways may be damaged, while in visual neglect, the parietal cortex suffered from the stroke and the visual pathways are intact.

Selective Looking and Reaching in Infants

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4 In the following section, we consider literature addressing the effect of the infant's new
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6 onset of reaching between four and five months of age on the infant's changing selective
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8 attention towards both right and left spatial fields. Harris and McFarlane (1974), Bower and
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10 Paterson (1973) and Aslin (1981) all observed that, even in a binocular condition, 3-4-month-
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12 old infants' eye-tracking of a moving object stopped in the middle of the spatial field,
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14 followed by a long saccade to the endpoint of the pathway, anticipating the object in the left
15
16 periphery. Bower classified this viewing pattern as anticipatory looking. More recent research
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18 dates the beginning of anticipatory tracking to six months of age (Shukla, Wen, White &
19
20 Aslin, 2011), but the exact age of onset for anticipatory eye movements is dependent on the
21
22 visual properties of the scene. There are fewer anticipatory eye movements when there are
23
24 central cues, and they seem to occur at an earlier age with repeated presentations (Clohessy,
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26 Posner, & Rothbart, 2001; Johnson, Posner, & Rothbart, 1991).

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29 In a study with 4-5 month-old infants, researchers observed infants' changes in visual
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31 neglect of the left side of the spatial field, as shown in Figure 2 (Lange-Küttner & Crichton,
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33 1999). Both visual and motor variables were video-analyzed in slow motion. Sixteen week-
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35 old (four month-old) infants still waved simultaneously with both arms outstretched when the
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37 object came close to their body on its trajectory (Crichton & Lange-Küttner, 1999). However,
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39 these researchers found that infants' newly emerging one-armed reaches occurred more often
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41 in the left, hitherto neglected, spatial field, and these one-armed reaches reliably predicted the
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43 disappearance of the IVN and unbiased attention to the full spatial field in each of the
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45 following four weeks.
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BIASED VISUAL ATTENTION AND REACHING 10

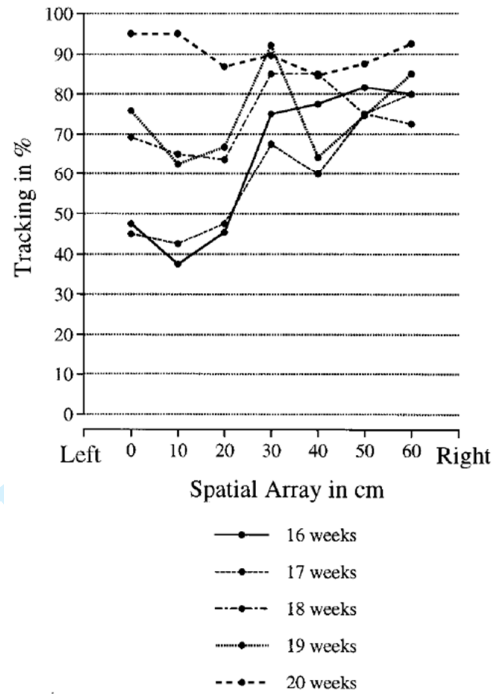


Figure 2. Disappearance of a right sided visual bias towards new gazing in the direction of left spatial field between 16 and 20 weeks (Lange-Küttner & Crichton, 1999).

In this process, a new segmentation of spatial fields emerged. The 16-week-old infants made stiff arm ipsilateral movements in both peripheral spatial fields (see also Coryell & Henderson, 1979). In this situation, the tonic neck reflex would tend to narrow eye fixations onto the stiff outstretched hand in the right periphery. In contrast, at 19 weeks of age, babies discovered the mid-line of the spatial field dividing them into right and left; this varied from an earlier three-field spatial perception of periphery-center-periphery (see Figure 3). At 20 weeks of age, they tend to exercise visual control over the entire spatial field. Thus, one can assume that with the beginning of reaching, there is increased flexibility in spatial attention and greater associated eye-hand coordination, loosening the tonic neck reflex and its association with visual neglect.

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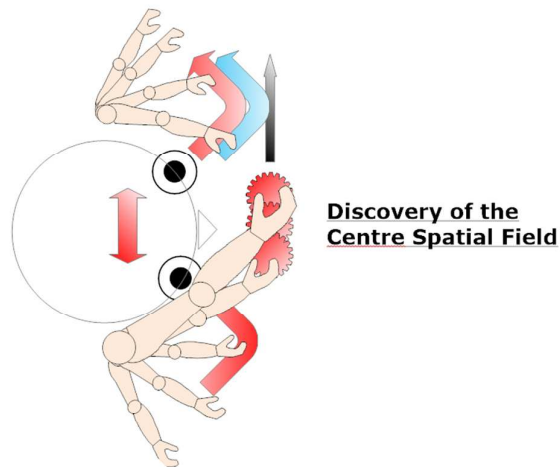


Figure 3 Development of reaching towards the center spatial field.

The more frequent simultaneous swiping with stretched out stiff arms in both peripheral spatial fields had no influence on remediating IVN in infants (Lange-Küttner & Crichton, 1999; see Figure 4, left), but the infants' just emerging reaches into the left half of the spatial field significantly predicted the disappearance of the visual neglect (see Figure 4, right). This finding was comparable to rehabilitation studies with adult stroke patients in which only reaches to the left contra-lesional spatial field led to lasting symptom improvement in adult stroke patients (Robertson, Hogg, & McMillan, 1998; Robertson & North, 1994).

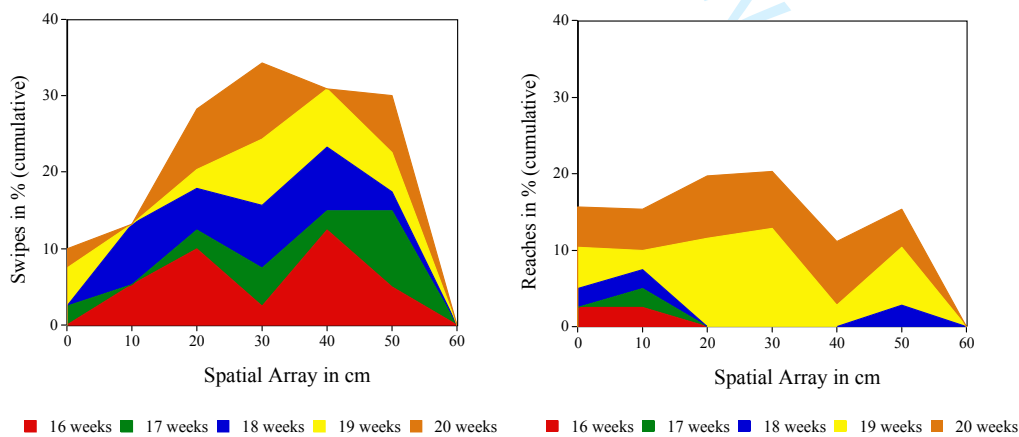


Figure 4 Spatial distribution of swipes (left) and reaches (right) (cumulative frequencies) (Lange-Küttner & Crichton, 1999)

BIASED VISUAL ATTENTION AND REACHING 12

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4 In a developmental adaptation of the Milner paradigm (e.g. Otto-de-Hart, Carey, &
5 Milne, 1999), fine motor eye-hand-coordination was only evident in 9-12-month-old infants
6 (Newman, Atkinson, & Braddick, 2001). At this age, infants also develop left-right hand
7 coordination (A. J. Bremner, Mareschal, Lloyd-Fox, & Spence, 2008; Kastner & Petermann,
8 2009). At the same time, infants show “object permanence” (Piaget, 1954) and become
9 successful in searching for objects that have changed places (Lange-Küttner, 1998, 2008;
10 Marcovitch & Zelazo, 2006; Munakata, McClelland, Johnson, & Siegler, 1997; Munakata &
11 Pfaffly, 2004; Thelen, Schöner, Scheier, & Smith, 2001). However, visual field asymmetries
12 can also occur in reaching at this later age. Fagard, Spelke and von Hofsten (2009) used the
13 same type of video analysis of spatial field segments used by Lange-Kuettner and Crichton
14 (1999), but with 6-, 8- and 10-month-old infants. The two younger age groups had
15 significantly less success in reaching when the object moved from right to left than when it
16 moved from left to right.

17
18 Reaching can be trained even with very young infants. A study with 3-month-old
19 neurotypical infants showed that training of self-initiated active reaches not only increased
20 the infants’ interest in objects, but also their interest in faces (social interest) (Libertus &
21 Needham, 2011). Babies also begin to develop fine motor hand coordination at a reflex level.
22 Initially, their hands are closed to fists and only open when something touches their hands, as
23 for instance when presented with a finger (triggering a grasp reflex). While movements with
24 open hands occur from seven weeks, the opening of the hand during reaching first occurred
25 when the object was visually controlled (von Hofsten, 1984). These object-adapted finger
26 movements are only possible in higher-order mammals and are controlled by the pyramidal
27 tract of the spinal system which has both ipsilateral and contralateral connections within the
28 brain (Brodal, 1998, p. 346). A flexed fist can also be a symptom of brain injury such as a
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BIASED VISUAL ATTENTION AND REACHING 13

stroke, both in children and in adults (Heijnen, Franken, Bevaart, & Meijer, 2008; Kanda, Pidcock, Hayakawa, Yamori, & Shikata, 2004; Ward, Roberts, Warner, & Gillard, 2005).

Visual Asymmetry

An alternative, purely visual, explanation for the disappearance of the IVN is visual asymmetry in motion perception. In primates, not only motor actions, but also binocular depth vision can suppress ortholithic eye reflexes in the event of changes in body posture (balance) (Misslisch, Tweed, & Hess, 2001). Hence, another explanation for visual neglect originates from ophthalmological research. Studies of the development of motion perception found an early visual asymmetry in infants (Aiello, Wright & Borchert, 1994; Braddick, Birtles, Wattam-Bell, & Atkinson, 2005). This was seen as an indication of a dorsal stream vulnerability, that is, a heightened susceptibility to failure of motion perception in a number of pathological conditions which may last into adulthood (Atkinson & Braddick, 2005; Atkinson et al., 2006).

In studies of motion perception, gratings are often used. Gratings are moving striped patterns which become a blurry gray if they are moving too fast for a visual system to track. In research with insects, insects in the middle of a rotating room have been shown to turn around along with the moving stripes to avoid having blurry vision (Blondeau & Heisenberg, 1982; Kalmus, 1949). Thus, the body of the insect is carried along by its visual attention to the mobile external stimulus. This visually determined motor behavior is called the optokinetic reflex (OKR). In an experiment with humans in a swinging room, children, but not adults, lost their balance, suggesting that adults compensated motorically (Lee & Aronson, 1974). The OKR can be triggered either by a mobile object or a dynamic background. Accordingly, researchers tested whether an infant would also fixate on an object if the background was dynamic - hypothesizing that object fixation should suppress the optokinetic reflex triggered by the dynamic background (Aslin & Johnson, 1996; Braddick, Atkinson, &

BIASED VISUAL ATTENTION AND REACHING 14

Wattam-Bell, 2003). This reflex suppression was observed in infants from the age of three months, though the age of onset for this suppression has varied in these studies. A number of factors facilitate infants' fixation of a moving object, including larger sized objects, slower object movement, and a straighter movement pathway (e.g. Aslin & Johnson, 1996; J. G. Bremner, Slater, Mason, Spring, & Johnson, 2013, 2017; Crichton & Lange-Küttner, 1999; Libertus et al., 2013).

In the ophthalmological literature, there are no defined allocentric spatial fields; rather, the visual asymmetry refers to egocentric nasal and temporal fields (i.e., the inner and outer fields of the retina of each eye) as depicted in Figure 3. The nasal fields of the left and right eye refer to the central spatial field, while the temporal fields refer to the left and right periphery (Smythies, 1996). This means that the spatial field consists of four spatial segments, the temporal and nasal field of the left eye, and the nasal and temporal field of the right eye. Visual asymmetry for motion perception during early infancy is evidenced by the fact that infants can see movement from the periphery into the central field (temporal to nasal; see solid lines in Figure 5), but not from the central field into the periphery (nasal to temporal; see the broken lines in Figure 5) (Aslin & Johnson, 1996; Atkinson & Braddick, 1981). This visual asymmetry, therefore, does not imply a visual neglect of the left spatial field, but, instead, a discrepancy in perception for movement into versus movement out of the central spatial field.

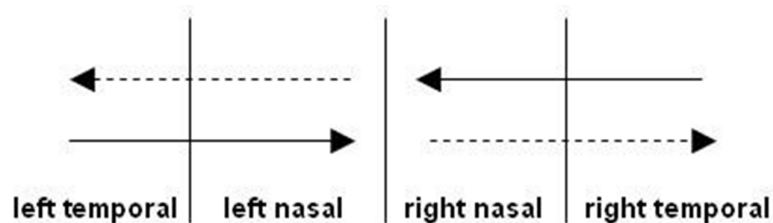


Figure 5 Asymmetry of object movement perception

BIASED VISUAL ATTENTION AND REACHING 15

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4 Longitudinal and cross-sectional studies of infants in the first year of life with
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6 monocular measurement have shown that development has a trajectory in which there is
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8 better nasally oriented movement perception in infants from 2 ½ months (10 weeks) of age
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10 that reaches its most pronounced manifestation from 3 ½ - 4 months (14 to 16 weeks), while
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12 at the age of six months nasal movement perception decreases, and, by eight months, it has
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14 nearly disappeared (Birch, Fawcett, & Stager, 2000). Also with binocular measurement, there
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16 was better nasally oriented movement perception between 3 ½ and 9 ½ months in each eye
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18 (Bosworth & Birch, 2005). Especially the peak in nasal movement perception at 14-16 weeks
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20 and its decline thereafter speaks to some role of visual asymmetry in the disappearance of the
21
22 IVN at this time.
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25 Braddick *et al.* (2003) assume that there are two brain based visual systems for two-
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27 and three-dimensional vision for processing movement – one an innate sub-cortical
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29 asymmetrical monocular system, and the other a later developing neocortical binocular
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31 system. During development, the latter will control the asymmetry of the former with the
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33 result that visual asymmetry would be observable only under monocular conditions after four
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35 months of age. Braddick *et al's* (2003) study on visual asymmetry mainly used abstract visual
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37 patterns, that is stripes and dots. As mentioned, focusing on a central static object in front of
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39 the grating visual pattern has been shown to help to suppress the visual asymmetry in
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41 movement perception (Aslin & Johnson, 1996; Braddick *et al.*, 2003). Kellman (1993)
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43 measured four-month-old infants' looking at objects moving on a stage per spatial field,
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45 though infants who looked only into one half of the spatial fields, that is, those who showed a
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47 total IVN, were excluded from this study. Despite this highly selective sample, in a binocular
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49 condition, infants looked at the spatial half field where the object actually was, but in an eye-
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51 patched monocular condition, infants looked at the right spatial field more often,
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53 independently of whether an object was there or not.
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BIASED VISUAL ATTENTION AND REACHING 16

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4 The origins of the visual asymmetry are unknown - especially because there is a
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6 reversed asymmetry in infants' visually evoked brain potentials (VEPs) (Mason, Braddick,
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8 Wattam-Bell, & Atkinson, 2001). The age range from 3 ½-5 ½ month is seen as the central
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10 transition phase from sub-cortical to neocortically controlled attention processes (Sinclair &
11
12 Taylor, 2008). Other developmental psychologists favor a purely neocortical explanation for
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14 visual asymmetry in which unilateral occipital activity changes to bilateral parietal brain
15
16 activations in visual perception (Rosander, Nyström, Gredebäck, & von Hofsten, 2007).
17
18 However, visual asymmetry may not be caused by the visual system on its own but could be a
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20 result of an immature neural network involving motor and visual cognition.
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23 The better temporal and nasal movement perception from the spatial periphery towards
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25 the central spatial field can be further explained by infants' behavior in classic object looming
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27 studies (Bower, Broughton, & Moore, 1971). In these experiments, even newborns who are
28
29 only a few days old showed defensive behavior by raising their arms when an object
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31 apparently moved towards them (dynamic enlargement of the object picture simulated the
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33 object approach). But when the object moved away, the infant made no observable defensive
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35 reaction (see Figure 6). This was confirmed by another infancy study (Van der Weel & Van
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37 der Meer, 2009) that also showed an absence of any reaction towards objects that were
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39 withdrawing in 5- or even 11-month-old infants. Visual perception of approaching, looming
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41 objects was processed in the occipital lobe V1, that is, without binocular neurons involved,
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43 and also without involvement of the parietal cortex, where spatial layouts are processed. Thus,
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45 the looming task measures a primitive defense reaction against objects which are
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47 hypothesized to come out of the depth of space even if it is actually an image expansion that
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49 is only interpreted as a change in depth. Withdrawal trials were not analyzed, nor were motor
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51 variables measured.
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BIASED VISUAL ATTENTION AND REACHING 17

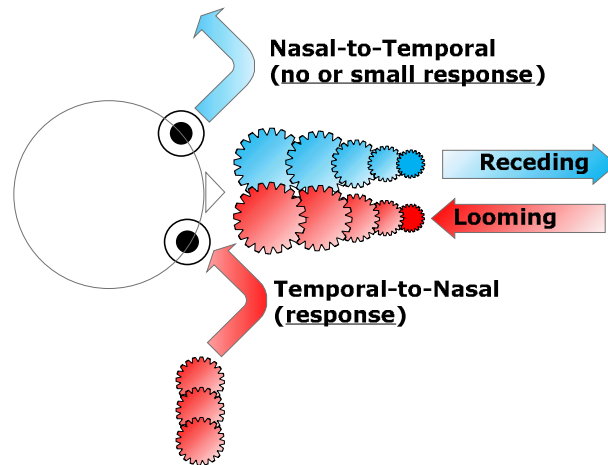


Fig. 6 Nasal-temporal and temporal-nasal object movements and ,object looming in the center spatial field

Monocular and Binocular Depth Perception

In movement perception, there is initially no binocular but only monocular perception. The right eye only reacts to left to right movement, while the left eye shows the opposite pattern, and reacts only to right to left movement (Norcia, 1996; Teller, Succop, & Mar, 1993). Binocular perception in visual evoked potential emerges in most infants in the 14th-20th weeks of age. While binocular movement perception in humans develops from four months, and can be delayed up to six months (Norcia et al., 1991), binocular movement perception is already present in apes at five weeks (Brown, Wilson, Norcia, & Boothe, 1998). Thus, studies with apes provided an opportunity to test in short-term longitudinal research the question of whether this ability develops innately or from visual experience. Apes were raised with eye patches that were swapped between the left and the right eye, respectively (binocular decorrelation) (Wilson *et al.*, 1999). The necessary duration of the decorrelation was 7 - 17 weeks and lead to a permanent prevention of a neural network between the neocortical area V1 and the parietal area MT (Tychsen, 2007). This clearly showed that, in monocular perception, visual and spatial processes are still functioning separately. We can conclude that binocular perception and evenly distributed visual spatial attention are not

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innate, but potentially follow a specifiable timetable. For this reason, future research should compare eye-tracker vectors of both eyes through weekly longitudinal investigations.

Future Research

In short, the change in human infants from automatic reflexive and spatially biased attention to an evenly distributed attentional system warrants future investigation. Longitudinal trajectories should prove that visual neglect and its suppression will occur in each and every infant and is truly innate. The period from 4-5 months of age should be investigated specifically, and the role of several factors, such as practice, reaching, handedness, object movement direction and sex of the child, should be controlled along with other aspects of developmental status. Future research should have several aims and objectives as detailed in the following paragraphs.

Is infant visual neglect universal and typically resolved (longitudinal trajectories); and, if so, in what time frame is it resolved (control of practice effects with a cross-sectional sample)?

For a developmental analysis of the origins of an infantile visual neglect (IVN), it is necessary to investigate factors that might lead infants to control the IVN by 3 ½-5 ½ months of age. Future research in visual asymmetry should test infants with a real (versus computer) display, using small moving toys (e.g., trains). Future studies should analyze whether infants' eye movements when tracking the moving object and arm movements towards these objects occur in synchrony in order to test eye-hand coordination. These methods would best test the progression from monocular to binocular visual perception in interaction with action parameters. Behavioral observations, using real objects, would provide increased ecological validity to these data. The aim of such research would be to validate a theoretical model that assumes that the infant's actions (i.e., reaches in the neglected left spatial field) control the IVN rather than the gradual automatic maturation of the visual perception system. If motor action precipitates IVN changes, the following factors may play a role in this process:

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4 **a) Handedness, motor development status, and both contralateral and ipsilateral**
5 **reaches into the left spatial field.** We propose that handedness would be present on a
6 probabilistic basis such that synchronous arm waving will occur less often and unilateral
7 arm movements will increase with maturation. Moreover, contralateral reaches across the
8 midline of the spatial field should be more predictive of the resolution of visual neglect
9 than ipsilateral reaches.
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16 **b) Speed of eye movements (saccades).** While Aslin (1981) assumed that the development
17 of saccades does not explain the control of attentional bias, it is difficult to prove a null
18 hypothesis, especially in the light of existing ophthalmological research. Future research
19 should measure how long infants can track a moving object and the generated saccades
20 infants use to catch up in their eye tracking. Bower et al. (1971)'s assertion that the infant
21 focuses on a central object but then 'anticipates' the endpoint of its movement trajectory in
22 the periphery can be tested with an eye tracker.
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31 **c) Eye-hand, hand-object and eye-hand-object coordination.** The combination of an eye
32 tracker with a motion capture system would allow for the measurement of eye-hand
33 coordination plus eye-object tracking plus the hand-object correlation. In this way, it
34 would be possible to compute the correlations between eye-hand and object vectors and to
35 create coordination dummy variables which predict the control of the IVN.
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42 **d) Mono- and binocularity.** The eye tracker registers eye movements separately for both
43 eyes. So far, it is not known whether the infants' emerging reaching behaviors facilitate
44 depth vision. Studies evaluating attention control by comparing left and right eye vectors
45 would yield information about the developmental contingencies of visual neglect, depth
46 perception and the emerging action system.
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53 **e) Mother-child interaction.** Future studies might employ video-assessments of mothers
54 holding infants to learn more about which way (holding the infant with the right or left
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arm) mothers typically hold infants, whether and how mother-infant eye contact is made, and whether the mother speaks more or less often to the infant with each method.

Is Object Tracking Dependent on the Object Starting Point?

It should be technically possible to test the spatial reference system for motor actions against the assumption of a visually determined asymmetry in movement perception. Current technology enables the use of fast and automatic calibrating eye trackers (Aslin & McMurray, 2004; Gredebäck & von Hofsten, 2004; Lécuyer, Berthereau, Ben Taieb, & Tardif, 2004) and motor trackers (Bhat & Galloway, 2006, 2007; Bhat, Heathcock, & Galloway, 2005; Bhat, Lee, & Galloway, 2007; Jung, Kahrs, & Lockman, 2015, 2018) in infant research. However, a combined eye- and motor tracker for infants during the 4-5 months developmental period must have a common point of origin with the onset of synchronized measurement so that vector correlations for eye-hand coordination can be computed and the best successful predictor for visual attention determined. A field camera might track the view onto a specific visual field area, while the eyetracker might measure the infant's selective attention towards the object (see Figure 7).



Figure 7 Infant wearing head set with eye tracker and field camera with motor markers mounted on the hands and the moving object. A binocular eye tracker could measure eye movements, while a field camera measured the entire spatial field in front of the infant (Smith, Yu, & Pereira, 2011). Because the eye tracker is not positioned in front of the infants, there would be no interference with their hand movements. Infants at this young age tolerate the headset without trying to remove it. Note the motor tracker markers on the head, the hands and on the moving train. The mother is holding the infant on the left side.

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In this way, researchers might test both an allocentric model that focused on the segmentation of the spatial fields, and an egocentric model that measured the development of sensitivity for smooth trajectories, based on object approach from nasal to temporal, and from temporal to nasal. Figure 1 previously showed that the neglect of the left spatial field in four-month-old infants was not complete. In Figure 8, Model 1 shows a complete neglect of the left visual field, while Model 2 shows an incomplete neglect with intact left-to-right tracking because the infant is gradually looking towards the right side; but interrupted right-to-left tracking from the midline leads to neglect of the left spatial field and an incomplete IVN because the infant would start looking from the right side.

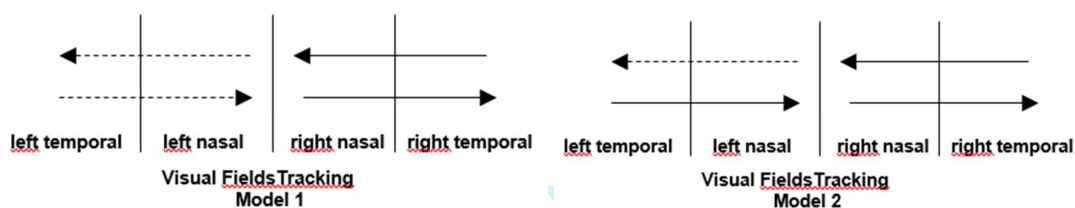


Fig. 8 Alternative IVN models: Model 1 complete IVN (left), Model 2 incomplete IVN (right).

Future studies of the relationship between visual asymmetry and visual neglect might analyze left/right (as well as left-middle-right) segments of the eye tracker data to determine how severe visual asymmetry or neglect is at varying ages. If a visual tracking omission is due to ATNR and thus has motor condition as its origin, very young infants would totally ignore the left spatial field and only improve with relaxation of the neck musculature precipitated by the onset of reaching (Figure 8, Model 1). Due to huge variability in infants' motor development (Darrah, Senthilselvan, & Magill-Evans, 2009) neurological tests of reflexes would also be necessary. But if the tracking omission is due to visual asymmetry associated with an object leaving the nasal field towards the left (upper arrows in Model 2), the neglect would be less pronounced because the infant would still track object motion from

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4 left to right (the lower arrows in Model 2). This setup would also allow the researcher to
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6 control the speed and accuracy of the infant's object tracking.
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8 Another question is how quickly development occurs from a right bias to an even
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10 monitoring of the spatial fields? It is crucial to investigate the normal time schedule of the
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12 IVN in longitudinal trajectories so that deviations from the typical time schedule and hence
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14 developmental delays can be diagnosed early and so that early interventions might be
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16 implemented to help avoid disadvantageous cascading effects in further development
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18 (Annaz, Karmiloff-Smith, & Thomas, 2008). In school children as well as in adults, recovery
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20 from neglect could be observed within a few weeks to several months (Stone, Patel,
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22 Greenwood, & Halligan, 1992). In adults, there were continued improvements of neglect up
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24 to 18 months after a stroke, but the strongest reduction of neglect occurred within the few
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26 weeks immediately after the brain insult (Karnath 2012, 2014). These results suggest a short
27
28 optimal intervention window for potentially remediating neglect. By comparing longitudinal
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30 and cross-sectional research data it should be possible to create age norms and to describe
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32 learning effects.
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38 **Implications for A Neuropsychological Model of Visual Cognition**

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40 Answers to these research questions about the relative contributions of motor versus
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42 visual factors in the development of depth perception and in evenly distributed visual
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44 attention across spatial fields may have implications for neuropsychological research and
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46 clinical management of adults with visual-spatial deficits. As previously explained, controlled
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48 outcome studies of physiotherapy with stroke patients have shown that encouraging patients
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50 to reach into the left spatial field efficiently remediated visual neglect (Robertson & North,
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52 1994; Robertson, Hogg, & McMillan, 1998). Also, patients with Alzheimer's disease have
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54 been found to show unexpectedly high sensitivity to two-dimensional patterns, accompanied
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BIASED VISUAL ATTENTION AND REACHING 23

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4 by a lack of awareness of three-dimensional space (Hussian & Brown, 1987). Extensive
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6 testing showed that while motion direction discrimination and visual acuity was intact in
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8 patients with Alzheimer's disease, there were deficits in visual attention, spatial contrast
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10 sensitivity and shape-from-motion identification as well as in visual memory (Mielke,
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12 Kessler, Fink, Herholz, & Heiss, 1995; Rizzo, Anderson, Dawson, & Nawrot, 2000). As in
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14 infants, enhanced stimulus strength improves visual cognition in patients with Alzheimer's
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16 disease (Cronin-Golomb et al., 2007). It is unclear whether retinal pathology or brain
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18 dysfunction is responsible for this two dimensional vision (Rizzo & Nawrot, 1998), but some
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20 studies show that both elderly patients with Alzheimer's disease (Hashimoto et al., 2002) and
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22 infants (Koletzko et al., 2008; Willatts, Forsyth, DiModugno, Varma, & Colvin, 1998) profit
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24 from intake of unsaturated fatty acid DHA (docosahexaenoic acid) which is essential for
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26 normal visual and neurological development and has beneficial effects on hypertension. Also
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28 in another neurological condition, autism, which can begin as early as infancy, there are
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30 reports of DHA depletion (Amminger et al., 2007). Infants at risk of autism show a deficit in
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32 the development of fine motor and grasping ability (Libertus, Sheperd, Ross, & Landa, 2014)
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34 and autistic adults show symptomatically slow and unfocused visual inspection time (Benson,
35
36 Castelhana, Howard, Latif, & Rayner, 2016). Hence, future research on the developmental
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38 interaction of the dynamic system of the tonic neck reflex, depth perception, visual
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40 asymmetry and the onset of reaching may have implications for a number of
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42 neuropsychological conditions.
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