

Associations between the developmental trajectories of visual scanning and disengagement of attention in infants

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Abstract

The relation between the developmental trajectories of visual scanning and disengagement of attention and gaze were examined throughout early infancy. A sample of 10 infants carried out a scanning and a disengagement task with the same visual stimuli six times between 6 and 26 weeks of age. Frequency and latency measures were analyzed using multivariate multilevel models and Monte Carlo analyses. The results suggest that the ability to scan a face or an abstract stimulus evolves slightly earlier than the ability to shift gaze to a newly appeared target in the periphery. This is consistent with the account that the parvocellular stream becomes functional slightly before the magnocellular stream. The study revealed no indications of a positive association between the development of scanning and disengagement on the level of the individual infant. Scanning and disengagement change scores contrasted more with one another than could be expected on the basis of chance. This implies that the magnocellular and the parvocellular stream develop rather independently up to the age of 26 weeks.

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1. Introduction

The visual system of an infant undergoes substantial developmental changes during the first few months of life (see, e.g., Atkinson, 1992). Infants are visually active already as newborns and move their eyes to seek and scan objects that appear in their visual field. Their visual behavior, however, falls far short of adult standards. During the first months of life, infants gain volitional control over their eye movements, and their gaze shifts become flexible and strategic.

When infants of 1–2 months of age examine visual stimuli, they show only very limited scanning with long fixations on few locations of the stimulus (Bronson, 1990; Leahy, 1976). An adult-like scanning pattern with more and shorter fixations emerges gradually during the first few months of life, and from the age of 3–4 months on, a controlled, strategic way of scanning has been described (Bronson, 1994).

Young infants also have problems looking away from a stimulus, once their attention has been engaged, and they often exhibit long periods of staring. This phenomenon of disengagement difficulty has been reported frequently (see, e.g., Aslin & Salapatek, 1975; Hood et al., 1996; Hopkins & van Wulfften Palthe, 1985) and has been referred to as “sticky fixation” (Hood, 1995) or “obligatory attention” (Stechler & Latz, 1966). As infants grow older, the frequency

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and speed of shifts of gaze from a stimulus to a target which appears in the periphery increase. By approximately 4 months of age, infants are able to shift their attention and gaze easily and rapidly, and staring behavior becomes rare (Butcher, Kalverboer, & Geuze, 2000; Hicks & Richards, 1998; Hood & Atkinson, 1993).

Several studies have examined the interrelations between different measures of attention in infancy, for instance between looking time during habituation and disengagement latency (Frick, Colombo, & Saxon, 1999) or between the rate of visual encoding and the quality of visual scanning (Bronson, 1991). Such studies are extremely valuable, as they increase our insight into attentional functioning during infancy in general (see, e.g., Bronson, 1991), explore the underlying processes which give rise to early individual differences (see, e.g., Bronson, 1991; Colombo, 1995; Frick et al., 1999), and help forming and examining different theoretical accounts of the neurological basis for early attentional development (see, e.g., Butcher, 2000; Johnson, Posner, & Rothbart, 1991). Longitudinal studies, which allow the comparison of developmental trajectories of different skills, are particularly important in this context, but also scarce (but see Butcher, 2000).

To date, no study has explored the interrelations of the development of functional scanning and the ability to disengage attention and gaze. In this study, the development of scanning and disengagement during early infancy is analyzed, and the results of a comparison of the two developmental trajectories are reported.

1.1. Neurophysiological models of eye movement generation in adults

Eye movements are controlled by different cortical and subcortical structures. Many neurobiological models of eye movement generation in adults proceed on the assumption of two visual systems, a phylogenetically older retinotectal system and a newer geniculostriate system. Early anatomical studies had already identified two distinct streams from the retina through the brain, but the functional distinction arose from studies in the 1950s and 1960s (see, e.g., Sprague & Meikle, 1965). In 1982, Ungerleider and Mishkin coined the dichotomy of a ventral versus a dorsal cortical stream. According to their model, the ventral stream, concerned with the “what” – aspects of an object such as color and form or face recognition, is assigned to the inferotemporal cortex (Ungerleider & Mishkin, 1982). The identification of spatial location, on the other hand, is thought to be subserved by the dorsal stream (“where”) which is anchored by the posterior parietal cortex. The dorsal versus ventral distinction has been associated with a division earlier in the visual pathway, namely between the parallel parvocellular and magnocellular systems (Livingstone & Hubel, 1988; Shapley & Perry, 1986; Van Essen & Maunsell, 1983). These two systems are anatomically segregated at the retina and the lateral geniculate nucleus and project to different parts of the primary visual cortex. The parvocellular-based system subserves form and color vision, while the magno cells are specialized in movement perception and some aspects of stereoscopic vision. However, the notion of a simple distinction into two strictly parallel systems has to be questioned (see Cowey, 1994; Merigan & Maunsell, 1993, for reviews): In adults, the two cortical pathways show appreciable anatomical cross-talk (see, e.g., Felleman & Van Essen, 1991; Van Essen, Anderson, & Felleman, 1992), and neurophysiological and behavioral studies have demonstrated functional intermixing (see, e.g., Everling & Munoz, 2000; Malpeli, Schiller, & Colby, 1981; Schiller, Logothetis, & Charles, 1990).

One of the currently predominant models of eye movement generation is the one developed by Peter Schiller (Schiller, 1985, 1998). In his recent model – based on adult primate electrophysiological and lesion data – Schiller (1998) also distinguishes between two different, but interacting and partly overlapping, neural systems of eye movement control: the anterior and the posterior eye movement control system. The anterior system is responsible for goal-directed, voluntary eye movements, while the posterior system generates fast, reflex-like eye movements and simple orienting responses, as they occur, for example, after the sudden appearance of a salient stimulus in the periphery.

The streams of the anterior system originate in retinal ganglia which are specialized for the analysis of fine detail and color (Richards & Hunter, 1998). They project through the parvocellular portion of the lateral geniculate nucleus to the occipital cortex, and from there they run through the temporal or the parietal lobe to the frontal eye fields. Then they project via the basal ganglia and the superior colliculus to the eye movement centers of the brain stem. These brain stem structures, however, also receive direct input from the frontal eye fields within the anterior eye movement control system.

The posterior eye movement control system receives the majority of its input from the retinal ganglia which are located in the peripheral retina and are specialized for the detection of sudden changes (Richards & Hunter, 1998). Its pathways run via the magnocellular portion of the lateral geniculate nucleus to the occipital cortex. Then, they project – partially via the parietal lobe – through the basal ganglia to the superior colliculus.

The activity of the superior colliculus thus is controlled via both systems, the anterior as well as the posterior eye movement control system. Their excitatory or inhibitory input plays an important role in the generation of eye movements to interesting locations and at the same time in the inhibition of reflexive eye movements in order to ensure a well organized input of visual information. However, within the anterior eye movement control system, there is also a pathway which bypasses the superior colliculus and hereby enables the generation or inhibition of eye movements independently from collicular control.

1.2. Explanations of the development of disengagement and scanning

Although the skills of visual scanning and disengagement of attention and gaze emerge during approximately the same period of time, they are considered to be based on different neurological systems. Shifting gaze away from a stimulus currently under attention to a newly appeared target in the peripheral visual field is – according Schiller’s model (Schiller, 1998) – mediated by the posterior eye movement control system, as this system is responsible for the generation of fast, reflex-like orienting responses.

To scan a stimulus, however, requires also higher-level eye movements. This kind of intentional eye movements to selected or remembered locations and organized sequences of saccades are thought to be generated by the anterior eye movement control system (Schiller, 1998), in which the frontal eye fields are thought to play an important role (Bichot, Schall, & Thompson, 1996; Guitton, Bachtel, & Douglas, 1985). As mentioned above, input to the anterior system is thought to originate mainly in the P cells of the retina and the parvocellular pathways, which subserve detailed form and color vision. The posterior system, on the other hand, is thought to receive mostly magnocellular input from cells which are specialized for the detection of sudden changes (Richards & Hunter, 1998).

There are indications that the two visual systems may have different developmental courses (Atkinson & Braddick, 2003; Lewis, Maurer, & Brent, 1989; van der Kamp & Savelsbergh, 2000). They arise mostly from comparisons between the developmental time courses of the cortical streams on basis of visual evoked potential (Braddick, 1993; Braddick, Birtles, Wattam-Bell, & Atkinson, 2005; Hood, Atkinson, Braddick, & Wattam-Bell, 1992) and behavioral measures (see, e.g., Atkinson, 1992; Colombo, 1995, for overviews). Several cortical mechanisms (such as color vision, orientation and direction selectivity, and selectivity to binocular relations) are associated with processing mainly within one of the two streams, and these functions have been shown to emerge at different ages. The order in which these mechanisms develop suggests that the two systems may have different developmental courses with the parvocellular pathway becoming functional slightly ahead of the magnocellular pathway (see Hickey & Peduzzi, 1987, for a review).

1.3. Aims of the study

As mentioned above, both behaviors – visual scanning and disengagement – undergo rapid development during the first few months of life. However, to date, there is no evidence available on the same infants’ performance on both behaviors during this period of development, nor have the developmental trajectories of these behaviors been compared. It was the goal of this study to compare the development of visual scanning and disengagement in the same infants, using data obtained in an intense longitudinal investigation. Considering the presumed neurological underpinnings of both behaviors, it was expected that functional scanning would emerge slightly earlier than reliable gaze shifting.

Although the magnocellular and the parvocellular system seem to subserve different functions, there is wide evidence from neurophysiological and behavioral studies that the two streams cannot be considered to be strictly parallel pathways, but rather that they interact (see Cowey, 1994; Merigan & Maunsell, 1993, for reviews). The second aim of this study was therefore to explore possible associations between the developmental changes in scanning and disengagement during the first months of life.

2. Method

2.1. Participants

Ten infants (5 girls; 5 boys) carried out a scanning task as well as a disengagement task. They were tested every 4 weeks, starting at the age of 6 weeks, until they were 26 weeks old. Mean ages at the testing dates were 46.7 days (S.D. = 3.8), 73.0 days (S.D. = 2.4), 102.2 days (S.D. = 3.4), 130.2 days (S.D. = 2.3), 158.0 days (S.D. = 3.4), and 186.7

days (S.D. = 4.4). If a measurement session could not be completed because the infant was sleepy, fussing, or crying, a new appointment was made within a few days. Eight of the infants carried out all six measurement sessions; two infants completed five sessions.

The group of participants is a subgroup of a sample from a larger study on the early development of visual attention (see, e.g., Hunnius & Geuze, 2004a, 2004b). The current sample is identical with the group described in an article on visual scanning (Hunnius & Geuze, 2004b), as the criterion for inclusion was whether the infants provided enough eye movement data during the scanning task. Data for an additional 10 infants had to be excluded, because fewer than five of their six test sessions could be analyzed mainly due to technical problems.

All participants were healthy, full-term infants with no history of complications during gestation or delivery and a birth weight above 2800 g. All infants scored within their age range on the Bayley Scales of Infant Development (BSID-II; Bayley, 1993) at 12 and 24 weeks of age. The mothers of the infants were contacted through childbirth education classes, midwives, or gym classes. They were told about the course and goals of the study and gave their written informed consent. The study was approved by the local Medical Ethics Committee.

2.2. Procedure

Appointments were scheduled for a time of the day when mothers expected their infants to be able to stay awake for about 30 min. After mother and infant had arrived at the lab, infants were given some time to get used to the new environment.

While the infants were carrying out the experimental tasks, they were seated in an infant seat in a reclined posture (about 45°) in front of a 21 in. computer monitor. The infant's head was slightly stabilized. Of the monitor only the screen was visible. The frame of the monitor and all the other equipment was concealed behind a gray curtain, which filled 180° of the baby's visual field. The distance between the infant's eyes and the screen was 35 cm. The infant's face and the display shown to the infant were visible to the experimenter on a video monitor and were recorded for off-line analysis.

2.3. Stimuli

In the tasks, two different dynamic stimuli were used. The first was a short video of the infant's mother's face. This video recording was made during a first visit of mother and baby to the lab. The mother's face was recorded while she was moving, smiling, and nodding as she would normally do in the interaction with her baby. This stimulus was matched with an abstract stimulus that was created to be comparable in terms of overall physical characteristics, such as movement dynamics, color, and luminance. These transformations rotated, scrambled, and distorted the initial video and were carried out in a graphic computer program (Corel PHOTO-PAINT 9). One frame from each type of video is given as a stimulus example in Fig. 1. Additionally, an example of both stimulus sorts can be found in Appendix A.

2.4. Scanning task

The infants were first presented with the scanning task. During this task, the infants were shown the two stimuli one after another for 30 s each. Each stimulus subtended 30° by 40° on the gray monitor screen. The eye movements infants made while scanning the dynamic displays were measured using an infrared eye-tracking system (ASL, model 504) in combination with a head-tracker (Polhemus Fastrak). Eye position data were sampled at 50 Hz. Experience in using eye-tracking methods with infants has taught us that the data yielded by an eye-tracker are often incomplete and contain artifacts. So the video-recordings of each infant were also coded off-line in order to correct errors and complete the data set. They were played back half-frame by half-frame (20 ms intervals) and compared with the available information from the eye-tracker data files. Coding was carried out by two different observers trained by the first author. Interobserver reliability was determined by double-coding 10% of the sessions and turned out to be good. For the classification of an eye movement indicated by the eye-tracker as a real eye movement versus an artifact the agreement was 94.7%. For identifying an eye movement in the absence of an eye-tracker signal, the interobserver reliability was 96.9%. The agreement between observers for the onset and the length of an eye movement was 92.5% and 94.6%, respectively.



Fig. 1. Examples of both stimuli.

2.5. Disengagement task

After the scanning task, infants carried out a disengagement task, in which shifts of attention and gaze between a central fixation stimulus and a peripheral target were measured. This experimental task made use of the same stimuli as the scanning task, however, they were presented much smaller. At the viewing distance of 35 cm, they subtended a visual angle of 10° by 10° . The disengagement task consisted of 32 trials. In these trials, a stimulus first appeared in the center of the monitor on a gray background. To attract the attention of the infant, the onset of this stimulus was accompanied by a short melody. When the infant was fixating this stimulus, a second stimulus was added in the periphery (at 20° eccentricity). After 5 s, both stimuli disappeared simultaneously. After 2.5 s, during which the screen remained blank, the following trial began. Fig. 2 shows a schematic representation of the task.

In half of the trials the peripheral targets appeared on the left, in the other half on the right. Both stimulus sorts – the face and the abstract stimulus – were used as central fixation stimulus and as peripheral target. The order in which the trials were presented was randomized. The infants' eye movements were videotaped, and the frequency and latency of gaze shifts to the peripheral stimulus were coded off-line. Therefore, the direction and latency of the first eye movement after the peripheral target appeared were scored. All direct eye movements to the peripheral stimulus were coded as looks. Eye movements which started less than 200 ms after the second stimulus appeared were considered anticipatory (Haith, Hazan, & Goodman, 1988).

Coding was carried out by different observers. The interobserver reliability was found to be on average 93.5% (range 89.5–100%) for the onset of an eye movement. Cohen's kappa for the category of first eye movement was on average .82 (range .72–1.0).

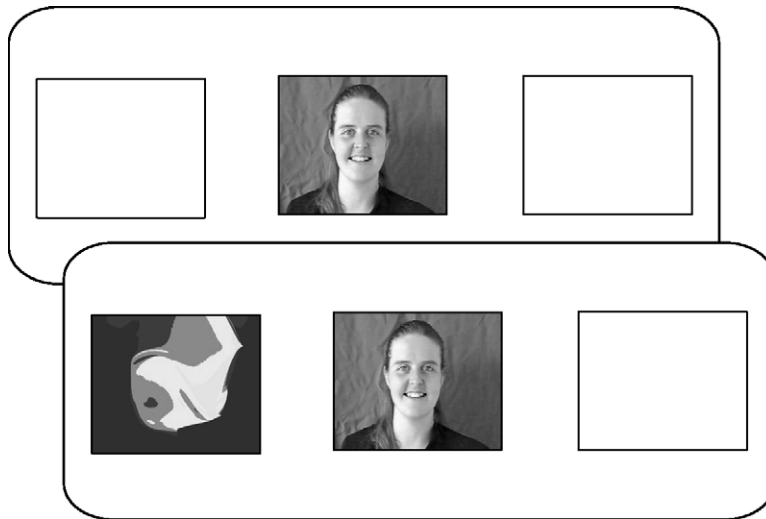


Fig. 2. Schematic representation of a disengagement task, in which first a central stimulus appears and then a peripheral stimulus is added.

2.6. Analysis

Two indices of performance in the scanning and in the disengagement task were analyzed: frequency and latency measures. Both measures have been used and shown to be suitable to describe the development of visual scanning and disengagement in earlier studies (see, e.g., Bronson, 1994; Butcher et al., 2000). The frequency measures consisted of the relative frequency of looks to the peripheral target in the disengagement task and the number of fixations during scanning. Both measures represent the frequency of eye movements during the tasks. The second measures were the averaged median latency of gaze shifts in the disengagement task and the median fixation duration during scanning. These measures both reflect the time before an eye movement to a new location of interest (within a scanning pattern or between two different stimuli) is started.

2.6.1. Multilevel analysis

First, the developmental changes of these pairs of indices were examined using multivariate multilevel models (Snijders & Bosker, 1999). Multilevel analysis is a regression procedure which takes into account a possible hierarchical structure of the data set. When applied to longitudinal data, the repeated measures are regarded as “nested” within individuals. Unlike a standard multiple regression model, a multilevel model contains more than one error term: one for every level of hierarchical data. One of the strengths of this approach is that it allows for both the number of observations per individual and the spacing of the observations in time to vary. Analyzing the data jointly in a multivariate model instead of with several separate models has the advantage that the tests of specific effects tend to be more powerful and that the danger of chance capitalization is avoided. The models had three levels: infant, test session, and stimulus sort. Based on the results of earlier analyses (see, e.g., Butcher et al., 2000; Hunnius & Geuze, 2004a), the development was described using three piecewise linear age functions (age periods 6–9, 9–16 and 16–26 weeks). The data were centered around 12 weeks of age, as this was approximately the middle of the period in which the largest changes were expected. The statistical significance of the coefficients was determined using *t* tests. *T* tests were also used as post hoc tests. With multiple testing, Bonferroni corrections were employed to keep alpha at .05 (Stevens, 1992).

2.6.2. Monte Carlo analyses

Further analyses were carried out using Monte Carlo methods (random permutation or random resampling methods). On the one hand, possible associations (i.e. similarities) between the development of scanning and disengagement in individual infants were investigated. On the other hand, it was examined whether the changes in the development of visual scanning stabilized earlier than those occurring in the emergence of reliable disengagement.

The data were examined using a permutation or a resampling method, which is a procedure linked to the group of bootstrap techniques (Good, 1999; Manly, 1997; Todman & Dugard, 2001; permutation boils down to random

selection without replacement, resampling is random selection with replacement). By carrying out a large number of randomizations (1000 or 5000, depending on the required accuracy), an approximation of the exact chance distribution of the test statistic used can be obtained, without having to make assumptions about expected distributions across the “population” of observations. Another advantage of permutation and resampling methods is that they are particularly suited for small datasets with missing data.

3. Results

3.1. Overall development

3.1.1. Frequency indices

The development of the averaged frequency of disengagement and the averaged number of fixations during scanning are presented in Fig. 3A and B. It can be seen that both indices first undergo a period of rapid change, before a stabilization takes place. However, this stabilization seems to occur earlier in the development of scanning behavior than of disengagement.

The multivariate multilevel model contained (almost) significant coefficients for all three age periods concerning the development of gaze shifting. Thus, the frequency of disengagement increased almost significantly between 6 and 9 ($t(342) = 1.93, p < .10$) and then significantly between 9 and 16 ($t(342) = 6.01, p < .001$) and 16 and 26 ($t(342) = 3.61, p < .001$) weeks of age. Looking at the development of scanning in these infants, the pattern was slightly different. The increase in the number of fixations was (almost) significant during the age period of 6–9 weeks ($t(342) = 1.70, p > .10$) and 9–16 weeks ($t(342) = 2.85, p < .001$). For the age period of 16–26 weeks, the age coefficient did not indicate a significant increase anymore (16–26 week period: $t(342) = .82, p < .10$). Accordingly, post hoc tests yielded a significant

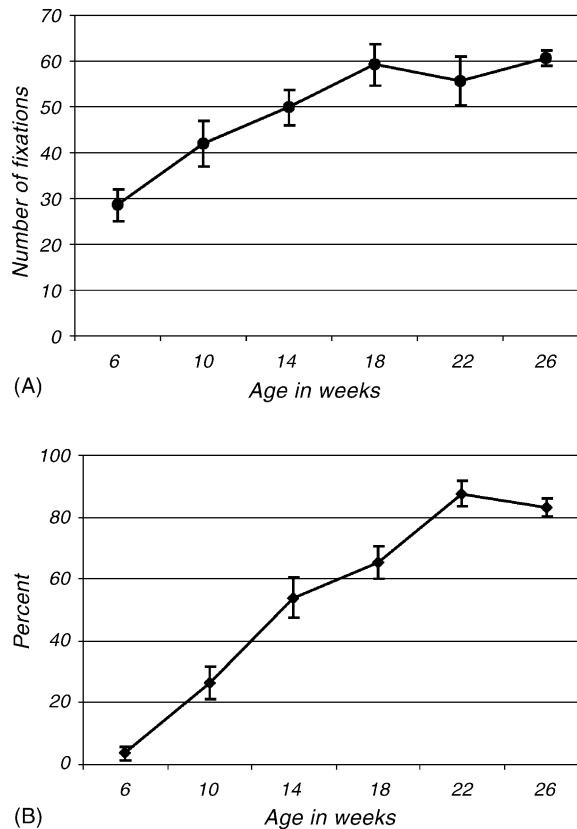


Fig. 3. The development of (A) the mean number (and standard error) of fixations during the scanning task and (B) the mean frequency (and standard error) of looks to the peripheral stimulus during the disengagement task.

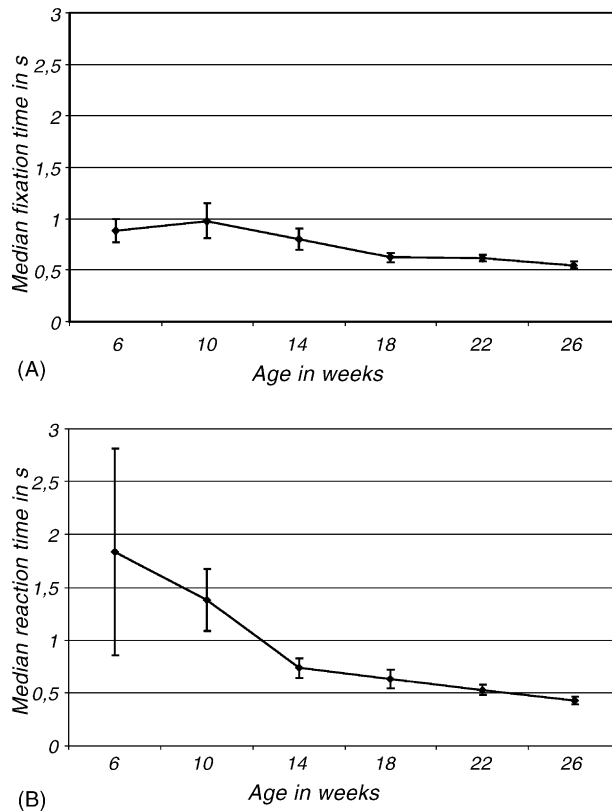


Fig. 4. The development of (A) the median fixation duration (and standard error) during the scanning task and (B) the averaged median latency (and standard error) of looks to the peripheral stimulus during the disengagement task.

increase in disengagement frequency between 18 ($M = 65.5\%$, $S.D. = 17.0$) and 22 weeks of age ($M = 87.7\%$, $S.D. = 13.0$; $t(9) = 5.65$, $p < .001$), but there was no significant change anymore in the number of fixations during scanning between the same two measurement points (18 weeks, $M = 59.2$, $S.D. = 13.9$; 22 weeks, $M = 55.7$, $S.D. = 16.7$; $t(9) = .54$, $p > .10$).

3.1.2. Latency indices

Fig. 4A and B depict the development of the averaged median fixation duration during scanning and of the averaged latency of gaze shifts in the disengagement task. The multivariate multilevel model showed that the latency of gaze shifts during the disengagement task decreased (almost) significantly between 6 and 9 ($t(303) = 2.19$, $p < .05$), 9 and 16 ($t(303) = 1.91$, $p < .10$) and between 16 and 26 ($t(303) = 2.69$, $p < .01$) weeks of age. So the reaction time in the disengagement task decreased throughout the entire measurement period. For the duration of fixations during visual scanning, the multilevel model contained only one significant coefficient. The fixation duration declined significantly solely between 9 and 16 weeks of age ($t(303) = 2.71$, $p < .01$), while it remained rather stable between 6 and 9 and 16 and 26 weeks of age.

The data thus indicate that both parameters – the frequency and the latency measure – leveled off slightly earlier for the development of scanning than for the development of gaze shifting.

3.2. Associations between the individual developmental trajectories

In this paragraph, the relation between the developmental trajectories of visual scanning and disengagement of attention are investigated at the level of the individual infant.

Figs. 5 and 6 depict the individual developmental trajectories of the standardized frequency and latency measures of visual scanning and disengagement.¹ Inspection of the individual curves of the frequency measures (see Fig. 5)

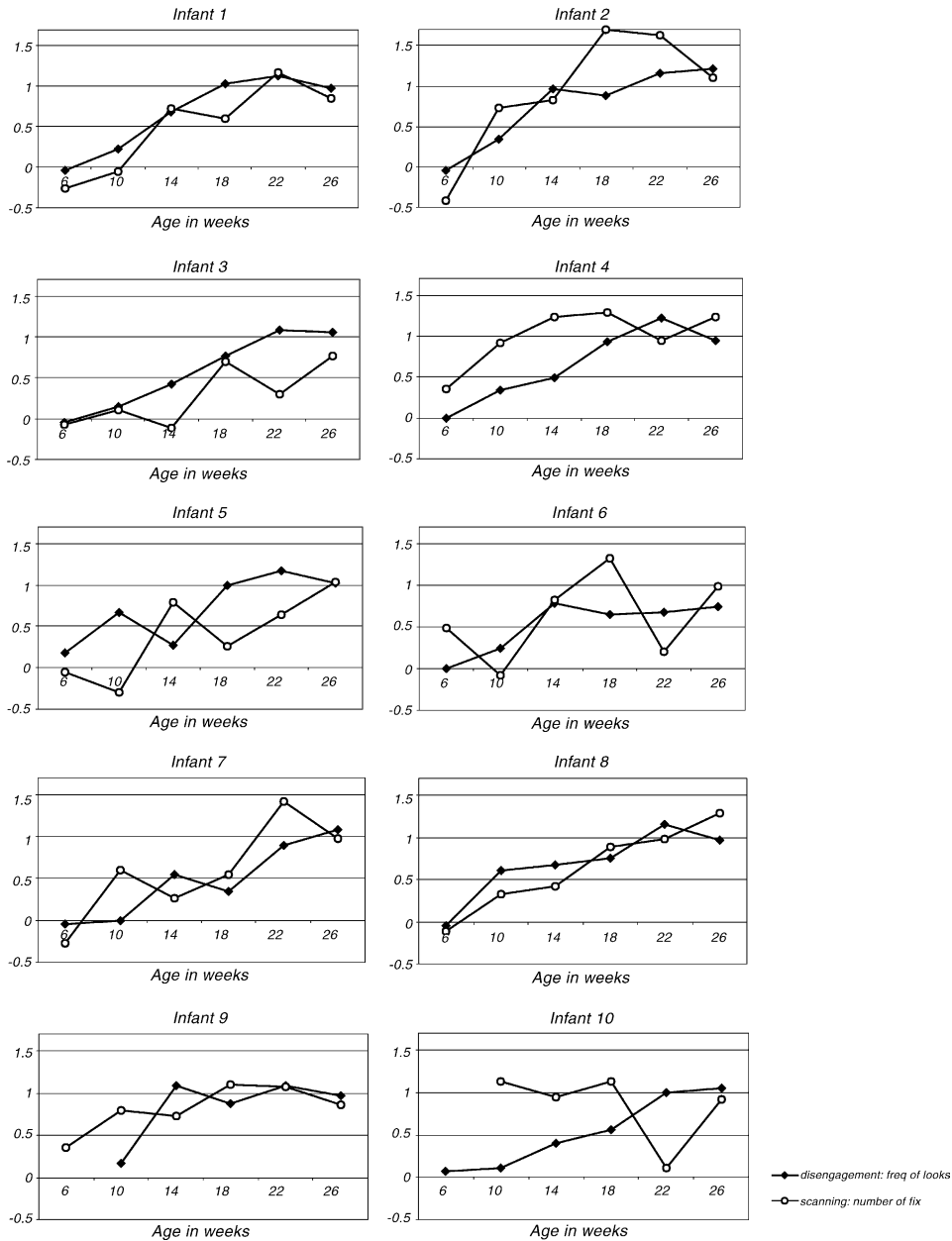


Fig. 5. The development of the mean number of fixations during the scanning task and the mean frequency of looks to the peripheral stimulus during the disengagement task for the 10 individual infants.

indicates that both the scanning and the disengagement curves show an increase roughly between the minimum and maximum values. Infant 10 is an exception: Here, the scanning curve fluctuates around the maximum and drops back to around the minimum value during the session at the age of 22 weeks. Some infants show a relatively smooth increase in both curves (infants 1 and 8 in particular), others show salient fluctuations, particularly in the scanning curve. While the averaged curves of the latency measures describe an overall decrease (see Fig. 4), the graphs of the individual infants show a rather large diversity (see Fig. 6). Infants 3, 5, and 6 show large fluctuations, especially concerning the median fixation duration during scanning. In two infants (infants 4 and 10), no decrease in the latency measures can be observed concerning their performance either in the scanning or the disengagement task. For infants 1, 2, 3, 7, 8,

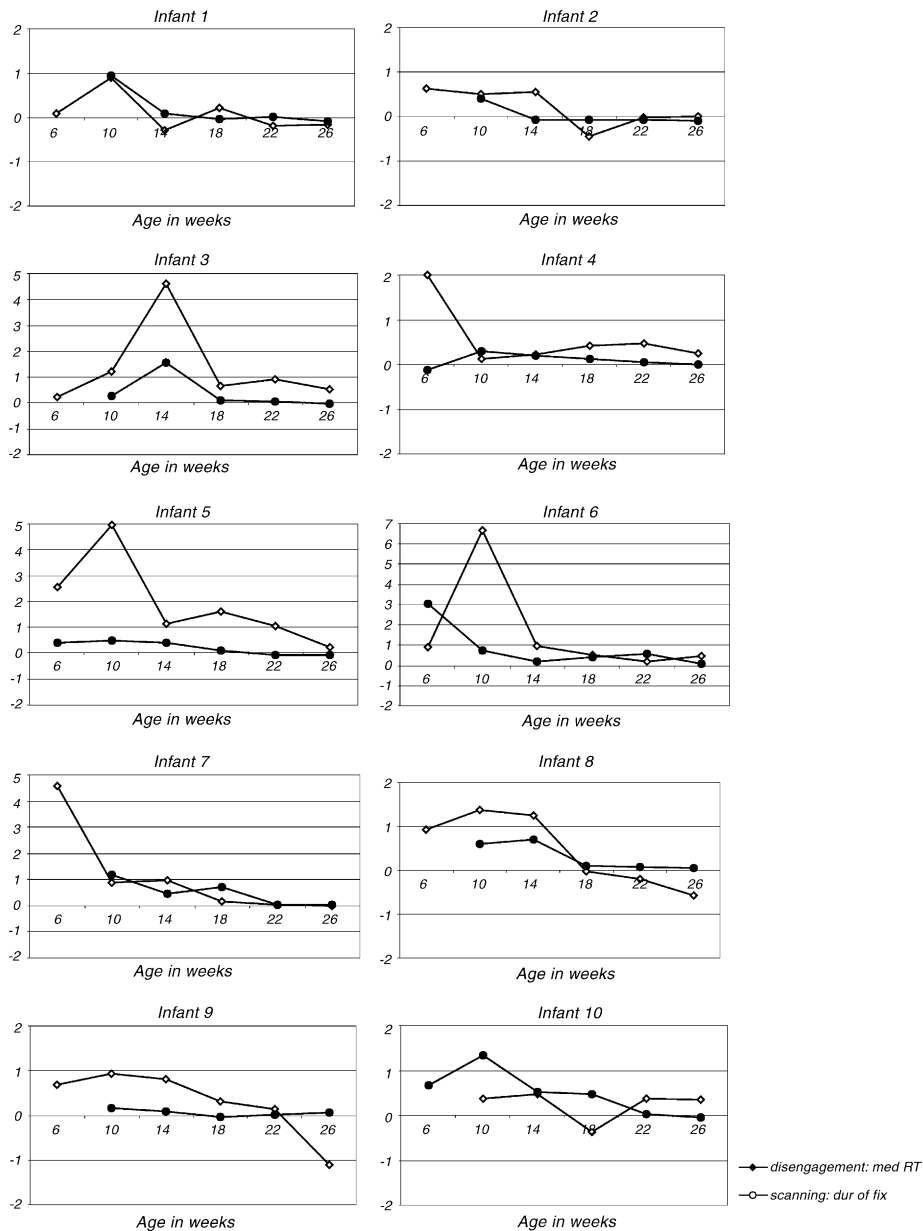


Fig. 6. The development of the median fixation duration during the scanning task and the latency of looks to the peripheral stimulus during the disengagement task for the 10 individual infants.

9, and 10, one measurement point was missing at 6 weeks. This was mainly due to the fact that infants rarely shifted their gaze during the disengagement task when they were young (as can also be seen from the frequency measures) but rather kept on staring to the central stimulus. However, in infants 1, 2, 7, 8, and 9 the latency measures decrease relatively smoothly throughout the measurement period.

The – eventual – similarity between the development of scanning and disengagement was also approached quantitatively.² Associations between the individual developmental trajectories were examined by means of inter- and intraindividual comparisons. First, the question was addressed whether the developmental trajectories of scanning and disengagement of the same infant tended to display similarity. Therefore, the similarity of the two trajectories in the same infant was compared to the similarity of one of these trajectories with one of another infant. Second, it was

examined whether the developmental changes concerning the performance on the scanning and the disengagement task were related within the individual infant.

If the two curves display related developmental courses, the within-subject similarity should be greater than the between-subject similarity. For instance, the similarity between the disengagement and scanning curve of one infant should on average be greater than the similarity between his own scanning curve and the disengagement curve of another, arbitrarily chosen infant. The null hypothesis – that within-subject similarity cannot be distinguished from between-subject similarity – was tested by means of a Monte Carlo procedure. The scanning data were randomly permuted across the subjects, with conservation of the individual trajectories (i.e. the six measurement points of each infant were kept together during the random permutation procedure). In this way, for all disengagement and scanning trajectories, a random assignment was made between a developmental trajectory of disengagement of a particular infant and a trajectory of scanning of another infant. The averaged χ value of the permuted data was compared to the value of the original data. By carrying out a large number of random permutations, an approximation of the exact chance distribution of the χ value was obtained. The proportion of the number of times that the within-subject similarity was greater than the between-subject similarity provided an estimation of the p value (i.e. the probability that the observed similarity was due to chance).

For both the frequency and the latency data, the random permutation procedure confirmed that the null hypothesis cannot be rejected: The within-subject and between-subject similarity could not be distinguished from one another. The p values for the frequency measures were .66 for a random permutation procedure and .59 for a random resampling procedure based on 5000 simulations. For the latency measures, the p values were .31 and .40, respectively.³

Second, if disengagement and scanning show a coupled developmental trajectory, changes in disengagement and changes in scanning should be similar. For instance, if in a particular child at a particular time, disengagement shows a rapid increase, scanning should do so, too. The assumption of similarity was tested by examining whether changes in disengagement and scanning levels measured during a particular occasion in a particular infant showed more similarity amongst each other than a change in a disengagement score compared with a change in a scanning score measured at an arbitrarily different moment. That is, it was investigated whether the changes in the variables (e.g., increases or decreases) were more similar in a particular infant at a particular measurement point than could be expected on the basis of chance. This question was examined by means of a random permutation procedure.⁴

The statistical test over the group of subjects led to the surprising finding that the resulting p value, based on 5000 simulations, was equal to .95, which shows that in 95% of the cases the random association of scanning and disengagement frequency scores provided a better similarity measure than the actual association. That is, over the whole sample, in individual subjects the frequency scores of disengagement and scanning tended to differ more strongly from one another than can be expected on the basis of chance alone. This difference eventually refers to a potential contrast or antagonistic relationship between the development of the number of fixations during scanning and the frequency of looks in the disengagement task. Inspection of the individual p values indicated that this overall effect was due to the majority of the infants (infants 2, 3, 4, 5, 7, 9, and 10; for two infants, 5 and 10, the difference was highly significant; $p < .001$). Concerning the latency measures of scanning and disengagement, however, there was no such effect: The resulting p value was .11 based on 5000 simulations.⁵

3.3. *Timing of development*

Finally, it was investigated to what extent the individual curves complied with the hypothesis that the development of scanning stabilizes slightly earlier than the development of disengagement. Therefore, the following procedure was carried out, which is based on the specification of a “point of stabilization”.

If a process stabilizes at time t , its average change (growth or fluctuation) before t must be (considerably) greater than its change or fluctuation after time t (since it cannot be expected that stabilization means a standstill, stabilization is defined as “little change” in comparison to “much change” the time before). In a time series consisting of n observations, a breaking point can be determined as the point in time t , where the difference in average change before t and average change after t is maximal (i.e. the stable phase is defined as the phase with minimal average change, in comparison with the average change preceding that phase). If – in the present case – the scanning variable stabilized earlier than the disengagement variable, the breaking point of the development of visual scanning should fall at an earlier time than that of the development of disengagement.

The statistical test of the null hypothesis went as follows: First, the change scores of the disengagement and the scanning variables were standardized. Second, for every infant a “compliance” value was determined, which was 1 if the breaking point of scanning was earlier than that of disengagement, .5 if they occurred at the same time, and 0 if disengagement preceded scanning. The scores of the individual infants were added up to receive an overall “compliance” score. Third, a within-subjects/within-measurements random sampling of the change scores was carried out. For each random sampling per subject, breaking points and a “compliance” score were calculated, as defined above. By carrying out a large number of randomizations, an estimation of the distribution of breaking points for each individual subject and for the average breaking point over all subjects was obtained, as based on the null hypothesis (“no difference”). With this distribution, the probability was calculated that the observed average breaking point was due to chance.⁶

In infants 1, 2, 3, 7, 9, and 10, the frequency scores of visual scanning stabilized earlier than the frequency of disengagement. In two of these infants, the difference between the breaking points was larger than one measurement interval. Scanning and disengagement stabilized at the same time in infants 4 and 8, and in infants 5 and 6 disengagement stabilized before scanning. This resulted in an overall “compliance” score of 7. The resampling procedure, based on 5000 randomized runs, yielded a *p* value of .007. That is, it is highly unlikely that the “compliance” score was based on chance, that means it is highly likely that the observed difference in stabilization between scanning and disengagement is a real phenomenon.

Thus, it can be concluded that the number of fixations during scanning stabilized earlier than the frequency of looks during disengagement. That is, concerning the frequency measures, the development of visual scanning came to rest earlier than the development of disengagement.

For the latency measures, there were no indications that the changes in one of the two variables leveled off earlier. The analyses yielded an overall “compliance” score of 5.5 and a *p* value of .41.

4. Discussion

In this study, infants carried out both a scanning task and a gaze shifting task six times during the first 6 months after birth. The developmental trajectories of scanning and disengagement were compared using the same stimulus material. Multilevel modeling revealed that both scanning and disengagement went through periods of rapid change until about 16 weeks of age, which is consistent with earlier findings on the development of these attentional skills (see, e.g., Bronson, 1994, 1996; Butcher et al., 2000; Hood & Atkinson, 1993). For the disengagement task, however, frequency and latency measures continued to change throughout the last age period of 16–26 weeks of age, while there was no change for the scanning task after 16 weeks. This finding was confirmed for the frequency measures by the Monte Carlo analyses: The changes in the number of fixations during scanning stabilized earlier than the frequency of looks in the disengagement situation.

The results thus suggest that the ability to scan a dynamic stimulus (face or abstract) evolves slightly earlier than the ability to disengage attention and shift gaze between these stimuli. While disengagement and gaze shifting is thought to depend on the posterior system, which receives magnocellular input and projects to the posterior parietal cortex, the voluntary, planned eye movements of visual scanning are considered to be mediated by the anterior system, which is parvocellular-based and projects to the inferotemporal cortical areas. Our findings thus are in accord with earlier accounts that the parvocellular stream becomes functional slightly before the magnocellular stream and that the differential rates of maturation are reflected in the early developmental changes in visual behavior (Atkinson, 1992; Atkinson & Braddick, 2003; Lewis et al., 1989).

It was the second aim of this study to explore possible associations between the development of scanning and disengagement at the level of the individual infant. The developmental courses of the scanning and the disengagement scores were compared but could not be shown to be more similar within the same infant than between different infants. Although earlier studies suggested that there might be close interrelations between the magnocellular and parvocellular system in the adult brain (see Cowey, 1994; Merigan & Maunsell, 1993, for reviews), our study thus revealed no indications for a relation between the developmental trajectories of these two visual abilities until the age of 6 months. However, other studies have also emphasized the independence of different ventral and dorsal mechanisms, as for example in children with Williams’ syndrome. These children show a profile in which ventral processes (such as face recognition) are unimpaired, while the dorsal function for visual control of action develops abnormally (Atkinson et al., 2001; Bellugi, Wang, & Jernigan, 1994).

It turned out that the developmental changes in scanning and disengagement of a particular infant at a particular measurement point were even less similar than one would expect on the basis of chance. The change scores of the frequency measures of scanning and disengagement thus showed some kind of contrast or complementarity. This contrast effect could be due to the fact that the processes governing scanning and disengagement do not only develop rather independently, but might even inhibit each other or compete for similar resources of development or performance. It is possible, for instance, that carrying out the two visual tasks was rather challenging for the young infants, as they required that the infants stayed alert and focused for about 10–15 min. An infant who did his best on one task might have been fatigued during the other and the other way around. On the other hand, the two processes – scanning and disengagement – might inhibit or dominate each other during their development. This is supported by observations from the disengagement task that infants who did not shift their gaze to the peripheral target often performed small eye movements on the central stimulus. These infants thus rather scanned the small stimulus in their central visual field than moved their gaze to the newly appeared target in the periphery. It is possible that these infants had a relatively well-developed parvocellular stream and anterior system and that their visual behavior was dominated by reactions that are mediated by this system.

The two stimuli used, the infants' mother's face and the abstract stimulus, elicited different visual behavior in both tasks (for a detailed description and discussion of these findings, see Hunnius & Geuze, 2004a, 2004b). During the scanning task, infants adjusted their scanning behavior to the stimulus they were exploring from about 14 weeks of age on. The way infants scanned the face stimulus stabilized slightly earlier than the scanning characteristics when scanning the abstract stimulus. During the disengagement task, infants of 10, 14, and 18 weeks of age were more likely to shift their gaze when the central stimulus was a face and the stimulus in their peripheral visual field was abstract than in the opposite condition.

In the fusiform area of the temporal lobe, neuronal assemblies have been identified which are specialized for face processing (Damasio, Damasio, & Tranel, 1986; De Renzi, 1982; Kanwisher, McDermott, & Chun, 1997). Developmental studies on face perception have shown that some rudimentary face processing exists already in neonates, such as preference for face-like stimuli (Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991) or visual recognition of a particular face (Bushnell, Sai, & Mullin, 1989). However, a more elaborate system for face perception – based on combined processing within V1 and the fusiform gyrus – has been shown to become functional only around the second to fourth month of age (Acerra, Burnod, & de Schonen, 2002; Bartrip, de Schonen, & Morton, 2000). The finding that infants used a different way of scanning for their mother's face and for an abstract stimulus from the age of 14 weeks on is consistent with the idea of these face-specific neuronal modules within the ventral stream becoming increasingly functional during the first few months of life. At the same time, the infant's increasing familiarity and experience with faces might play an important role. Especially the observation that the infants' mother's face was less able to hold and attract attention in the disengagement task as the infants grew older might be due to the infants' decreasing interest for their mother's face. From studies on face-to-face interaction we know that infants of 12 weeks begin to look away from their mother's face more often (van Wulfften Palthe, 1986) and that mothers must interact more actively to hold their infant's attention (Kaye & Fogel, 1980).

To sum up, it seems that during the first 6 months of life the two skills examined in this study – visual scanning and gaze shifting – develop independently and follow their own developmental time courses. However, one has to keep in mind that these conclusions are based on a relatively small (but representative) sample. Larger samples are needed not only to make the results more reliable, but also to obtain a better understanding of the nature of the inter- and intra-individual differences. Furthermore, it is clear that a study of behavioral change cannot provide hard evidence on the developmental status of neurological substrates. However, detailed descriptions of behavioral development provide valuable information and form the basis for specific future investigations of neurological change.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at [doi:10.1016/j.infbeh.2005.08.007](https://doi.org/10.1016/j.infbeh.2005.08.007).

Notes

1. The method of standardization was the following: Based on the group data, averages were calculated for the first observation and the last, for both pairs of variables (see Figs. 3 and 4). The distance between the average of the first and last observation was taken as the unit interval, that means the interval with value 1. Individual scores were standardized by means of the following transformation

$$y_{\text{norm}} = \frac{y_{\text{obs}} - \min_V}{\max_V - \min_V}$$

for y_{norm} the normalized score, y_{obs} the observed score and \min_V and \max_V the average score of the first and last observation, respectively. By doing so, individual scores were compared on a unit interval defined by the developmental trajectory based on group data.

2. Similarity was expressed by means of averaged χ values. The χ value is defined as the average of the distance between corresponding scores. It was chosen as it is an intuitively understandable measure of distance and – other than a χ^2 value – does not carry the risk of overestimating the effect of larger differences. Its chance distribution can be obtained by means of the Monte Carlo simulation. All analyses were double-checked by means of χ^2 value analyses. These analyses yielded results that were consistent with those based on the χ value analyses.
3. It has been hypothesized that the development of visual scanning stabilizes before the development of disengagement does. This implies that the within-subject similarity with lag 1 (or more) could eventually be greater than the similarity based on simultaneous observations (i.e. disengagement at time $t + 1$ should be more similar to scanning at time t than to scanning at time $t + 1$). However, χ values with lag (1 or 2) resulted in even less similarity than simultaneous comparisons.
4. The procedure will be explained by means of an example, based on the standardized disengagement and scanning scores of the first subject (see Table 1). To begin with, change was defined as the difference between a score and the preceding score. For instance, the change at t2 for disengagement is $.23 - (-.05) = .28$ (see the column “disengagement change” at t2). The difference between the amount of change in disengagement and scanning is an indicator of how strongly the change in disengagement and scanning are coupled (the smaller the difference, the more they are coupled). For instance, the difference between the change in disengagement and in scanning at time t2 is $|.22 - .28|$, which reads as “the absolute value of $.22 - .28$ ” which is equal to $.06$ (see the column “distance change”; the term “distance” refers to the fact that the absolute value of the difference is used as a criterion). The average distance between the changes in disengagement and scanning for infant 1 is $.296$ (see average of distance change). Does this particular distance measure indicate that the changes in disengagement and scanning are coupled? In order to answer that question, we must know what the average score is if the changes are not coupled. If the change scores of disengagement are randomly reordered and those of scanning are also randomly reordered (see the columns labeled “shuffle 1”), they are certainly no longer coupled (if they were coupled anyway). Table 1 gives two examples of such randomly re-ordered change scores and of the resulting distances ($.348$ and $.196$, respectively). In order to obtain an estimation of the average distance resulting from unordered (i.e. uncoupled) change scores, the random permutation must be carried out a great number of times (e.g., 5000 times). The estimated distance based on 5000 runs is $.39$. The probability that the unordered change scores produce a distance that is as small as or smaller than the observed distance is $.2$ (i.e. the p value is $.2$), which implies that the null hypothesis that the changes are not coupled cannot be rejected. It goes without saying that this conclusion holds for this particular example – infant 1 – alone. In order to obtain an estimation of the p value for the whole sample, the random permutation procedure must be carried out for all subjects simultaneously. The test statistic of interest (χ value) is the average over all subjects of the average distances between the changes in disengagement and scanning.
5. As it was hypothesized that visual scanning develops earlier than disengagement does, it is possible that the obtained effect is due to a lag in the developmental course of disengagement, as the distance score of two data series with a phase shift might be greater than should be expected on the basis of randomly permuted series. However, it could be shown, that this is not necessarily the case: A simulation was carried out with two series of five imaginary scores, which displayed a clear phase shift. The simulation showed that in only 21% of the cases the random association of the two imaginary series provided a better simi-

Table 1
 Procedure to examine the similarity in change in disengagement and scanning (infant 1)

	Disengagement		Scanning		Distance change
	Score	Change	Score	Change	
Data					
t1	−0.05		−0.27		
t2	0.23	0.28	−0.05	0.22	0.06
t3	0.68	0.45	0.73	0.78	0.33
t4	1.03	0.35	0.6	−0.13	0.48
t5	1.13	0.1	1.16	0.56	0.46
t6	0.97	−0.16	0.85	−0.31	0.15
					0.296 (average)
Random permutations		Shuffle 1	Shuffle 1		
		−0.16	−0.13		0.03
		0.1	0.56		0.46
		0.35	0.78		0.43
		0.45	−0.31		0.76
		0.28	0.22		0.06
					0.348 (average)
		Shuffle 2	Shuffle 2		
		−0.16	−0.31		0.15
		0.35	0.56		0.21
		0.1	−0.13		0.23
		0.45	0.78		0.33
		0.28	0.22		0.06
					0.196 (average)

larity measure than the actual association (compared to the 95% which resulted from the analyses of our data).

- The statistical procedure will be explained by means of an example, based on the data of the first infant. Table 2 shows the standardized scores of infant 1 on disengagement and scanning. Since we wish to know the amount of change, we are not interested in the direction of the change. Hence, we define the change as the absolute difference between a score and the preceding score. For instance, at time t6, the change is $|.97 - 1.131| = .161$. Note that in the previous method (see footnote 4) we took the simple difference between a score and its predecessor, which in this case would be $-.161$. This was done because, in the preceding method, the magnitude and direction of the change mattered. In the present case, however, it is only the magnitude of the change that matters. In order for the various change scores to be comparable within subjects, the change scores are standardized into *z* scores (with a translation, such that the minimal score of the entire set is 0). After this additional standardization, the only meaningful distinction that remains between the disengagement and scanning change scores is the presumed difference in the way they are ordered, which corresponds with the similarity or dissimilarity in breaking points. The breaking points are calculated as follows. Take for instance the value .816 under the heading “breaking points disengagement” (lower right of Table 2). This value is the difference between the average of the first two change scores, 1.211 and 2.113 (which is 1.662) and the last three change scores 1.575, .326 and .638 (which is .846). The third value in the “breaking points disengagement” column, for instance, is based on the average of the first three change scores and the average of the last two. The breaking point is the point of the biggest possible difference between the averages of scores before that point and the average of scores after that point. In the “disengagement” column, it is the value 1.151, which occurs on the third position. In the “scanning” column, it is the value .539, which occurs on the second position. Thus, in this subject, stabilization in scanning occurs earlier than stabilization in disengagement. This subject thus complies with the hypothesis that scanning stabilizes earlier than disengagement and is assigned a “compliance score” of 1. Then, a summed compliance

Table 2
Procedure to examine the timing of development in disengagement and scanning (infant 1)

	Score		Distance score		Standardized distance score		Random permutation between variables within time	
	Disengagement	Scanning	Disengagement	Scanning	Disengagement	Scanning	Disengagement	Scanning
t1	−0.047	−0.266						
t2	0.229	−0.048	0.276	0.218	1.211	0.606	1.211	0.606
t3	0.685	0.729	0.456	0.777	2.113	2.424	2.424	2.113
t4	1.033	0.605	0.348	0.124	1.575	0.303	0.303	1.575
t5	1.131	1.165	0.098	0.560	0.326	1.717	0.326	1.717
t6	0.970	0.854	0.161	0.311	0.638	0.909	0.909	0.638
					Breaking points		Breaking points	
					Disengagement	Scanning	Disengagement	Scanning
					0.048	−0.732	0.221	−0.905
					0.816	0.539	1.305	0.050
					1.151	−0.202	0.695	0.254
					0.668	0.354	0.157	0.865

score for the whole group of subjects is calculated. In order to test the probability that this summed compliance score can be expected on the basis of chance alone, the following random permutation procedure is carried out. First, the occurrence of stabilization implies that change scores are ordered in time (i.e. they will on average diminish with time). However, if there exists no difference between the time of stabilization of disengagement and of scanning (the null hypothesis), the standardized change scores at time t , or any other time for that matter, are, statistically speaking, interchangeable. For instance, under the null hypothesis, the standardized distance scores at time t_2 , namely 1.211 and .606 are interchangeable, at time t_3 2.113 and 2.424 are interchangeable, at time t_4 1.575 and .303 are interchangeable, and so forth. For any such random interchange of scores, breaking points can be calculated and a compliance score can be given. Based on 5000 such random permutations, a p value of .007 was found. This p value implies that the probability that the compliance score found is consistent with the assumption that disengagement and scanning do not differ in their moment of stabilization, is .007.

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