

A phase transition in infants' ability to disengage visual attention

Abstract

The development of the ability to disengage gaze was followed in 16 infants. Two phases were identified: infrequent disengagement and frequent, flexible disengagement. All infants moved rapidly from the first to the second phase. The infants differed in the age at which the shift began, and in its smoothness. We were unable to conclude definitively that the shift between the two phases was a noncyclic, discontinuous phase transition. There was clear evidence for anomalous variance and tentative evidence for bimodality and inaccessibility. However, whether the rapid change in behaviour was an example of a sudden jump rather than rapid growth was not clear. An experimental investigation to determine if hysteresis is present is recommended.

Introduction

The human visual system is relatively well developed at the time of birth and continues to develop rapidly in the first several months of life. Young infants are able to explore visually, with some degree of efficiency, objects in their environment that they cannot touch or manipulate. At the same stage, caretakers use infants' relatively well organised looking behaviour as an index of their attention or interest, and adapt their behaviour accordingly. For a short but crucial period of development, looking behaviour is both a primary way of acquiring information and an important means of communication.

There have been many investigations of early visual development (See Banks & Salapatek, 1983, for a review). A steady increase in the size of the peripheral visual field during the first 12 months, and the emergence of the ability to accommodate, processes which bring distant objects within visual 'reach', have both been documented. A steady increase in acuity, enabling the perception of detail, and increases in both the speed and the accuracy of eye movements have also been found.

The processes just mentioned, however, are all aspects of the sensory processing activities of the visual system. Research with adults has provided convincing evidence for the existence of covert visual attention systems, anatomically distinct from the visual system, with the function of modulating its activity (Posner, 1988; Klein, 1979). Such systems are involved not in sensory processing, but rather in its modu-

lation to meet the specific demands of the task at hand. Covert attention systems have been shown, for example, selectively to enhance the processing of stimulus features, or locations that are particularly relevant for the task at hand (Corbetta, Miezin, Dobmeyer, Shulman & Petersen, 1990; Posner, 1988).

Covert attention systems have only recently been identified in adults, and there have been few investigations of their functioning in young infants. However, it is likely that the development of such 'strategic' systems will have as great an impact on the quality of infant looking behaviour as increases in acuity, or the emergence of the ability to accommodate. We have seen that looking behaviour plays a crucial role in information acquisition and communication in early life. The emergence of the attentional mechanisms which regulate looking behaviour is therefore likely to have a profound impact on the quality of development. Factors that may delay or impede their emergence, for example, the brain damage often associated with a premature birth, may have a negative impact on the quality of early development in general.

The goal of our investigation was to describe the course of development of covert visual attentional mechanisms in healthy infants, as the first step towards a comparison of the development of such mechanisms in healthy infants and those at risk for later attentional problems. We focussed on the development of the posterior attention system (PAS), perhaps the most simple of the covert visual attention systems, and the subject of intensive investigation in adults during the last 15 years. The PAS is involved in shifts in the focus of covert visual attention, which moves rapidly around the visual field, two or three times within a single visual fixation. Such shifts are thought to play an important role in determining the focus of visual fixations, and to be a precondition for a shift in gaze (Saarinen & Julesz, 1991).

Investigations of covert visual attention in adults have identified three operations in a shift in the focus of covert visual attention (Posner, Inhoff, Friedrich & Cohen, 1987). First, attention is disengaged from its current focus. Next, it is shifted to a new location, and finally, it is engaged at the new location, a necessary condition for all but the simplest perceptual processes. Each operation has been associated with a specific area of the brain: disengagement with the posterior parietal lobe; shifting with the superior colliculus and engagement with the thalamus (Posner, 1988). Together these three areas make up the PAS. The development of the first operation, disengagement, is the subject of this report. Disengagement is a particularly important operation for young infants because disengagement of covert visual attention is generally accepted to be a precondition for a shift in gaze, and infants shift gaze frequently and systematically in the process of acquiring information about their environment, and in communicating.

A number of sources provide information on the course of the development of the ability to disengage. Since the operations involved in a shift in covert attention have each been associated with a particular location in the brain, current knowledge of neurological development allows us to form expectations about the approximate ages at which specific functions will emerge. The thalamus, (engage), and the superior colliculus, (shift), are both functional at the time of birth. The posterior parietal, (disengage), however, does not become functional until the third month (Chugani, Phelps, & Mazziotta, 1987). Shortly after birth, then, the infant should be able to shift

and engage covert visual attention, but not to disengage it. At this stage shifts in covert visual attention should be slow and unreliable, occurring only after the activation eliciting engagement has subsided spontaneously. Slow, unreliable shifting should persist until the posterior parietal becomes active, during the third month of life, and the ability to disengage emerges. From this age on, shifts should be fast and reliable. Knowledge of neurological development thus suggests that there will be a phase of slow, unreliable disengagement, lasting until sometime during the third month, followed by a phase of fast, reliable disengagement.

The results of experiments directly measuring the frequency of disengagement of gaze also suggest there are two phases in the development of disengagement of visual attention. (Because of the infant's limited behavioural repertoire, the ability to disengage covert visual attention is measured by tasks which also require the disengagement of overt visual attention, or gaze. This gives rise to problems of interpretation. However, since the areas of the brain associated with disengaging covert attention and with shifting the focus of overt visual attention become functional at different ages, the third and fourth month respectively, we should be able to disentangle the roles of covert and overt attentional mechanisms) The 6-week-olds Hood & Atkinson (1993) studied shifted gaze from a central stimulus to look at a peripheral target within the allotted 2.1 seconds on less than 20% of the trials, while the 3- and 6-month-olds did so on almost all trials. Johnson, Posner & Rothbart (1991) found that 2- and 3-month-olds shifted gaze to the peripheral target on 35% and 45% of trials respectively, while 4-month-olds did so on approximately 80% of trials.

Investigations which measure disengagement of gaze less directly, e.g. measurement of peripheral visual field size using kinetic arc perimetry, produce converging results. Measurements requiring disengagement of gaze show a stable visual field from birth until 7 weeks of age, followed by rapid expansion (Mohn & van Hof-van Duin, 1986; Harris & MacFarlane, 1974). Measurements not requiring disengagement of gaze show a more continuous expansion from birth onwards (Harris & MacFarlane, 1974).

Finally, incidental reports of particularly long fixations, sometimes accompanied by signs of distress, in infants between 2 weeks and 10-12 weeks of age suggest that the disengagement difficulties observed in structured experimental conditions also occur in more spontaneous situations (Stechler & Latz, 1965; Hopkins & van Wulfften-Palthe, 1985).

The empirical evidence, then, is consistent in indicating two stable, qualitatively different phases in the development of the ability to disengage. The first, lasting from shortly after birth until 2-3 months of age, is characterized by slow, infrequent disengagement; the second, beginning at about 4 months of age, is characterized by swift, reliable disengagement. The transition to swift, reliable disengagement was observed at different ages in different studies, but was in each case quite abrupt, occurring in the period between 2 consecutive measurements. Two considerations led us to speculate that the abrupt emergence of disengagement occurs against a background of gradual change on the neurological level. First, it seems likely that the neurological development leading to functionality in the posterior parietal lobe will not occur overnight, but rather over a period of a few weeks. Second, the integration of

the newly active posterior parietal area into an already (partly) functioning PAS network also seems likely to require time.

Catastrophe theory provides a mathematical description of noncyclic, discontinuous transitions between two qualitatively different phases of a behaviour which are associated with continuous change in variables thought to 'control' the behaviour (Gilmore, 1981). Catastrophe theory also specifies a number of criteria, the catastrophe flags, which enable us to determine if a rapid change in behaviour meets the conditions for this class of transition, or can better be described as rapid growth. It may thus provide the quantitative description of the development of disengagement we are seeking to allow a comparison of developmental trajectories in low and high risk infants.

Our hypothesis was that the development of disengagement would be an example of a noncyclic, discontinuous phase transition.

Method

Subjects

The subjects were 16 healthy babies, selected from 31 volunteers on the basis of an optimal gestational, and peri- and postnatal history. The babies were seen 10 times, at approximately 2-week intervals, between 6 weeks and 6 months of age. A normal gestation lasts between 38 and 42 weeks. Since the development of visual processes is very closely linked to the maturation of the nervous system, gestational rather than chronological ages were used.

Procedure

The mothers were asked to bring their infant to the laboratory, usually only a short distance, at a time at which he would be alert for at least 30 minutes. During each session, the babies carried out two brief looking tasks. The babies were seated in an infant car seat, facing three monitors, 45 cm from the central monitor. The monitors were screened off from the rest of the room by a dull grey curtain. A videocamera below the central monitor recorded the infant's eye movements, and displayed them on a fourth monitor, allowing the researcher to move through the tasks in response to the infant's eye movements. A soft headrest provided extra support for the youngest subjects, and limited, although it did not prevent, head movements.

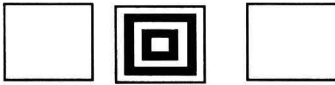
Task

The task used to measure frequency of disengagement is shown in Fig. 1. First, a brightly coloured, moving pattern was presented on the central monitor. When the infant had fixated the pattern, a second pattern, equal in contrast to, and flashing in phase with, the central pattern, was presented 30 degrees to the left or the right. The peripheral pattern remained visible for 5000 ms. Both patterns then

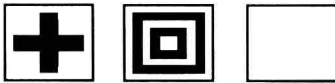
disappeared. After an interval of 1250 ms, the following trial began with the appearance of the central pattern. Ten trials with left peripheral targets and 10 with right peripheral targets were presented in pseudo-random order. Interspersed among the disengagement trials were eight trials in which the central pattern disappeared when the peripheral target appeared. These 'unilateral' trials showed whether the target would elicit an eye movement in the absence of the central stimulus

Disengagement Trials

Central Fixation Stimulus



Competing Target (5000 ms)



Unilateral Trials

Central Fixation Stimulus



Unilateral Target (5000 ms)



Fig. 1. Disengagement Task.

The tapes were scored by third and fourth year psychology students. Infant eye movements are not always unambiguous, often involving blinks or half-closed eyes and head movements. Direction, but not response latency, was recorded where blinks or head movements obscured the beginning of an eye movement. Intensive training and scoring of the tapes half frame by half frame, (20 ms segments), produced high levels of reliability for the direction and timing of the infants' eye movements, 92% and 96% respectively.

Results

The percentages of successful disengagement, errors and looking at a unilateral target for three of the babies are presented in Fig 2. Not all of the babies completed 20 disengagement trials. The number of trials on which a infant succeeded in disengaging was therefore expressed as a percentage of the disengagement trials completed.

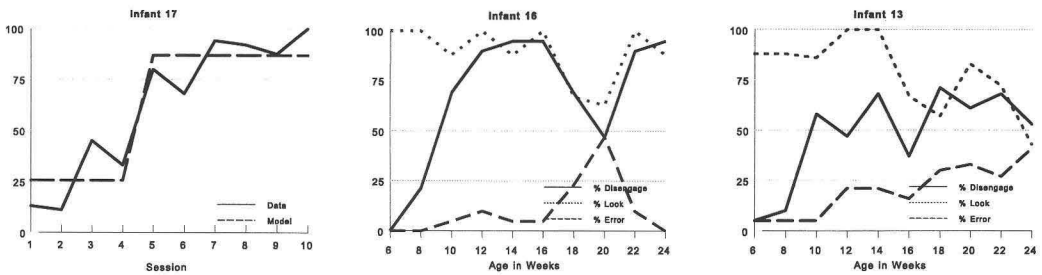


Fig. 2. Percentage of Disengagement, Errors, and Looking to a Unilateral Target for three infants.

Fourteen of the 16 infants showed steep, rather abrupt increases in the frequency of disengagement, from 10% or less to more than 70% over a 4-6 week interval. The frequency of looking at the unilateral targets hovered between 70% and 100% during this interval, showing clearly that the low incidence of disengagement in the first session(s) was not the result of failure to respond to the peripheral target. The percentage of errors remained stable until two or three sessions after the increase in disengagement, showing that the sudden increase in disengagement cannot be attributed to a generalised increase in random looking.

While all infants showed sudden, steep increases in the frequency of disengagement, there were considerable inter-individual differences in the age at which the first significant increase occurred. The earliest increase was observed at 8 weeks of age, the latest at 12 weeks of age. The interval between the first significant increase and criterion ranged from 2 to 6 weeks, reflecting the fact that while six of the 16 infants made a smooth, swift transition the majority plateaued, or dropped back after the initial increase before stabilising at 70-100% disengagement.

When the scores of the infants are combined, the steep increase in frequency of disengagement remains clear, but the first phase, frequency of disengagement less than 20%, is restricted to the sessions at 6 and 8 weeks of age (Fig. 3a). However, significant increases in variance in Sessions 3 and 4 suggest that the inter-individual differences in the age at which the increase began, and the steepness of some of the earliest jumps may conceal the persistence of the first phase in some infants. The data was fitted to a sudden jump model, and then regrouped according to the progress of the transition by aligning the sessions at which the initial jump occurred. Two phases can now be seen more clearly (Fig. 3b).

To determine whether the quite dramatic increase in frequency of disengagement meets the criteria for a non-cyclic, discontinuous phase change as described in catastrophe theory, we tested for the presence of four flags which do not require experi-

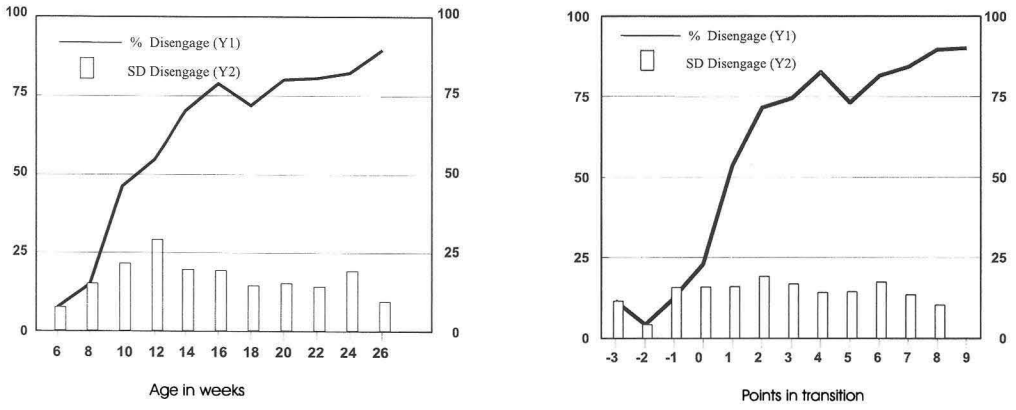


Fig. 3. Frequency of Disengagement: Mean and Standard Deviation a. By Age; b. By Point in Transition.

mental manipulation and could therefore be checked with our descriptive data: a sudden jump, bimodality, inaccessibility, and anomalous variance.

Fig. 4 presents the frequency distribution for the frequency of disengagement over the 10 sessions for the group as a whole. Visual inspection suggests that the distribution is bimodal. However there are two peaks, albeit small, in the area of inaccessibility. Two statistical methods were used to determine if the distribution was bimodal. The first, *Hartelman's Modes (1996)*, is more appropriate for our data which was in the form of percentages rather than absolute frequencies. It showed a much higher probability for a bimodal than a unimodal model, and a slightly higher probability for a bimodal model than for a trimodal model (Table 1).

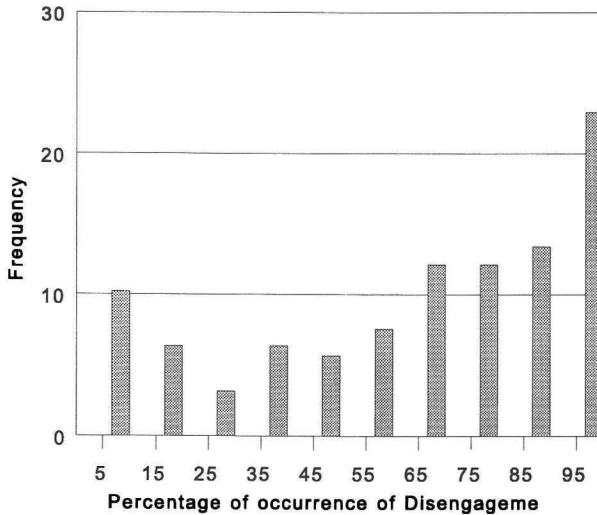


Fig. 4. Frequency Distribution: Percentage of occurrence of Disengagement for all infants across all sessions.

A bimodal model also explained considerably more variance than a unimodal modal on the second measure, mixture distributions (Van der Maas, 1993). Inclusion of a third component produced a further, although slight, increase in explained variance. The clear gain from bimodal models in each case, and the small differences in fit for bi- and trimodal models supports a tentative conclusion of two modes separated by a region of inaccessibility.

Table 1.

a. Model Estimates using Modes

No of modes	P
1	.07
2	.87
3	.63

b. Model Estimates using mixture distributions

No. of components	AIC	χ^2	VAF
1	1104	13147	.234
2	771	57	.885
3	730	4	.994

To determine whether the transition to frequent, reliable disengagement took the form of a sudden jump, individual developmental trajectories were fitted to a sudden

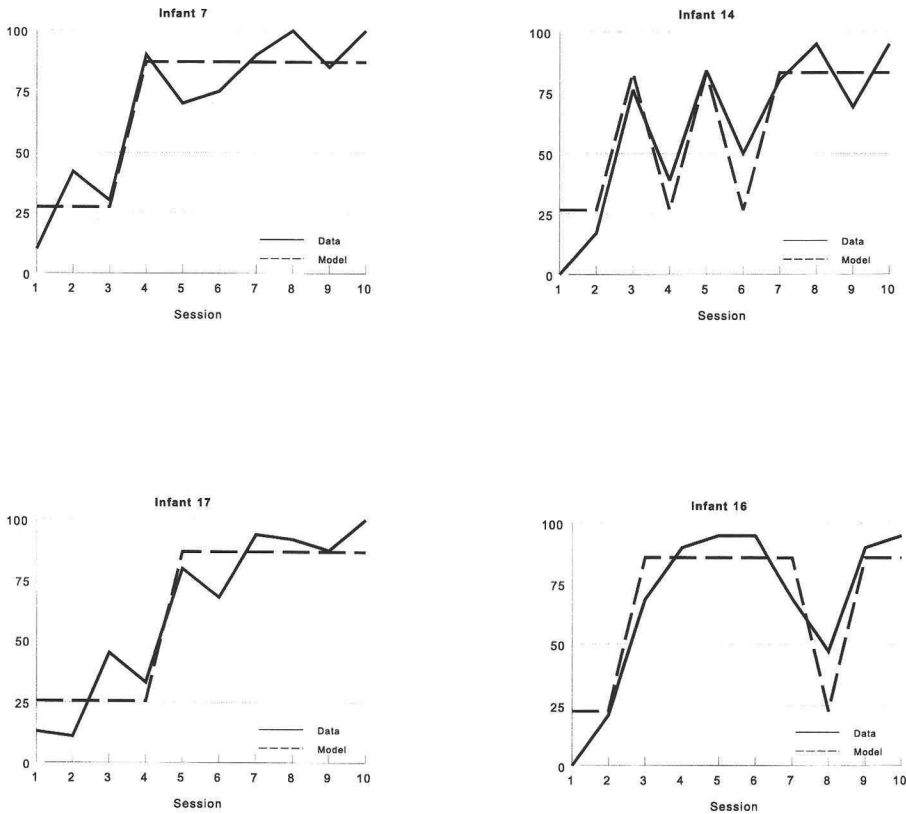


Fig. 5. Fits based on sudden jump model.

jump model, with two levels (Fig. 5), and a logistic growth model, using least squares (Fig. 6. See for details van Geert, 1994). In 10 of the 16 cases, there was very little difference between the fit of the data to each model. The sudden jump model did not provide consistently better fits. The mean of the individual R^2 's for the sudden jump model was not significantly higher than that for the logistic growth model, .799 and .720 respectively. We were therefore unable to conclude that there was evidence in our data for a sudden jump.

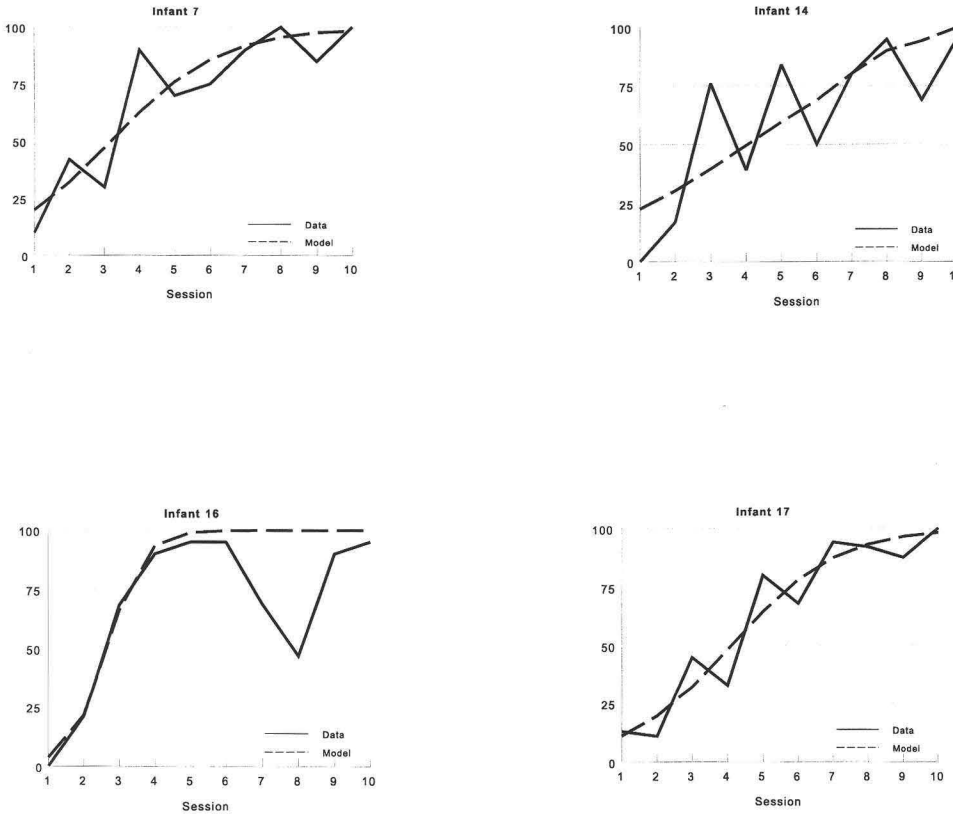


Fig. 6. Fits based on a growth model.

Sudden jump and logistic growth models differ quite clearly in how they approach the fluctuations that were found in the frequency of disengagement following the initial increase. Fluctuations in behaviour are predicted around a transition by a sudden jump model, and treated as oscillations between the level of disengagement found in the initial infrequent or no disengagement phase and that found in the final, frequent disengagement phase (Hartelman, van der Maas & Molenaar, 1998). (Values between these two levels fall in the area of inaccessibility, and should not, in theory, occur.) A growth model does not predict such fluctuations, and treats them as externally induced perturbations. If the observed fluctu-

tuations can be shown to coincide in time with other indications of intrinsic instability of disengagement behaviour, this would favour an interpretation of fluctuations as internally generated, anomalous variance, and strengthen the case for the sudden jump model.

Anomalous variance is one of the strongest criteria for a transition in the sense of catastrophe theory (van der Maas & Molenaar, 1996). It may take the form of behaviours intermediate between the pre- and posttransitional behaviours, or of irregularities in the behaviour itself, e.g. large variations in behavioural frequency or response latencies. We found evidence for the first form of anomalous variance. Two intermediate behaviours were observed during the disengagement task: delayed disengagement, looking to the peripheral target only after both central and peripheral patterns had disappeared, and partial disengagement, moving the eyes only partway to the target. Intermediate behaviours occurred on 25% or more trials in 5 subjects one session before, and during the first significant increase in frequency of disengagement. Fig. 7 shows the frequency of intermediate behaviours, and the stage in the transition at which they occurred for three infants. The nature of the intermediate behaviours provided valuable insights into the role of overt and covert visual attention in disengagement of gaze.

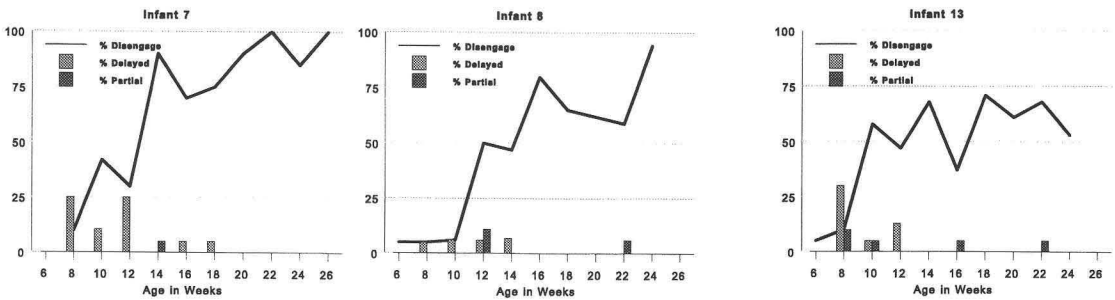


Fig. 7. Frequency of Disengagement and Intermediate Behaviours by Age.

Response latencies for 11 of the 16 infants showed a steady, sometimes initially steep, decline over the 10 sessions. The remaining five infants showed a definite peak at some point in the general decline. Three typical trajectories are shown in Figure 8. The case for seeing fluctuations in frequency of disengagement as a reflection of internally generated, anomalous variance would be strengthened if they coincided with fluctuations in response latency.

Significant fluctuations in frequency of disengagement were observed in one infant during the transition, and in five infants after the transition. The single fluctuation in frequency during the transition coincided with a fluctuation in response latency (See Fig. 8, Infant 14); however, fluctuations after the transition did not. We concluded that there was no evidence for anomalous variance as indexed by a correspondence between fluctuations in response frequency and response latency.

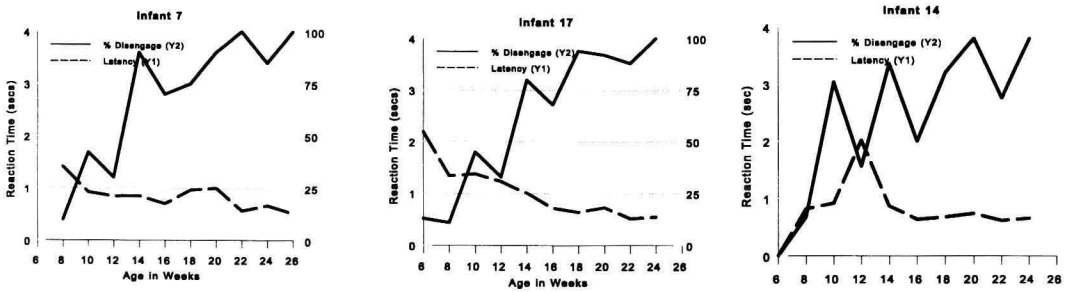


Fig. 8. Frequency of Disengagement and Latency to Disengage by Age.

Conclusion

The finding of two phases in the emergence of the ability to disengage is in agreement with the results of previous research. The age at which the transition between the phases began differed considerably among the infants we studied, with the earliest transition beginning at 8 weeks, and the latest at 14 weeks. The duration of the transitional period also varied considerably, with the result that the transition spanned a period extending approximately from the lowest to the highest ages that have been associated with significant increases in frequency of disengagement in the literature. Both the occurrence of two phases and the timing of the transition between them are consistent with current understanding of early neurological development.

Statistical measures provided only tentative support for bimodality and inaccessibility. The results of curve fitting did not allow us to choose between a sudden jump and a growth model. There was evidence for a fourth flag, anomalous variance. This strengthened the case for a sudden jump over a growth model. However, at this stage of the analysis we are unable to reach a definitive conclusion as to whether the emergence of disengagement is a noncyclic discontinuous phase transition. Further investigation involving the experimental manipulation of control variables necessary to establish the presence of criteria such as hysteresis and critical slowing, which provide particularly strong evidence for a catastrophe theory type transition (Van der Maas & Molenaar, 1996), is necessary.

Experiments to gather evidence for hysteresis would be a fruitful next step. Manipulation of potential control parameters would not only clarify the nature of the transition we observed but may also allow us to identify the variables which control the emergence of the ability to disengage. Two basic processes seem to play a central role in disengagement: arousal evoked by the peripheral stimulus and inhibition evoked by the fixated stimulus. Possible control variables are those which reflect continuous developmental processes, which are known to affect frequency of responding to visual stimuli, and which could influence the intensity of both arousal and inhibition. One such variable may be the spatial frequency of the stimulus. Variations in spatial frequency are used to assess infant visual acuity. Varying the spatial frequency of the peripheral target and its background, with the central stimulus held constant, would provide insight into the effect of changes in intensity of arousal.

Varying the spatial frequency of the central stimulus and its background, with the peripheral target held constant, would provide insight into the effect of changes in intensity of inhibition. At the same time, evidence for the presence of hysteresis on the basis of both arousal and inhibition would be obtained.

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