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REPORT

The distribution of infant attention during object examination

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Abstract

The distribution of attention during toy play was studied in 6-, 9- and 12-month-old infants. Heart rate and behavior measures of attention were collected as the infants interacted with objects. There was a large deceleration of heart rate at the beginning of behaviorally defined focused attention, but little heart rate change for looks that only had behaviorally defined casual attention. Heart-rate-defined sustained attention occurred more frequently at the transition from the first instance of casual attention within a look to focused attention and during the cycling between subsequent epochs of casual and focused attention. These results show that heart rate and behavioral measures of attention are closely related in young infants at the beginning and end of object interaction but are inconsistently related within a single look at an object.

Infants attain information from their environment by selectively attending to objects or events in their surroundings. Ruff (1986) found that infants' degree of engagement, or 'attentive state', was not the same throughout an episode of looking at objects or playing with toys. Attentive state was defined by combining types of behavior with facial expressions. Behaviors such as fingering or slow, deliberate object manipulation coincided with an intent facial expression (furrowed brow and/or pursed lips). This behavior was termed 'focused attention'. Alternatively, object-directed activity not classified as focused attention such as certain types of mouthing and repetitive banging corresponded with uninterested facial expressions. This type of behavior was labeled 'casual attention'. The duration of focused attention has been shown to decrease over the course of object examination. This decrease in focused attention duration is consistent with the hypothesis that information-gathering activities decrease as object familiarity increases (Oakes, Madole & Cohen, 1991; Ruff, Saltarelli, Capozzoli & Dubiner, 1992). In contrast, behaviors indicating casual attention do not decrease over the course of object play, suggesting that information-gathering processes do not affect them. Casual attention in this understanding indicates that the infant is engaged with the object (or fixates the object) in an inattentive manner. Focused attention represents periods of time when the infant is actively engaged in information processing while casual attention reflects a passive type of attending (Ruff, 1986; Ruff & Lawson, 1990; Oakes & Tellinghuisen, 1994; Lansink & Richards, 1997; Tellinghuisen & Oakes, 1997).

Infant attention has also been defined using measures of heart rate. Richards and colleagues have determined that a single episode of fixation to a visual stimulus is composed of a sequence of attention phases identified by systematic changes in heart rate (Richards, 1987, 1997, 1998, 2000; Richards & Casey, 1991, 1992). Stimulus orienting is identified as an initial deceleration in heart rate at the onset of the stimulus. Sustained attention immediately follows stimulus orienting and is accompanied by a sustained lowered heart rate. Heart rate returns to pre-stimulus level during attention termination. Attention phase (sustained attention, attention termination) has been found to be related to distraction latency in a manner similar to behavioral ratings of attention. Infants took longer to look at a distractor when it was presented during sustained attention than at attention termination (Richards, 1987, 1997; Casey & Richards, 1988; Lansink & Richards, 1997). Informa-

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tion processing is posited to occur during stimulus orienting and sustained attention. Sustained attention and attention termination represent heart-rate-defined periods of 'attentive' and 'inattentive' activity, respectively.

Recently, we assessed the relation between heart-rate-defined and behavior-defined attention phases in a study of infant distractibility during toy play (Lansink & Richards, 1997). Infants at age 6, 9 and 12 months were presented with objects that elicited periods of fixation and toy play. After they had started interacting with the object, a peripheral distractor was presented. We found that the longest latencies for distraction by the peripheral distractor occurred when *both* heart rate and behavior measures indicated that active attention was occurring, and found the shortest distraction latencies when the measures indicated that attention was unengaged. These results with the two measures combined paralleled findings concerning distractibility and attention with heart rate alone (e.g. Richards, 1987, 1997) or with behavior alone (Oakes & Tellinghuisen, 1994; Ruff, Capozzoli & Saltarelli, 1996; Tellinghuisen & Oakes, 1997; see Richards & Lansink, 1998). Some questions about the relation between behavior-defined measures of attention and heart-rate-defined measures of attention were raised by the results from Lansink and Richards (1997). On the one hand, there was some concordance between the two measures. For example, heart rate changes in response to the presentation of a toy were larger during focused attention than during casual attention, indicating an agreement between the measures (see Lansink & Richards, 1997, Figure 2). On the other hand, when casual attention was judged to be in progress by behavioral measures, the heart rate could have been decelerated, indicating heart-rate-defined sustained attention was occurring, or could have returned to pre-stimulus levels, indicating heart-rate-defined attention termination was occurring (Lansink & Richards, 1997, Figure 2). There was a fairly high concordance between ratings of casual attention and attention termination at the point of distractor onset (67%), but a poor concordance between ratings of focused attention and sustained attention (51%). Thus, the measures of attentive and inattentive behavior defined by behavioral measures were not totally consistent with measures of attentive and inattentive behavior defined by heart rate.

The present study analyzed the relation between the heart rate and behavior measures of attention, and the distribution of attention phases, during toy play of 6-, 9- and 12-month-old infants. Infants were presented with objects that elicited periods of active examination and toy play. The periods of play were judged with behavioral measures as focused or casual attention, and for heart-rate-defined phases of stimulus orienting, sustained attention, and attention termination. We used these ages because they represent the onset of object-oriented, exploratory toy play, and have been used in similar studies in previous research (e.g. Ruff, 1984, 1986; Lansink & Richards, 1997). One goal of the study was to examine the relation between heart rate and behavior measures of attention in a relatively unstructured situation. This was done because previous studies using behavioral measures have examined the development of the distribution of focused and casual attention in free play (e.g. Ruff & Lawson, 1990; Ruff *et al.*, 1996) whereas studies using heart-rate-defined attention phases (e.g. Lansink & Richards, 1997) have not. The second goal of the study was to examine the sequence of attention phases during toy play and the relation of heart-rate-defined and behavior-defined attention measures during this sequencing. Previous studies of attention phase distribution (e.g. Ruff & Lawson, 1990; Ruff *et al.*, 1996) examined the duration and frequency of focused and casual attention, but not the relation of these phases within looks. We defined the sequencing of attention as the relation between periods of attentive activity (i.e. behavior-defined focused attention and heart-rate-defined sustained attention) and inattentive activity (i.e. behavior-defined casual attention and heart-rate-defined attention termination) within a single fixation. The relation between behavior- and heart-rate-defined attention phases was examined with respect to this sequencing of attention.

Methods

The participants were infants tested at 6 months ($N = 11$, $M = 184.8$ days, SD = 4.24, seven male, four female), 9 months ($N = 11$, $M = 274.6$ days, SD = 9.67, seven male, four female) or 12 months ($N = 11$, $M = 367.8$ days, SD = 8.93, six male, five female) postnatal age. The infant was held on a parent's lap in front of a small table. Small objects were placed in front of the infant on the table. The infant was then allowed to interact with the objects in an unrestricted fashion. Each participant received a single object for 2 min followed by a 1 min break, repeated for each of four objects, and six objects for 10 min without a break. The four single object trials were presented together, and the order of presentation was counterbalanced across subjects such that approximately one-half received the single object trials first and one-half received the multiple object trial first.

The stimuli consisted of ten objects that varied in color combinations as well as number of moveable parts. The objects were of different shapes but were easily graspable by the infant. These objects included a clear plastic ball with smaller balls inside and attached to a suction cup base, a soft-rubber replica of Bambi and Donald Duck, a disk-shaped object with balls inside and handles attached, a weeble-wobble type Big Bird and Cookie Monster, a soft-rubber car that rolled and squeaked when squeezed, a plastic trumpet that could make noise when blown, a hard plastic bear attached to a plastic rod, and a doughnut-type object with balls rolling inside. The objects ranged in size from a minimum width/height of about 10 cm to a maximum width/height of about 20 cm.

The session was recorded on videotape with a time-code in order to synchronize physiological and experimental information for analysis. Each session was judged off-line by two observers and data for the analysis came from one observer's (JL) judgments.[1] The observers judged the infant as being in focused attention, casual attention, or as looking away. Focused attention was defined as periods in which the infant was judged to be looking at the object, with some combination of fingering and turning the object around, and an intent expression on the face. Mouthing behaviors were classified as focused attention only if they were preceded and followed by behavior coded as focused attention. Casual attention was defined as an episode in which the infant was judged to be looking at the object while not showing any of the focused attention criteria (see Ruff, 1986).

The ECG was recorded with Ag–AgCl electrodes on the infant's chest and was digitized at 1 kHz. A computer algorithm identified the QRS complex in the ECG, and interbeat interval was defined as the duration between successive R-waves in the ECG. The interbeat interval changes also were used to define four attention phases: stimulus orienting (before heart rate deceleration), sustained attention (during heart rate deceleration), attention termination (following heart rate deceleration for 5 s) and post-attention termination (following attention termination until sustained attention or look away) (Richards, 1987, 1997, 1998; Richards & Casey, 1991; Lansink & Richards, 1997).[2] The analysis of the interbeat interval changes was done by assigning interbeat interval values to 0.5 s intervals. The interbeat interval changes occurring during the looks, and corresponding to epochs of focused and casual attention, were analyzed.

Results

Interbeat interval changes

The interbeat interval changes occurring during the object examination were examined to show the relation between interbeat interval changes and the behavior-defined attention phases. We hoped that this might clarify the inconsistency between interbeat interval changes showing sustained attention for either casual or focused attention (e.g. Lansink & Richards, 1997, Figure 2).

The looks toward the object were separated into those with a single casual attention phase, focused attention as the first phase, and casual attention followed by focused attention. The interbeat interval changes occurring at look onset are shown in Figure 1. There were four findings that were of interest to the study. First, the looks with a single casual attention phase had little or no change in interbeat interval regardless of the length of the look (Figure 1(a), squares). The interbeat intervals occurring during the looks with a single casual attention phase were not significantly different across the 0.5 s intervals, $F < 1.0$. Second, the interbeat interval changes for the looks that had casual attention followed by focused attention were separated on a *post hoc* basis because the interbeat interval change for a casual attention episode 7.5 s or less in length that changed

[1] The ratings of looking, casual attention and focused attention were compared for the two judges. Of 752 total looks judged by the observers, the judges agreed on the occurrence of focused attention in a look for 224 of the 258 looks (87%) in which the first observer judged focused attention to occur and 379 of 494 looks (76%) in which the first observer judged casual attention to occur. Thus, overall agreement for the presence of focused attention on a look was 80%, and a measure of inter-observer agreement, Cohen's κ (Hunter & Koopman, 1990), was 0.609. This indicates a substantial level of agreement for the occurrence of focused attention (Landis & Koch, 1977). The overlap between observers for the duration of looking toward the stimuli averaged across trials was 0.87 ($SD = 0.106$, $Md = 0.894$, $90P = 0.983$, Cohen's $\kappa = 0.489$). This shows a moderate reliability for the observations, with the level of Cohen's κ being largely due to the relatively high frequency of fixation toward the objects (Hunter & Koopman, 1990).

[2] An algorithm was used to identify the QRS complex in the ECG, and interbeat interval was defined as the duration between successive R-waves. Note that the interbeat interval is the reciprocal of heart rate, so lengthening of the interbeat interval corresponds to heart rate deceleration, and shortening of the interbeat interval corresponds to a return of heart rate to its pre-stimulus level. The 'heart rate deceleration' was defined as five successive beats with the interbeat intervals each longer than the median of the five pre-stimulus beats. The 'return of heart rate to pre-stimulus level' was defined as occurring after a heart rate deceleration and when five successive beats occurred each with the interbeat intervals shorter than the median of the five pre-stimulus beats (see Richards, 1987, 1997, 1998).

to focused attention had the same pattern of no interbeat interval change during casual attention as the looks with a single casual attention episode (Figure 1(a), circles). These interbeat interval changes were not significantly different across the 0.5 s intervals, $F < 1.0$. Third, the looks with an extended (> 7.5 s) episode of casual attention before focused attention showed interbeat interval changes beginning at the look onset, i.e. during casual attention, and continuing into the period judged as focused attention (Figures 1(a), 1(b), triangles). The interbeat interval changes occurring during casual attention for the looks with an extended episode of casual attention were different across the 0.5 s intervals; $F(24, 689) = 1.94$, $p = 0.0046$.

Fourth, there was a dramatic deceleration of heart rate for the looks beginning with focused attention (Figure 1(b), stars). There was also a deceleration of heart rate coincident with focused attention onset for the looks that began with a brief episode ($\leqslant 7.5$ s) of casual attention that was followed by focused attention (Figure 1(b), circles). The interbeat interval changes occurring at focused attention were analyzed, with the trials separated into those that began with focused attention, casual attention followed by focused attention with casual attention 7.5 s or less, and casual attention followed by focused attention with casual attention more than 7.5 s (Figure 1(b)).[3] The only significant effect was an intervals main effect, $F(24, 629) = 3.62$, $p < 0.0001$, indicating that the changes in interbeat interval level during focused attention were significant. For all three types of looks, there was a rapid deceleration of heart rate at the onset of focused attention. There were no other effects involving the intervals factor.

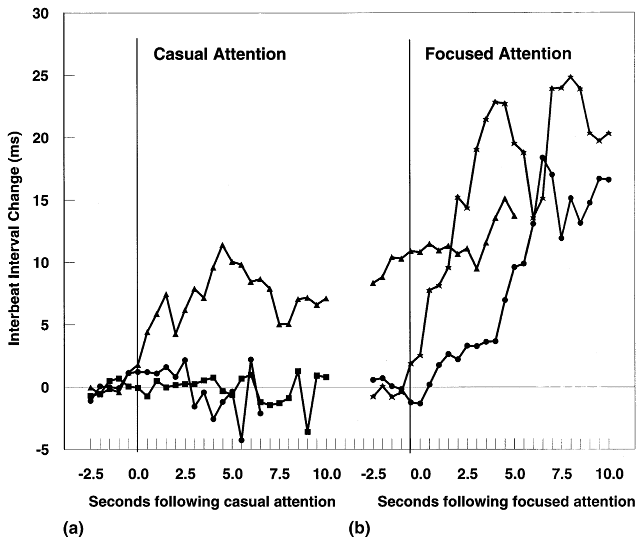

Figure 1 *The changes in interbeat interval occurring at the trial onset: (a) the changes occurring in casual attention for the casual attention only trials (squares), casual attention of 7.5 s or less followed by focused attention (circles), and casual attention of more than 7.5 s followed by focused attention (triangles); (b) the changes occurring in focused attention for the trials beginning with focused attention (star), and the focused attention portion when preceded by casual attention of 7.5 s or less (circles), or preceded by casual attention of more than 7.5 s (triangles).*

The results of these analyses may be summarized. The separation of looks toward the objects into categories defined by the behavior-defined attention resulted in different patterns of interbeat interval change (Figure 1). Those sequences that began nearly immediately with behaviorally defined focused attention were accompanied by a dramatic deceleration of heart rate. In contrast, those sequences that only had casual attention were not accompanied by heart rate changes irrespective of the duration of the look. Finally, a behavioral sequence in which a very long episode of casual attention was followed by focused attention was accompanied by a heart rate deceleration during the period when casual attention was occurring, indicating that heart-rate-defined sustained attention had occurred.

Behavior and heart-rate-defined attention phase sequencing

The sequence of the behavior-defined attention phases in individual looks was examined in conjunction with the type of heart-rate-defined attention phase occurring at changes in behavior. The purpose of this analysis was to determine the types of heart-rate-defined phases that occurred at the transitions between behavior-defined attention states. Figure 2 is a schematic diagram showing the number of behavior changes and the associated heart-rate-defined attention phases at each behavior change. Six places were identified in each look: the look away on a look when only casual attention occurred, the change from the first casual attention epoch in a look to the first focused attention, the change within a look when casual and focused attention were alternating in a cycle, and the change from focused to casual attention immediately preceding a look away from the object. The looks began with casual attention

[3] The interbeat interval changes at look onset were also tested separately for those looks occurring at the beginning of the trial following the initial toy presentation, and those occurring within a trial following a look away from the toy(s). There were no significant differences in the interbeat interval change response that interacted with an initial look/subsequent look factor. Note that interbeat interval is the reciprocal of heart rate. That is, increasing interbeat interval signifies a heart rate deceleration.

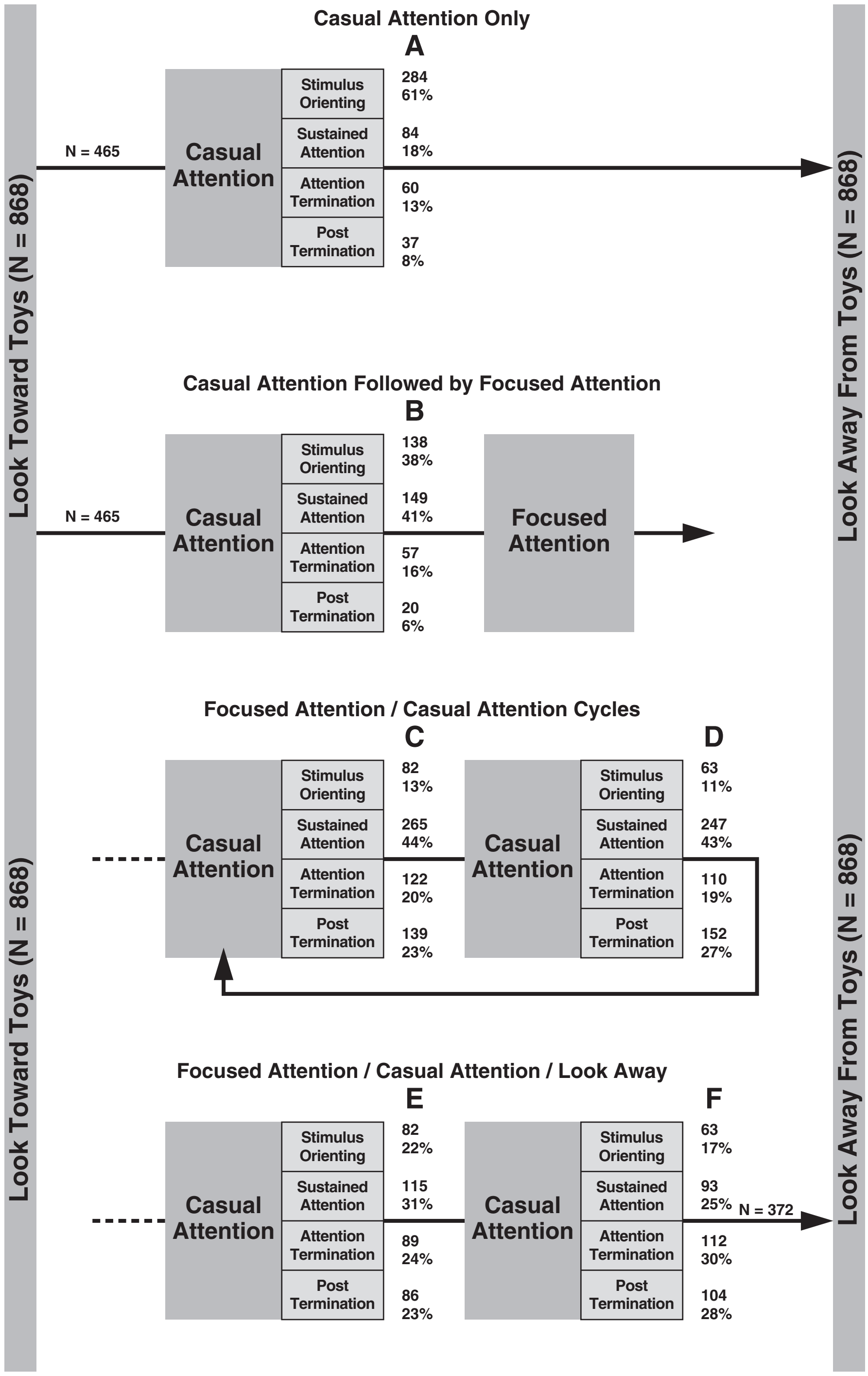

Figure 2 *A schematic showing the sequences of behavior-defined attention phases and heart-rate-defined attention phases within a single look. The larger boxes represent the behavior-defined attention phases, and the small boxes represent the heart-rate-defined attention phases, including stimulus orienting (i.e. before heart rate deceleration), sustained attention (i.e. heart rate deceleration), attention termination (i.e. heart rate return to pre-stimulus level and subsequent 5 s), and the period between attention termination and the subsequent sustained attention (i.e. post attention termination, or 5 s after return of the heart rate to its pre-stimulus level). The numbers represent the number of looks or epochs that change from one phase to another, or from one phase to looking away. The percentages represent the percentage of looks changing with the four heart-rate-defined phases.*

for 829 of 868 looks (95.5%) and began with focused attention for only 39 of 868 looks. The looks away from the toys occurred when the infant was in casual attention for 837 of 868 looks (96.5%) and for only 31 of 868 looks when the infants were in focused attention.

Three characteristics of these data were analyzed. First, we compared the heart-rate-defined attention phases when the infant looked away from the toy. This could occur for the looks with only casual attention (Figure 2, A) or containing focused and casual attention (Figure 2, F). There was a difference in the distribution of heart rate phases for these two types of looking away: $\chi^2(3, N=356)=18.56$, $p=0.0003$. The looks away from the stimulus when only casual attention was judged occurred before a significant heart rate change had occurred, in stimulus orienting (61%). The looks away from the stimulus for looks containing focused and casual attention occurred primarily in the period after heart rate change, during attention termination or post-attention termination (58%, Figure 2, F, from 'Attention Termination' or 'Post Termination'). Thus the look away from the object during casual attention, an inattentive behaviorally defined phase, occurred primarily before the heart rate response was engaged or after the heart rate response was finished, and not when heart rate was engaged (attentive heart-rate-defined phases).

Second, the heart-rate-defined attention phases were examined for looks when casual and focused attention occurred alternately in a cycle within a single look (Figure 2, C and D). Heart rate during these cycles occurred approximately equally in sustained attention (44%) or inattentive (45%, Figure 2, C and D, 'Attention Termination' and 'Post Termination') heart-rate-defined phases. There were no differences between these behavior sequences in the distribution of the heart rate phases. There were age differences in the distribution of heart rate phases in this cycling: $\chi^2(6, N=1180)=15.09$, $p=0.0196$. There was an increase in the proportion of these behavior sequences occurring in sustained attention over the three testing ages (36%, 44% and 51% for the three ages), and a corresponding decrease in the inattentive phases (48%, 40% and 36% for the three ages). Thus, when focused attention and casual attention were alternately occurring within a single look, the heart rate and behavioral measures were not precisely concordant. Instead, there was only a loose association of changes from one attention state to another as defined by heart rate or by behavior.

Finally, we compared the heart rate changes when focused and casual attention were cyclically alternating within a look (Figure 2, C and D) to the focused and casual attention immediately preceding a look away from the objects (Figure 2, E and F). The incidence of sustained attention was larger during the cycling of the behavior-defined phases within a look (44%, Figure 2, C and D) than at the end of the look (28%, Figure 2, E and F) and looks ended primarily during inattentive periods (58%, Figure 2, F, 'Attention Termination' and 'Post Termination'). These differences were statistically significant: $\chi^2(3, N=1509)=41.16$, $p<0.0001$. The age of the infant affected the incidence of the heart-rate-defined attention phases during the focused and casual attention cycles (Figure 2, C and D; see previous paragraph) but not in the period preceding the look away from the objects (Figure 2, E and F). These results imply that the last episode of focused attention and casual attention preceding a look away from the object (Figure 2, E and F) show a distinct association with heart-rate-defined attention termination.

In summary, the behavior-defined attention phase sequences were compared to the heart-rate-defined attention phases occurring at changes in looks toward the object and away from the object. An overarching finding of these analyses was that looks toward an object generally began and ended in casual attention and when heart rate indicated either that attention had not yet been engaged or that attention to the object had been engaged but now was waning. This suggests that when a concordance occurred between heart rate and behavioral indices indicating that attention was not engaged, the infants were very likely to look away from the object. A second finding was that the cycling of casual attention and focused attention (behavior) within a look was accompanied by the cycling of sustained attention and attention termination (heart rate) within a look. However, the cycling of these two attention systems was not necessarily concordant and there was only a loose association of behavior and heart-rate-defined phases during this cycling.

Discussion

Several findings from the current study show how attention and fixation are related in infant toy play. First, the beginning of each look toward the object(s) was accompanied by behavioral indices showing the occurrence of casual attention. That is, the infants were engaged in object-directed activity that involved mouthing, banging, and uninterested facial expressions at the beginning of toy play. Heart rate continued at its pre-look level. The behavioral and heart rate indices indicated that attention was unengaged at the beginning of toy play. Many of these looks towards the toys then ended without active attentive engagement. Second, for some looks towards the toy, this initial period of 'inattentive' object-directed activity was followed by periods of active attention engagement. During this time, exploratory behaviors (fingering or slow, deliberate object manipulation) and facial expressions (furrowed brow and/or pursed lips) occurred, and heart rate decelerated rapidly. It is believed that during this time the infant is actively engaged in information processing (Ruff, 1986; Richards, 1987, 1997, 1998; Ruff & Lawson, 1990; Oakes & Tellinghuisen, 1994; Lansink & Richards, 1997; Tellinghuisen & Oakes, 1997; see Richards & Lansink, 1998). Infants cycled between this attentive state and an inattentive state several times. Finally, the infants looked away from the toys predominantly in periods of time when heart rate had returned to its pre-stimulus level and when the infants' behavior indicated that casual attention was occurring. Attentive fixation (focused attention, sustained attention) occurred within a look and was preceded and followed by inattentive fixation. Looking away primarily occurred during casual attention before attention was engaged or when attention had waned following attention engagement.

The age effects observed in this study suggest that attention may be becoming more organized and/or efficient during the second half of the first year. During the alternation between focused and casual attention in the multiple cycles, there was an increasing incidence of heart-rate-defined sustained attention and a decreasing incidence of the inattentive phases as age increased. Thus, age changes occurred in the sequencing and organization of attention within a look rather than in absolute levels of attention engagement. Infants at the two older ages were more likely to engage in multiple attention cycles than the younger infants. This implies that infants at the two older ages were engaging in extended exploratory behavior with the objects immediately upon their presentation and that attention was sustained throughout the toy play. This is consistent with findings from other studies of exploratory play in infants (e.g. McCall, 1974; Ruff, 1984; McCune & Ruff, 1985; Rochat, 1989) showing over the first year of life an increasing amount of play time taking in information from their surroundings.

This study suggests some resolution to the consistencies and inconsistencies in the heart-rate-defined and behavior-defined attention phases. First, these results imply that at changes in look direction (looking toward, looking away) heart rate and behavior definitions consistently index attention engagement. If attention is not sufficiently engaged by the objects at the beginning of a look toward the object, casual attention is behaviorally rated and sustained attention never occurs. Such inattentive fixation is generally followed by a look away from the object. Looks toward the object that engage attention sufficiently to hold the look are accompanied by immediate heart rate deceleration and (at least eventually) by behavioral ratings of focused attention. After extended exploration of the object, and when attention begins to wane, casual attention and post-attention engagement (attention termination, post termination) occur and the infant looks away from the object. Thus, at major changes in look direction there is consistency in the two systems indexing level of attention. This explanation is consistent with the finding in Lansink and Richards (1997) that infants were distracted easily by a peripheral stimulus when heart rate and behavioral measures indicated that attention was unengaged.

This study does not resolve the consistency or inconsistency of the two systems in assessing attention *within* a look. The finding that attentive or inattentive heart rate phases accompanied cycling between focused and casual attention showed an inconsistency between the two rating systems. This inconsistency may be due to the sequencing of the attention phases for heart rate and behavior. Object play usually is initiated with casual attention, casual attention occupies a larger proportion of time and may occur in an episode of toy play without focused attention, and casual attention is not sequentially linked to focused attention (Ruff *et al.*, 1996). On the other hand, the heart rate changes occurring within a look to a visual pattern occur in a relatively fixed sequence of stimulus orienting, sustained attention, and attention termination (Richards & Casey, 1991, 1992). The inconsistent relation between these two measures may be due to the sequence in which phases occur within an episode of toy play or visual fixation. This explanation would apply only to the period of time within a look since there was a clear relation between the two measures during the initial sequences of a look and during the final sequence within an extended look. It may also be that the behavior and heart rate systems are indexing relatively independent cognitive systems or separable cognitive functions for the period of fixation within a look. In this explanation, one should expect coherence between the measures when both indicate very intense cognitive processing (focused attention + sustained attention) or almost no cognitive processing (casual attention + attention termination). But, there would be periods in which the measures were inconsistent in indexing level of attention engagement.

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