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Autonomic correlates of individual differences in sensitization and look duration during infancy

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Abstract

Patterns of infant visual attention have been attributed to both the processes of habituation and arousal. Previous research has linked individual differences in arousal (sensitization) with measures from habituation that have been associated with the efficiency of stimulus encoding (look duration). The aim of current study was to validate individual differences in these realms with a convergent measure of attention based on heart rate (HR) that might presumably reflect autonomic function and arousal. In contrast with previous work, neither habituation nor look durations differed significantly as a function of the presence of sensitization. HR variables did not differentiate infants who showed sensitization from those who did not. HR analyses on individual differences in look duration, however, yielded two significant findings: short-looking infants maintained higher levels of HR variability than long-looking infants across the session, and long-looking infants had greater HR accelerations to stimulus onsets than did short-looking infants. © 2000 Elsevier Science Inc. All rights reserved.

1. Introduction

Visual habituation is perhaps the most widely studied indicator of infant attention and information processing. The typical visual habituation paradigm exploits the fact that the infant's attentional responses (i.e., the duration of looks), will decline across repeated presentations of the same stimulus. Look duration, or the length of time an infant spends looking at a stimulus, has been identified as one core indicator of attention and information

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processing in habituation. Look duration is moderately stable across various test-retest intervals and has been reported to be correlated with concurrent and lagged measures of cognitive functioning (Colombo, 1993; Colombo & Mitchell, 1990). Traditionally, individual differences in look duration have most often been interpreted in terms of Sokolov's (1963) comparator theory, which suggests that decrements in responding reflect how quickly the infant is able to form an internal representation of the stimulus. According to this theory, look duration can generally be posited to represent the rapidity or efficiency of stimulus encoding (Cohen, 1988; Colombo & Mitchell, 1990), with shorter looks to repetitive visual stimuli reflecting more rapid stimulus processing.

Over the last decade, however, some studies of infant attention have suggested that infants' habituation performance may be attributable to more than one underlying process. Dual process theory (see Bashinski, Werner, & Rudy, 1985; Kaplan & Werner, 1986, 1987; Kaplan, Werner, & Rudy, 1990) proposes that behavior in the habituation paradigm is a function of both (a) the long-term waning of the Sokolovian orienting response, and (b) a transient "spike" or "burst" of arousal at the start of the session (Groves & Thompson, 1970). This manifestation of arousal is called sensitization, and is typically inferred from increases in responding during the initial portions of a habituation session. Generally, an increase (rather than a decrease) in looking is observed from the first to the second trial when sensitization occurs. Some evidence suggests that the occurrence of sensitization is related to the arousing properties of the stimulus, or the general arousability of the infant (Kaplan et al., 1990). An important implication of the dual process theory is that individual differences in infants' responses during habituation paradigms (i.e., length of looking and habituation rate) may not be solely attributable to individual differences in information processing or encoding.

One previous study has examined the link between sensitization and look duration in a fixed-trial habituation paradigm. Colombo, Frick, and Gorman (1997) habituated 4-month-olds to various checkerboards and classified individual infants as "sensitizers" or "nonsensitizers," depending on whether they showed early increases in looking across the first two trials of the session. In this study, infants who showed sensitization also showed slower habituation and longer look duration overall than infants who did not show nonsensitization. The Colombo et al. (1997) findings suggested that the sensitizer/nonsensitizer dichotomy might have some validity for classifying individual differences in infant attention and arousal, and that this dichotomy might help illuminate previous work on individual differences on infant look duration.

The present study was designed to follow up and extend the Colombo et al. (1997) findings by attempting to validate individual differences in both sensitization and look duration with a convergent measure that presumably reflects both attention and arousal. Therefore, we investigated whether sensitizers and nonsensitizers could be discriminated from one another using heart-rate (HR) based indices of cognition and responsiveness. Studies dating back to the inception of infant attention research have shown that HR change is a valuable index of infant attention (Clifton & Nelson, 1976; Graham & Clifton, 1966; Kagan et al., 1966; Kagan & Lewis, 1965; McCall & Kagan, 1967; McCall & Nelson, 1970) and many studies of infant attention and cognitive functioning now routinely include measures of HR as indices of the infants' attentional state (e.g., Richards, 1985a,b, 1987). Repeatedly, researchers have found that attention to stimuli during habituation is generally

accompanied by decelerations in HR, while stimulus events that elicit arousal are generally associated with accelerations in HR (Sokolov, 1963; Graham & Clifton, 1966; Gardner & Karmel, 1983). Thus, infants who are most aroused by stimuli (i.e., those classified as sensitizers and/or long-lookers), may also display similar cardiac increases since both classifications have been considered indicative of increased arousal.

2. Method

2.1. Participants

The participants were 68, healthy, full-term, 4-month old infants (33 males and 35 females) recruited by mail and telephone from the greater Kansas City metropolitan area. Of these 68 infants, 12 were excluded from final analyses for the following reasons: fussiness ($n = 10$), prematurity ($n = 1$), or failure to look at the stimuli during the protocol ($n = 1$). Demographic characteristics obtained from this sample were similar to those documented previously in reports from this laboratory (e.g., Colombo et al., 1996).

2.2. Apparatus and stimuli

Infants were tested in a 3.0×3.0 m room with black walls and ceiling. The infants were placed in a car seat, with a 0.7×1.0 m rear-projection screen centered in the wall 0.6 m in front of them. A Kodak carousel 440H projected the targets from behind the screen.

A video camera centered below the screen was focused on the infant's face, and the video image from this camera was used to view and record visual fixations. An observer coded fixations on-line from the video image via button presses interfaced with a Zenith Z-159 microcomputer fitted with a Scientific Solutions LabTender Board and programmed with custom software. Sessions were videotaped to allow later calculation of interobserver reliability.

In addition to monitoring visual behavior, infants' HR responses were simultaneously collected during the task using a commercial psychophysiological data acquisition package (BioPac, Inc., Santa Barbara, CA). This package includes a basic data acquisition unit, an electrocardiogram (EKG) amplifier, an A-D board, and software that controls data acquisition and facilitates HR calculation. The EKG was recorded by placing Ag-AgCl electrodes on the infant's chest and abdomen. The EKG was digitized at a sampling rate of 250 HZ. Beat-to-beat rates were calculated using software provided by BioPac that measures and records *R-R* intervals from the digitized waveform to a separate data file; these were then processed to show infants' mean HR during various portions of the experimental protocol. The HR data were then combined with the data from the habituation session (stimulus onsets and offsets, look onsets and offsets) to determine how HR was changing during each second of the infant's looking behavior.

The stimuli consisted of 4×4 and 20×20 black-and-white checkerboard patterns. The patterns were projected so that they subtended a visual angle of 10° . The patterns had a contrast value of 0.92, average-space luminance was $2.37 \log \text{cd/m}^2$. The determination of which stimulus patterns to use and the size at which they were projected were based on

previous publications by Kaplan and his colleagues in which the frequency of sensitization was reported to increase with the presence of increasing elements in the checkerboard (e.g., Kaplan et al., 1990). A blank slide was used during the interstimulus intervals.

2.3. Design and procedure

The study was a mixed-design factorial with a between-subjects factor of Stimulus (4×4 or 20×20), and a within-subjects factor of Trial (8). During the interstimulus interval a blank slide was inserted so that a homogeneous white field was projected onto the screen. The stimulus and interstimulus periods were demarcated by a brief period of darkness that occurred when the slide was advanced or reversed.

The primary dependent measure for this study was the cumulative total of looking per 10 s stimulus trial.¹ Interobserver reliabilities were obtained for 49% of the infants tested by having a second observer independently code looks from the videotape. The Pearson coefficient between the on-line and reliability observers' judgments of the average for per-trial cumulative fixation totals was 0.95.

Once the infant was situated in the car seat, the door to the room was closed and the lights were turned out. HR data were collected for a baseline period of 30 s before the session started. Immediately after this, a stimulus was projected on the screen to start the sequence. The habituation procedure that followed was a fixed-trial sequence, in which the checkerboard stimulus was projected for 10 s, and then removed for 10 s. During the 10 s intertrial interval (ITI), the stimulus was removed, and the blank slide was presented. That is, the ITIs were bright, rather than dark. The sequence ended after eight stimulus presentations, and HR continued to be collected during a 10 s postsession period.

3. Results

3.1. Analyses of looking across trials

A Stimulus (2) \times Trial (8) mixed-design ANOVA was performed on infant's cumulative total of per-trial looking. This analysis yielded significant main effects for both factors, but no interaction, $F(7, 48) = 0.98$, *ns*. The Stimulus effect, $F(1, 54) = 28.97$, $p < .001$, was attributable to the 20×20 stimulus eliciting more looking overall than the 4×4 stimulus. The Trial effect, $F(7, 48) = 4.51$, $p = .001$, was attributable to the expected overall decline in looking across the eight stimulus presentations (e.g., Trial 1 $M = 5.69$ s, $SE = 0.33$; Trial 8 $M = 3.50$ s, $SE = 0.35$). Although this analysis found support for previously observed trends regarding look duration and stimulus complexity, inspection of the means revealed no overall evidence for sensitization to either of the targets. The cumulative totals for per-trial looking as a function of stimulus are shown in Fig. 1.

3.2. Analyses of individual differences in sensitization

In previous work, Groves and Thompson (1970) and Kaplan et al. (1990) describe sensitization as an increase in responding from the first to the second trial, before the

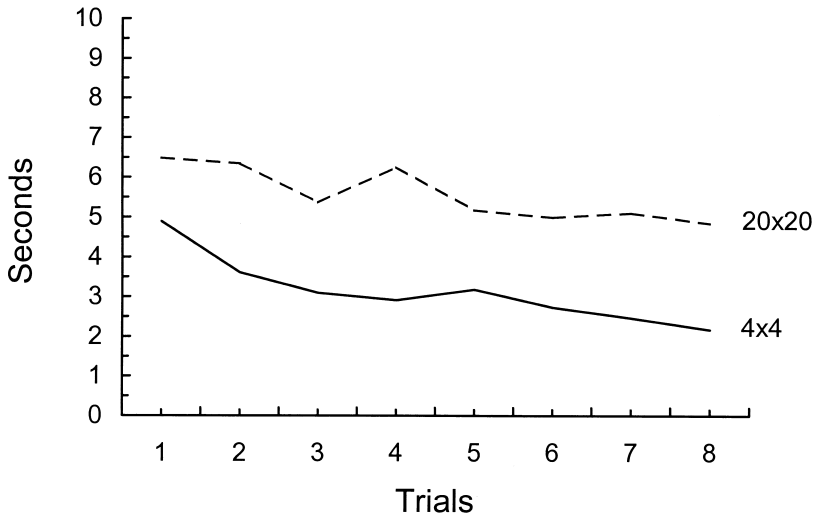


Fig. 1. Cumulative per-trial looking totals as a function of stimulus.

occurrence of a decrement. As in Colombo et al. (1997), infants were characterized as “sensitizers” if their total per-trial looking increased from Trial 1 to Trial 2. Overall, 21 (38%) of the infants were classified as sensitizers.

3.2.1. Sensitization and looking

In keeping with previous work on this topic, stimulus complexity was associated with the presence of sensitization. The percentages of infants showing sensitization increased from 26% for the 4×4 checkerboard, to 48% for the 20×20 checkerboard. This trend approached but did not attain statistical significance, $\chi^2(1) = 2.98, p = .08$.

3.2.1.1. Sensitization and total per-trial looking across the session. The data were then analyzed to see if sensitizers and nonsensitizers showed different patterns of look duration across portions of the habituation sequence beyond the initial trials on which the infants were classified as sensitizers. In the Colombo et al., (1997) study, sensitizers showed significantly greater looking across trials 3–8 of the habituation session. This was done by performing a mixed-design Sensitization Status (2: Sensitizer vs. Non-Sensitizer) \times Stimulus (2: 4×4 vs. 20×20) \times Trial (6: Trial 3 through Trial 8) MANOVA on infants’ total looking within trials. The Sensitization Status \times Trial interaction was not significant, suggesting that neither habituation nor look duration differed significantly across the two groups as they had in the Colombo et al. (1997) study (see Fig. 2).

3.2.2. HR analyses of sensitization

The next step was to examine whether the Sensitizer/Nonsensitizer classification could be validated by analyses of infants’ HR during different portions of the habituation session. Specifically, we report here on three analyses that we thought might be fruitful for revealing differences between Sensitizers and Nonsensitizers: (a) HR rate, variability, and change from

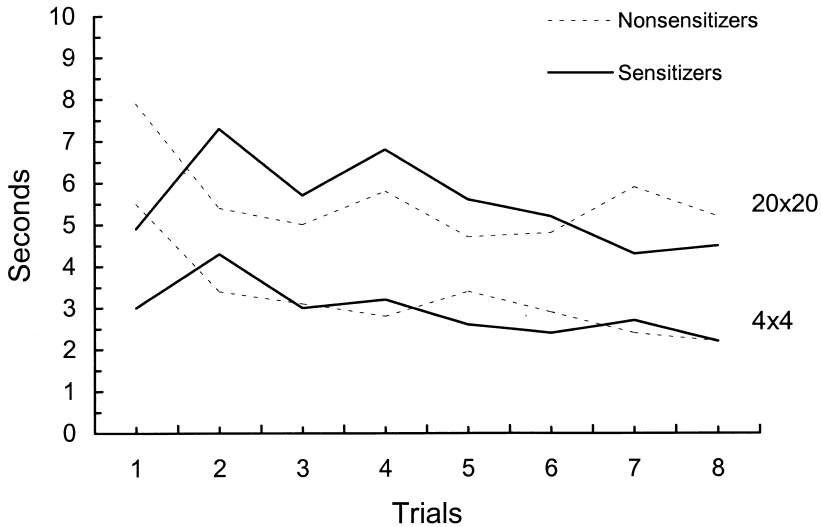


Fig. 2. Total per-trial looking for sensitizers and nonsensitizers as a function of stimulus.

before the session to the end, (b) HR change to stimulus onsets, and (c) HR change during looks.

3.2.2.1. Baseline/postsession HR parameters. The paradigm featured a 30 s baseline prior to the start of the habituation session, and a 10 s postsession period during which HR was collected. The first analysis was conducted on infants' mean HR to determine if it changed across the session, and whether that change varied as a function of the sensitization status of the infant. A Sensitization Status \times Stimulus \times Baseline/Postsession mixed-design MANOVA revealed a main effect for Baseline/Postsession, $F(1, 50) = 18.56, p < .001$, as overall HR increased significantly from baseline ($M = 145.4, SE = 1.73$) to the postsession ($M = 155.29, SE = 2.27$) periods. Furthermore, a significant effect emerged for the Baseline/Postsession \times Stimulus term, $F(1, 50) = 4.25, p = .045$. This was attributable to greater HR increases from baseline to post session for infants who saw the 4×4 stimulus (Baseline $M = 143.9$ bpm, $SE = 2.62$; Postsession $M = 158.5$ bpm, $SE = 3.45$) compared to those who saw the 20×20 stimulus (Baseline $M = 146.9$ bpm, $SE = 2.25$; Postsession $M = 152.1$ bpm, $SE = 2.95$). However, it is worth noting that infants' increases in HR were significant for both stimulus conditions, $t(25) = 4.25, p < .001$ for the 4×4 stimulus, and $t(27) = 2.15, p = .04$ for the 20×20 stimulus. Neither the main effect nor any interactions involving the Sensitization Status factor approached significance.

We then examined HR variability across the session in the same analysis. The same Sensitization Status \times Stimulus \times Baseline/Postsession mixed-design MANOVA on the infants' standard deviation HR yielded no significant main effects and no significant interactions.

3.2.2.2. HR to stimulus onsets. On each of the 8 trials, HR change to stimulus onsets was measured by looking at the change in HR from the ITI to the period after illumination of the stimulus but prior to the initiation of the infant's look to it. This is called the "latency" period

(e.g., Colombo et al., 1997). A Sensitization Status \times Stimulus \times ITI/Latency \times Trial mixed-design MANOVA was performed on infants' HR change to the onset of the stimulus. This analysis yielded a significant main effect for ITI/Latency and Trial, but no other main effects. The ITI/Latency effect, $F(1, 50) = 21.11, p < .001$, was the result of HR increasing to stimulus onsets. The average HR during the ITI periods was $M = 150.78$ ($SE = 1.39$), while the average HR during the latency period was $M = 152.46$ ($SE = 1.42$). The Trial effect, $F(7, 44) = 5.51, p < .001$, was attributable to overall HR increasing across trials, similar to that seen in the Baseline/Postsession analyses reported previously. The average HR on Trial 1 was $M = 146.09$ ($SE = 1.77$), and the average HR on Trial 8 was $M = 158.43$ ($SE = 2.15$). The ITI/Latency \times Stimulus interaction, $F(1, 50) = 7.54, p = .008$, was the result of greater HR accelerations associated with the onsets of the 20×20 stimulus than with the 4×4 stimulus. It is worth noting that significant accelerations occurred in both stimulus conditions; t tests showed HRs during the ITI to be significantly different from HRs during the Latency period with the both the 4×4 ($t(27) = 2.37, p = .025$), and 20×20 ($t(28) = 5.04, p < .001$) checkerboards. Again, no main effects or interactions involving the Sensitization Status factor attained statistical significance.

3.2.2.3. Sensitization and average HR during looks. A Sensitization Status \times Stimulus \times Latency/Look \times Trial mixed-design MANOVA was performed on infants' HR during the first look of each trial. This analysis yielded a significant main effect for Trial and Latency/Look, but no other main effects, and no interactions. The Latency/Look effect measured the change in the infants' HR from the Latency period to the first look on each trial. The Latency/Look effect, $F(1, 22) = 15.78, p = .001$ was expected, and was attributable to significant HR decelerations during the first look. The infants' HR during the latency period was $M = 155.80$ ($SE = 2.58$), and it decreased to $M = 151.40$ ($SE = 3.04$) during the first look. The Trial effect, $F(7, 16) = 3.16, p = .027$, was the result of the global HR increase observed across trials, as was also evident in previously reported analyses. Again, no main effects or interactions involving the Sensitization Status factor attained statistical significance.

3.3. Analyses of individual differences in look duration

In addition to classifying infants as Sensitizers and Non-Sensitizers, we were also able to classify infants "Short-" or "Long-looking" as has been done in past work on individual differences in infant cognition (e.g., Colombo et al., 1996). This was done by first calculating a mean peak look for each infant across the 8 trials. Next, because look duration varied significantly as a function of stimulus (i.e., 4×4 vs. 20×20 checkerboards), we calculated the median peak look for the two stimulus conditions. This median was then used to split the sample (again, the split was conducted within stimulus condition) into the two groups. Previous research suggests that differences in the efficiency or rapidity of stimulus processing might reflect differences in arousability (Bashinski et al., 1985; Kaplan et al., 1990), and the Colombo et al. (1997) results had directly linked measures of the two processes. Thus, we thought it important to analyze whether individual differences in the behavior of short- and long-looking infants might be related to long-looking infants being in a higher state of

arousal than short-looking infants. The same analyses that were conducted for sensitizers vs. nonsensitizers were repeated for infants classified as short versus long lookers. As a result of repeating these analyses, effects reported in the previous sections emerged; for the sake of brevity and avoiding redundancy, explication of these results is not repeated here.

3.3.1. Baseline/postsession HR parameters

A Look Duration Status (Long/Short) \times Stimulus \times Baseline/Postsession mixed-design MANOVA did yield a main effect for Baseline/Postsession, $F(1, 50) = 12.83, p = .001$, as HR increased across the session. However, no main effects or interactions involving Look Duration Status emerged.

We next examined HR variability of infants' HR by conducting a Look Duration Status \times Stimulus \times Baseline/Postsession mixed-design MANOVA on infants' standard deviation HR. The MANOVA yielded no significant main effects, but the Baseline/Postsession \times Look Duration Status interaction attained significance, $F(1, 50) = 4.30, p = .043$. For long-looking infants, HR variability decreased significantly from a high HR SD at baseline ($M = 7.74, SE = 1.05$) to a lower HR SD value at postsession ($M = 4.41, SE = 0.86$). On the other hand, short-looking infants' variability remained at moderate levels and did not change across the session ($M = 5.76$ at baseline, $SE = 0.83$; $M = 6.03$ at postsession, $SE = 0.68$).

3.3.2. HR and stimulus onset

A Look Duration Status \times Stimulus \times ITI/Latency \times Trial mixed-design MANOVA was performed on infants' HR change to the onset of the stimulus. As for the analysis of Sensitization Status reported above, the ITI/Latency factor was derived by comparing infants' HR during a prestimulus period and a poststimulus (but prelook) period.

The Look Duration Status \times Stimulus \times ITI/Latency \times Trial analysis yielded a significant main effect for Trial, $F(7, 44) = 2.76, p = .018$; as noted before, overall HR increased across trials. It also yielded a significant main effect for ITI/Latency, $F(1, 50) = 23.19, p < .001$, as infants' HR increased to stimulus onsets. Most importantly, there was a significant Look Duration Status \times ITI/Latency interaction, $F(1, 50) = 6.33, p = .018$. This interaction was attributable to the fact that long-looking infants showed significantly stronger HR accelerations to stimulus onsets than did short-looking infants. Both groups of infants showed significant accelerations ($t(25) = 5.67, p < .001$ for long-looking infants; $t(29) = 2.11, p = .04$ for short-looking infants), but the accelerations were larger for the long-looking group. Means for short- and long-looking infants' HR reactions to stimulus onsets can be seen in Fig. 3.

Before this analysis could be interpreted, however, it was necessary to determine whether the length of the Latency (i.e., the period following stimulus onset but preceding look initiation) varied as a function of the infant's look duration status. We thought it possible that short-looking infants might have longer latencies; if that were the case, then HR accelerations to stimulus onsets in short-looking infants would have been averaged over a significantly longer period of time. In turn, accelerations in this group would have had a longer period over which to return to prestimulus levels, and thus appear on average to be lower. This was addressed in a Look Duration \times Stimulus \times Trial analysis of the length of latency. When

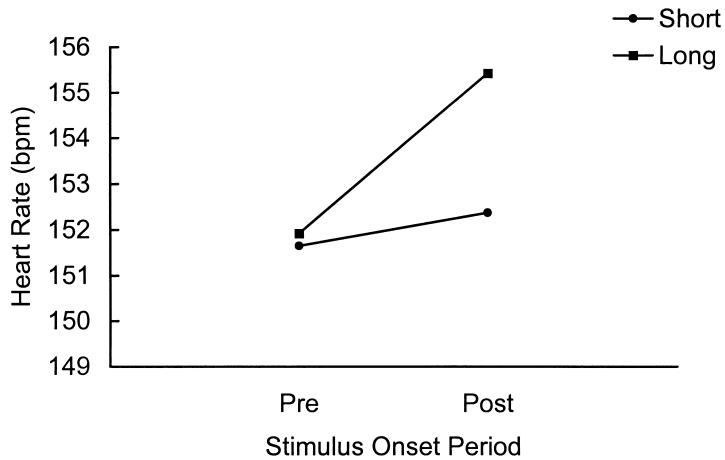


Fig. 3. Differences in short- and long-looking infants' HR changes to stimulus onsets.

conducted, however, this analysis yielded only a significant effect of Trial, $F(7, 46) = 2.32$, $p = .041$; latencies increased during later trials. Since none of the terms involving the Look Duration Status factor were significant, the apparent difference in responses of long- and short-looking infants to stimulus onsets was not artifactual.²

3.3.3. Look duration and average HR during looks

Next, a Look Duration Status \times Stimulus \times Pre/Post \times Trial mixed-design MANOVA was performed on infants' HR during the first look of each trial. This analysis yielded significant main effects for Trial and Pre/Post, but no other main effects, and no interactions. The Pre/Post effect measures the change in the infants' HR from the latency period to the first look on each trial. The Pre/Post effect, $F(1, 22) = 13.25$, $p = .001$, was the result of HR decreasing during the looks. The infants' HR prior to the look was $M = 155.46$ ($SE = 2.63$) and decreased to $M = 151.52$ ($SE = 3.07$) during the look. As reported earlier, a significant Trial effect emerged, $F(7, 16) = 2.83$, $p = .040$, and was the result of HR during the looks increasing across trials. No significant terms involving the Look Duration Status factor emerged from this analysis.

4. Discussion

4.1. General trends in infant HR across testing session

The results of the current study both confirm some expectations and document other effects that have not been widely disseminated in the literature on infant attention and HR. As expected, HR decelerated during looks to the stimulus and such decelerations were shallower in later trials, as compared to early trials. However, several analyses showed significant increases in overall HR from the start of the session to its end. This increase was

especially pronounced when infants were presented the less complex 4×4 checkerboard, as compared with the 20×20 checkerboard. The observed increase in infant HR is likely attributable to increasing arousal as the session wore on (Graham & Clifton, 1966); this interpretation is bolstered by the interaction with stimulus complexity.

In addition, HR was also observed to accelerate significantly to stimulus onsets. HR accelerations to stimulus onsets have been previously observed in human infants (e.g., Berg & Donohue, 1992; Berg, Berg, & Graham, 1971; Clifton, 1974) as part of the defensive response portion of the orienting reflex (see Berntson, Boysen, & Cacioppo, 1992). HR acceleration has been linked to rapid decreases in ambient illumination (Dailey, Wigal, & Amsel, 1986), as occurred here during transitions from the ISI to stimulus trials. Infants' initial reaction to the stimulus onset is probably a fundamental reactive automatic (sympathetic nervous system) component of the orienting reflex (Sokolov, 1963). Interestingly, the strength of this response varied with the stimulus involved, with greater accelerations observed to the onset of the 20×20 checkerboard, as compared to the 4×4 checkerboard. This effect may have been attributable to the formation of some expectation over repeated trials, although the lack of an interaction between Stimulus and Trial in the evaluation of this effect suggests otherwise. Rather, it appears that infants may have perceived differences in stimulus properties immediately after onset, perhaps with peripheral vision. This finding is consistent with prior research showing that, with infant-control procedures, infants display shorter latencies to look at complex stimuli than simple stimuli (Cohen, 1976). It is worth noting that the ability to document this response is a further indication of the utility of the concurrent use of HR in standard infant attention paradigms, given that this effect would not be readily manifest with common behavioral dependent measures.

4.2. *Individual differences in sensitization*

Qualitative/dichotomous classifications of sensitization were observed in 38% of the cases, and such classifications did occur almost twice as often with the more complex stimuli (20×20 checkerboard) than with the simple one (4×4 checkerboard). The luminance of our stimuli (as with Colombo et al., 1997) was somewhat higher than those used in previous studies, and this may have attenuated the overall stimulus-based sensitization effects relative to those which have been previously reported (Kaplan & Werner, 1987).

We hypothesized that the manifestation of sensitization would be related to differences in some aspect of HR during the session. However, this hypothesis was not confirmed across a number of analyses. These findings thus suggest that increases in HR within or across trials may be independent of behavioral indications of sensitization. Since none of these measures discriminated sensitizers from nonsensitizers, the utility of classifying infants on the basis of the presence or absence of sensitization may be called into question.

In addition to trying to validate sensitization with an independent measure of arousal, this study also tried to replicate previous research, which suggests that sensitizers show slower habituation and longer look durations than nonsensitizers (Colombo et al., 1997). In this study, neither habituation nor look duration significantly discriminated these two groups (beyond the first two trials, on which basis they were classified). Two procedural differences between this study and the Colombo et al. (1997) report may explain the discrepancies in the

findings. First, the current study involved the application of chest leads to monitor the infant's HR; the Colombo et al. (1997) study did not include this pre-session step. Second, the present study included a 30 s baseline period for HR collection that was not part of the Colombo et al. (1997) study. These procedural differences would result in (a) an increase in the time between the infant's arrival in the laboratory and the beginning of data collection, (b) increased contact between the infant and an unfamiliar individual (i.e., the lab staff applying the chest leads) and (c) an increase in the interval prior to the start of the habituation/sensitization assessment. Such differences may have worked to either increase the infant's arousal, or to promote familiarity with the testing environment. The frequency of sensitization in the current study is slightly higher (38%) than that observed with the same two stimuli in the previous study (about 24%), but one would expect that increasing sensitization would *amplify* the previously observed effect rather than attenuate it. It thus seems more likely that the added time spent in the test surroundings (and resulting familiarity with the environment and equipment), as a function of the application of the chest leads and/or the added baseline period, may have affected habituation and look durations in sensitizers.

4.2.1. Individual differences in look duration

We also sought to apply the use of autonomic indicators (i.e., HR) to validate individual differences in look duration within this paradigm. Two findings emerged from these analyses. First, long-looking infants did show significantly greater HR accelerations to stimulus onsets than did short-looking infants. Second, long-looking infants showed a decrease in HR variability (as indexed by HR SD) from the baseline to post-session periods that was not present in short-looking infants.

The finding that long-looking infants are more reactive (i.e., had greater HR accelerations) to stimulus events than short-looking infants is interesting and somewhat unexpected. Indeed, the finding indirectly implicates the contribution of arousal/reactivity to individual differences in look duration. This was the motivation for the original study, although it was hypothesized that this link might have been made through the behavioral measure of sensitization, rather than directly from the autonomic/psychophysiological measures themselves. Look duration has generally been interpreted as an index of the rapidity or efficiency of stimulus encoding (Colombo & Mitchell, 1990). The current findings, however, link look duration with reactivity to stimulus events as well.

These findings may be reconciled in the following ways. First, it is possible that increased reactivity to stimulus onsets may simply delay the initiation of visual processing/encoding. In this way, reactivity may contribute to the slower processing often reported in long-looking infants. If this is true, then eliminating rapid stimulus onsets and offsets from infant paradigms in which visual processing is assessed could improve the performance of long-looking infants. Thus, future research could involve the gradual fading of stimulus events.

Second, it has been suggested that various dimensions of reactivity, arousal, or emotion may be linked with disturbances of visual processing and object recognition. Experimental research in this area has established that the medial temporal lobe structures are involved in the regulation of affect and memory functions (Bachevalier, 1994). Furthermore, damage to the temporal lobes has frequently been linked to visual agnosia and disturbances of affect.

Indeed, the link between temporal lobe damage and affective reaction has long been recognized in the clinical realm in the consideration of individuals with Kluver-Bucy syndrome (Shraberg & Weisberg, 1978; Lilly et al., 1983). If it is indeed true that reactivity, arousal, and emotionality are linked to visual processing and object recognition, then one should find other instances in which individual differences in look duration are correlated with individual differences in affect. There is some recent empirical support for this contention in the infant cognition literature; positive affect has been found to be correlated with long look durations and slower learning in 5-, 7-, and 9-month old infants (Rose, Futterweit, & Jankowski, 1999).

The finding of different patterns of change in HR variability in long- and short-looking infants from baseline to postsession was also interesting. HR variability has been quantified in several forms, such as measures of variance (Richards, 1985b), vagal tone (e.g., Fox & Porges, 1985), and respiratory sinus arrhythmia (Richards, 1985a); it has been suggested that these measures are all intercorrelated (Izard et al., 1991). Higher levels of HR variability in infancy are generally predictive of more optimal outcomes in a number of domains (e.g., Doussard-Roosevelt et al., 1997) including attention and information processing performance (DiPietro, Porges, & Uhly, 1992; Frick & Richards, in press; Linnemeyer & Porges, 1986). Suppression of HR variability within prescribed periods of attention demarcated by HR decelerations may be considered to be a positive indication of cognitive activity (Bornstein & Suess, 2000). However, the pattern of response here in long-looking infants was a drop in HR variability over the session within the context of an increase in HR. This alternative pattern has been documented in infants tested with distressing or stressful stimuli (Fracasso et al., 1994; Weinberg & Tronick, 1996). DiPietro et al. (1992) have also specifically reported a link between less optimal attentional patterns and decreases in HR variability in 8-month-old infants.

Taken together, these findings indicate that longer-looking infants may experience higher levels of arousal or stress during the test session than their shorter-looking counterparts. This hypothesis may be further tested in a number of ways. As suggested by the current experiment, it may be useful to examine the effects of presenting stimuli in a less-startling manner, such as by using a gradual fade-in for stimulus onsets, as opposed to using an instantaneous onset and illumination. Similarly, other more global means of reducing infant stress, such as having the infant sit together with a caregiver (as opposed to sitting alone in a car seat) may affect infants' attentional or cognitive performance during these sessions.

Notes

1. It is possible to calculate an average look length within each trial by taking the cumulative total of per-trial looking and dividing by the number of looks the infant made within the trial. However, the results reported for average look length and cumulative per-trial looking were the same across all analyses conducted and reported here.
2. Another convergent test of this possible artifact is to repeat the Look Duration Status \times Pre/Post \times Trial analysis of HR to stimulus onsets, but to enter latency

length as a covariate. We conducted this analysis as well, and found that covarying the latency length did not change our conclusion regarding the Look Duration Status \times Pre/Post interaction.

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