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Sensitization during Visual Habituation Sequences: Procedural Effects and Individual Differences

John Colombo

University of Kansas

Janet E. Frick

University of Georgia

and

Sheila A. Gorman

University of Kansas

Although individual differences in visual habituation have long been interpreted in terms of processes derived from comparator theory, research over the last decade has suggested that arousal or arousability as manifest in sensitization may contribute to infants' attentional profiles, and thus, to individual differences in those profiles. We explored this possibility by habituating 4-month-old infants to 4 × 4, 10 × 10, or 20 × 20 checkerboards in a fixed-trial paradigm. The first specific aim was to examine the attentional characteristics of infants with habituation patterns showing sensitization versus those that did not. The second specific aim was to determine whether patterns of attention suggestive of sensitization effects reported in past research might be attributable to the use of illuminated interstimulus intervals (ISIs). Trends were observed for sensitization to occur more frequently with more complex than with less complex checkerboards. Infants who showed looking patterns characteristic of sensitization looked longer and did not habituate as readily as infants who did not show sensitization. Finally, different ISIs did not engender different levels of sensitization, but dark ISIs significantly increased infants' looking times to stimuli during trials. © 1997 Academic Press

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Address correspondence and reprint requests to John Colombo, Department of Human Development, 4001 Dole Human Development Center, University of Kansas, Lawrence, KS 66045-2133 E-mail: colombo@ukans.edu.

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Visual habituation is among the most widely used paradigms for the study of attention, perception, and cognition in human infants. In the paradigm, repetitive stimulus presentations are made with the expectation that the infant's attentional responses (e.g., distribution of visual fixations) will decline in strength across such presentations. This decline in attention has been theoretically attributed to cognitive processes that involve the formation of an ''engram,'' or internal representation, of the stimulus presented during the sequence, and the continuing revision of that engram that occurs as a result of comparisons between the engram and the actual stimulus itself (Sokolov, 1963). Along with research that has shown the basic perceptual abilities of the human infant, habituation has also yielded measures that are modestly predictive of cognitive function in childhood and adolescence (see reviews by Bornstein & Sigman, 1986; Colombo, 1993; McCall & Carriger, 1993). Included in these measures is looking duration, which, in the tradition of the Sokolovian model, has been widely interpreted to reflect the speed with which the infant comes to process the external stimulus (e.g., Cohen, 1988, 1991; Colombo & Mitchell, 1990).

Across the last decade, however, an alternative interpretation of the processes underlying infants' responses in visual habituation paradigms has been raised. Kaplan and his colleagues (Kaplan & Werner, 1986, 1987; Kaplan, Werner, & Rudy, 1990) have systematically studied the contribution of sensitization (Groves & Thompson, 1970; Petrinovich, 1984; Thompson & Glanzman, 1976; Thompson, Berry, Rinaldi, & Berger, 1979) to infants' visual responses (see also Bashinski, Werner, & Rudy, 1985). Sensitization is a transient increase in responsiveness (here, an increase in looking) that is manifest during the initial portions of the repetitive presentations that comprise the habituation sequence, and is thought to be related to the arousing qualities of the stimulus presented, or perhaps to the arousal of the subject (see Fig. 1).

Of particular interest is the fact that sensitization is presumed to affect the duration of looks during the early part of the habituation sequence, which is the part of the sequence from which look duration measures (e.g., peak looks, as in Colombo, Mitchell, O'Brien, & Horowitz, 1987a,b) have been drawn for use in individual difference studies. Thus, it is possible that individual differences in such habituation measures may reflect individual differences in arousal or arousability. The present study was conducted to examine the possibility that longer looking might be attributable to individual differences in sensitization. We employed habituation methods and stimulus classes used by Kaplan and Werner (1986, 1987) to elicit sensitization in 4-month-old infants in order to examine the characteristics of infants who show sensitization versus those who do not.

The present study was also designed to examine an alternative hypothesis concerning the determinants of looking patterns that are suggestive of sensitization. In Kaplan's work (e.g., Kaplan et al., 1990), a stimulus (usually a

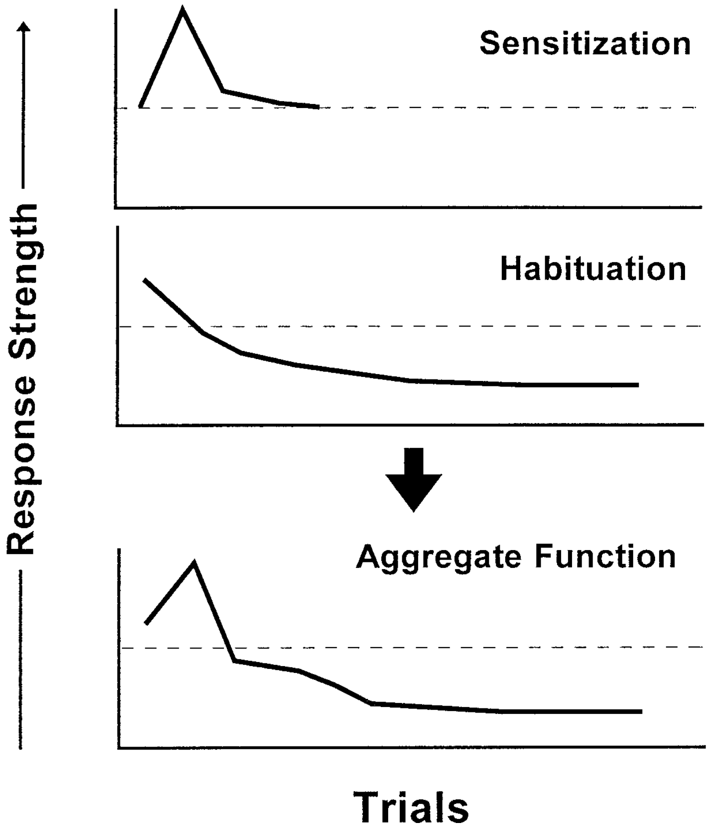

FIG. 1. The theoretical contribution of sensitization to overall habituation patterns. Sensitization (top panel) is a transient increase in arousal that occurs as a result of initial stimulus presentations, that is manifest in an increase in response strength at the start of the sequence. Habituation (middle panel) is a relatively monotonic decline in response strength presumably as a result of comparator-like processes. The resulting habituation curve (bottom panel) is an aggregate of these dual processes (after Kaplan et al., 1990).

checkerboard) is shown for a fixed 10-s trial, during which the infant's looking is monitored; this 10-s trial is typically followed by a 10-s intertrial interval that features the presentation of a ''blank slide.'' That is, the interstimulus interval (ISI) is illuminated. Such a procedure represents a variation from habituation procedures in which the ISI is dark (e.g., Colombo et al., 1987a,b; Horowitz, Paden, Bhana, & Self, 1972; Roberts & Horowitz, 1986). We thought it possible that such a blank slide, with its sharply defined border, might be construed as a second ''stimulus'' by infants in the procedure. After such an ISI, the return of the first pattern (i.e., the initial stimulus) might produce some sort of increase in looking, owing to a type of ''recovery'' of looking that might be attributable to the infant's comparison of the actual stimulus (i.e., checkerboard) with the rectangle of light presented in between stimulus trials. Extended and more variable attentional patterns have in fact been reported in habituation sequences that feature multiple exemplars (e.g., Colombo, McCollam, Coldren, Mitchell, & Rash, 1990). Aside from any theoretical consideration, the effect of ISI illumination has not been systematically investigated to this point, and because illuminated ISIs had not been used previously in our laboratory, we sought to investigate its possible effects on infants' looking during habituation sessions.

METHOD

Subjects

We recruited 108 4-month-old infants by mail and telephone from the greater Kansas City metropolitan area. Of these infants, 27 were excluded from final analyses for the following reasons: fussiness ($n = 21$), prematurity (gestation of 37 weeks or less; $n = 3$), chronic medical condition with cognitive risk ($n = 1$), and inattentiveness (i.e., failure to look at stimuli for five or more of the eight trials; $n = 2$). The final sample of 81 infants was balanced closely for sex and included healthy, full-term, 4-month-olds (age range of 113–127 days). Demographic characteristics obtained from this sample are identical to those documented previously in reports from this laboratory (e.g., Colombo, Frick, Ryther, & Gifford, 1996).

Apparatus and Stimuli

Infants were tested in a 3 × 3 m room with black walls and ceiling. The infants were placed in a car seat, with a .7 × 1 m rear-projection screen centered in the wall .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 infants' face, and the video image from this camera was used to view and record infants' fixations. An observer coded infants' looks ''live'' from the video image. Look durations were recorded via button presses interfaced with a Zenith Z-159 microcomputer fitted with a Scientific Solutions LabTender Board and programmed with custom software.

Two dependent measures were examined in this study. The first was the cumulative total of looking per 10-s stimulus trial. The second was the average length of look occurring within each trial, which was calculated by taking the cumulative total of per-trial looking and dividing by the number of looks the infant made within the trial. Interobserver reliabilities were obtained in 28% of the infants tested by having a second observer independently code looks from the videotape. The Pearson coefficient between the ''live'' and reliability observers' judgments of per-trial cumulative totals was +.93; for the average duration of looks, it was +.87.

Three different black-and-white checkerboards were used in this study: a 4×4, a 10×10, and a 20×20. All three were projected so that they subtended a visual angle of 10°. The patterns had a contrast value of .92, and average-space luminance was 2.37 log 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). We replaced the ''moderate'' 12×12 checkerboard used in previous reports with the 10×10 checkerboard for purposes involving the ease of stimulus generation. However, the targets at the two extremes of complexity (4×4 and 20×20) were as previously described (e.g., Kaplan et al., 1990).

Design and Procedure

The study was a Stimulus (3: 4×4, 10×10, 20×20) $\times$ ISI (2: Light vs Dark) $\times$ Trial (8) mixed-design factorial, with Trial run within-subjects and ISI and Stimulus run between-subjects. In the Dark ISI condition, a cardboard square was inserted in the slide carousel, so that no light appeared in between stimulus trials. In the Light ISI condition, however, a ''blank'' slide was inserted so that an empty but illuminated rectangle was presented during interstimulus intervals.

The procedure was relatively straightforward; after the infant was placed in the car seat, a stimulus was projected to start the sequence. The habituation procedure was a fixed-trial sequence, in which the stimulus remained projected for 10 s, and then was removed for a 10-s ISI. The sequence ended after eight stimulus presentations. We did not use an infant-controlled first trial, as has been used in some previous reports (see, e.g., Kaplan et al., 1991), but infants' latencies to look on the first trial were generally brief (averaging 1.3 s) and did not significantly vary as a function of stimulus, nor were they significantly different from latencies observed on subsequent trials.

RESULTS

Analyses of Looking across Trials

Cumulative total looking per trial. An ISI $\times$ Stimulus $\times$ Trial mixed-design MANOVA was performed on infants' cumulative total of per-trial looking. This analysis yielded significant main effects for all three factors. The Trial effect (multivariate $F(7,66) = 5.05$, $p < .001$) was attributable to a decline in looking across the eight stimulus presentations. The Stimulus effect ($F(2,72) = 7.98$, $p = .001$), was attributable to the 20×20 stimulus eliciting more looking than the 10×10 or 4×4 stimulus. These two first main effects, however, were qualified by a significant Stimulus $\times$ Trial interaction ($F(14,132) = 2.06$, $p = .018$) which was attributable to significant decrements across trials for the 10×10 (Multivariate $F(7,18) = 3.38$, $p <$

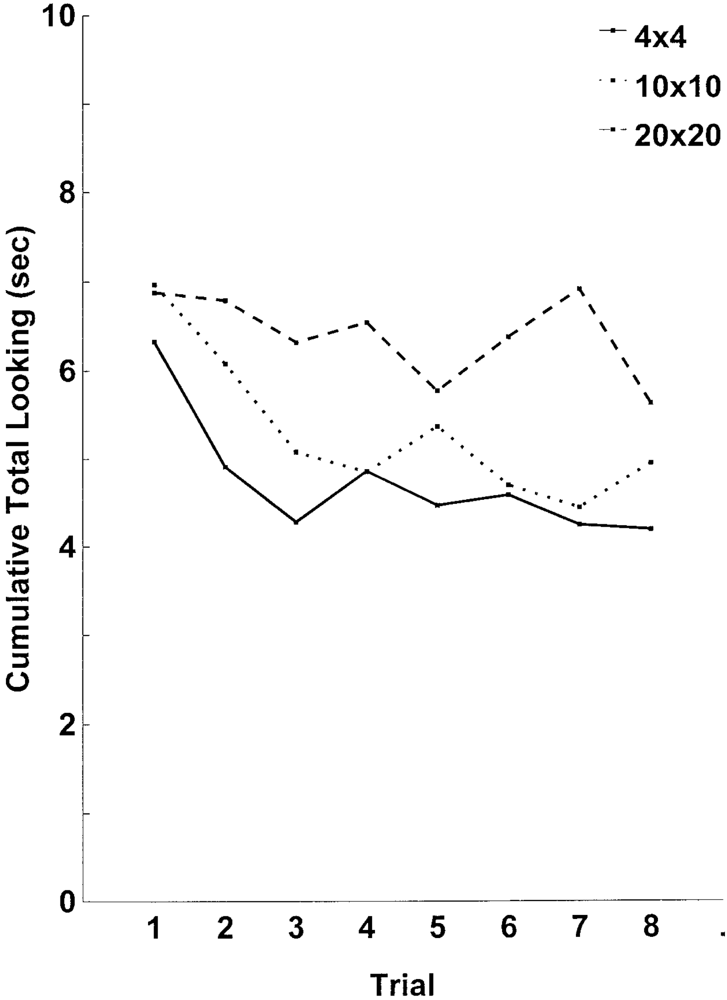

FIG. 2. Infants' cumulative total per-trial looking as a function of stimulus.

.025) and the 4 × 4 (multivariate $F(7,18) = 4.03$, $p < .01$) checkerboards, but not for the 20 × 20 stimulus (multivariate $F(7,18) = 1.34$, $p =$ ns). Figure 2 shows the cumulative totals for per-trial looking, broken down by stimulus.

Finally, a significant main effect for ISI was observed ($F(1,72) = 11.78$, $p < .001$), which was due to infants' cumulative per-trial looking totals being significantly longer under dark-ISI conditions ($M = 5.63$ s, $SD = 2.0$) than under light-ISI conditions ($M = 4.20$ s, $SD = 2.0$). Figure 3 shows this effect across the eight habituation trials.

Average look length within trials. The same ISI × Stimulus × Trial MANOVA was performed on infants' average look duration within each trial.

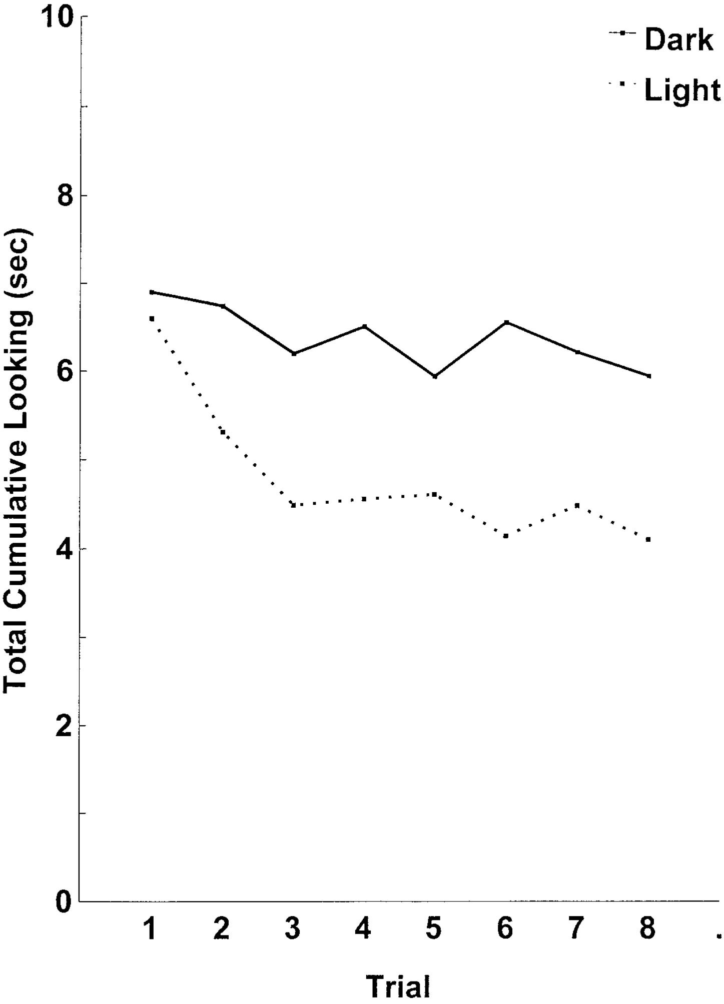

FIG. 3. Effect of ISI condition on infants' cumulative total per-trial looking. The main effect for ISI is highly significant ($p < .001$); although response decrement appears to be less robust in the dark ISI condition, the ISI × Trial interaction only approached statistical significance (Multivariate $F(7,66) = 1.86$, $p = .09$).

This analysis yielded significant main effects for all three factors, but no interactions. The main effect for Stimulus ($F(2,72) = 9.01$, $p < .001$) was attributable to the 20 × 20 checkerboard eliciting significantly longer looks than either the 10 × 10 ($p = .015$) or 4 × 4 stimuli ($p < .001$). The main effect for ISI ($F(1,72) = 7.84$, $p < .025$) was caused by average looks being longer under the dark-ISI condition ($M = 2.75$, $SD = 1.5$) than under the light-ISI condition ($M = 2.00$, $SD = 1.3$). Finally, the main effect for Trials

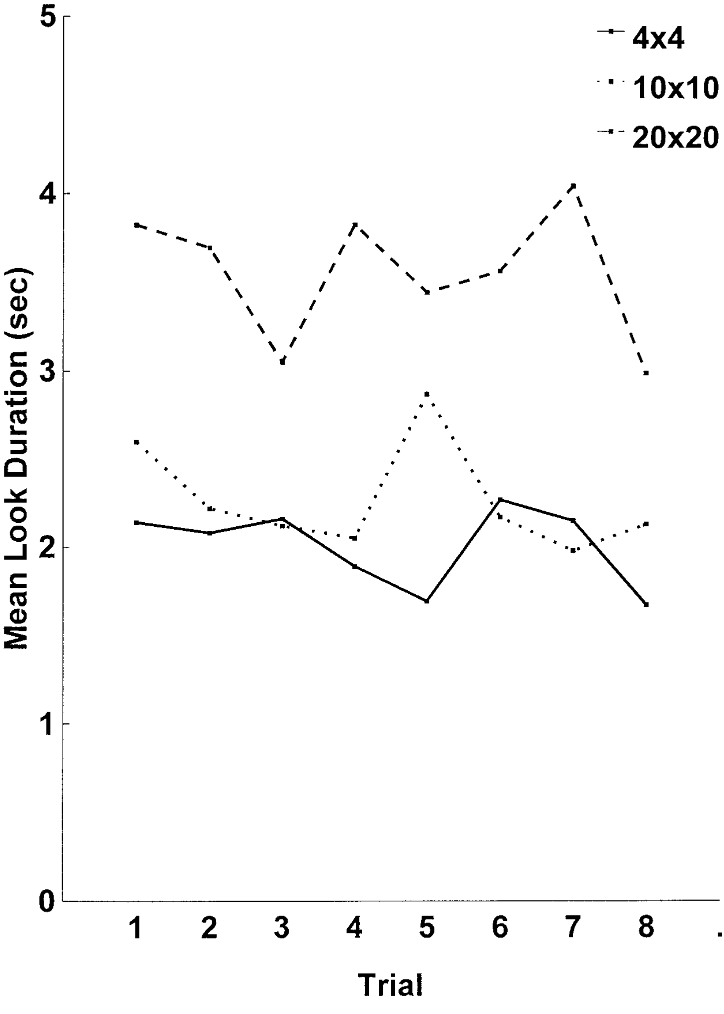

FIG. 4. Infants' mean per-trial look duration as a function of stimulus.

(Multivariate $F(7,66) = 2.27$, $p < .05$) was the result of average look durations declining across trials (e.g., first trial $M = 2.86$ s; eighth trial $M = 1.96$ s). Means for average looks across trials are presented in Fig. 4.

Effects of ISI and Stimulus on Sensitization

Next, we examined infants' habituation curves for the presence of sensitization as a function of either ISI condition and Stimulus. This was done in two ways. First, following both Groves and Thompson (1976) and Kaplan (e.g., Kaplan et al., 1990), who describe sensitization in terms of an increase in responding from the first to the second trial, before the occurrence of a decrement, we analyzed the pattern of cumulative total and average looking across the first two trials as a function of ISI and Stimulus. Overall sensitization would be manifest in these analyses in significant ISI × Trial or Stimulus × Trial interactions, but neither the two-way interaction terms, nor the three-way Stimulus × ISI × Trial interaction approached significance (all Fs < 1.0, ns).

Next, since it was possible to qualitatively characterize sensitization by a pattern of increase (rather than decrease) across the first two trials, we categorized individual infants respectively as ''sensitizers'' or ''non-sensitizers'' based on such an increase or decrease. This yielded frequency counts that could then be analyzed for effects of ISI or Stimulus with χ^2 tests. Overall, when classified in this way, 30% of the infants showed sensitization. Kaplan et al. (1990) reported relatively strong sensitization effects with stimuli very much like those used here. We did observe an increase in the frequency of sensitization from the least complex to the two more complex stimuli, as the percentages of infants showing a sensitization pattern went from 15.4% for the 4 × 4 checkerboard, to 42.3% for the 10 × 10 checkerboard, and 32.1% for the 20 × 20 checkerboard. This trend approached statistical significance ($\chi^2(2) = 4.58$, $p = .10$). ISI condition was unrelated to the occurrence of sensitization, with 33.3% of infants showing sensitization in the dark-ISI condition, and 26.8% showing sensitization in the light-ISI condition ($\chi^2(1) = 0.40$, $p =$ ns).

Individual Difference Analyses

Finally, we examined whether infants who showed sensitization, again defined by an increase (rather than a decrease) in looking across trials 1–2, showed different patterns of look duration across more than the initial portions of the habituation sequence on which the infants were classified (i.e., trials 3–8). This was done by performing a mixed-design ISI (2: Light vs Dark) × Stimulus (3: 4 × 4, 10 × 10, vs 20 × 20) × Sensitization (2: Yes vs No) × Trial (6: Trial 3–Trial 8) MANOVA on infants' per-trial cumulative total and average look duration within trials. Of particular interest from these analyses were main effects and interactions involving the Sensitization factor. It should be noted that, in reporting the results of these analyses, some of the basic main effects (e.g., for ISI, Stimulus, and Trial) mirror findings previously reported in overall analyses above. Thus, descriptions of these effects are not repeated here; although these factors had been analyzed previously, we entered them as terms into these analyses to determine whether they interacted with the Sensitization factor.

Significant main effects for Sensitization were observed across Trials 3 through 8 for both total cumulative looking per-trial ($F(1,66) = 4.12$, $p < .05$), and for average look duration within trials ($F(1,66) = 7.65$, $p < .01$). Infants who showed sensitization looked longer than infants who did not show sensitization (see Figs. 5 and 6). This finding indicates that infants who

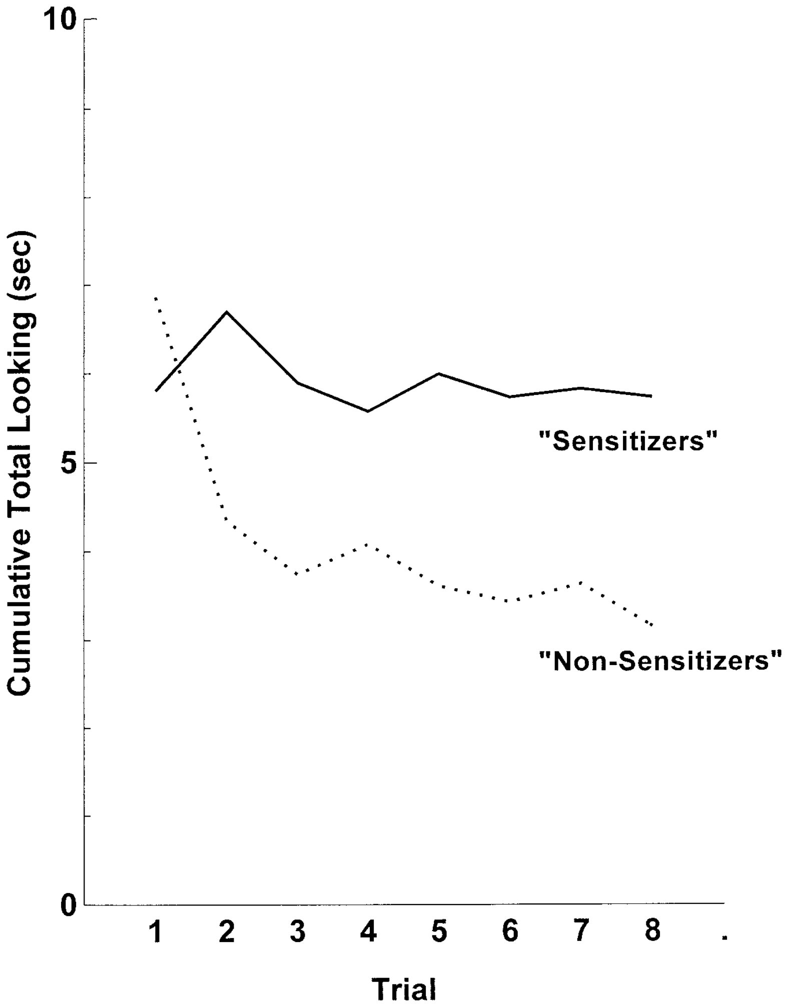

FIG. 5. Total cumulative per-trial looking of infants showing sensitization patterns (''sensitizers'') and those who did not show such patterns (''non-sensitizers'').

were sensitized by presentation of the stimulus (irrespective of stimulus or ISI conditions), looked longer across the entire habituation session, including portions of the habituation session beyond that which contributed to the actual classification of sensitization.

DISCUSSION

First, although parametric analyses did not yield strong effects for sensitization, qualitative/dichotomous classifications of sensitization were observed in

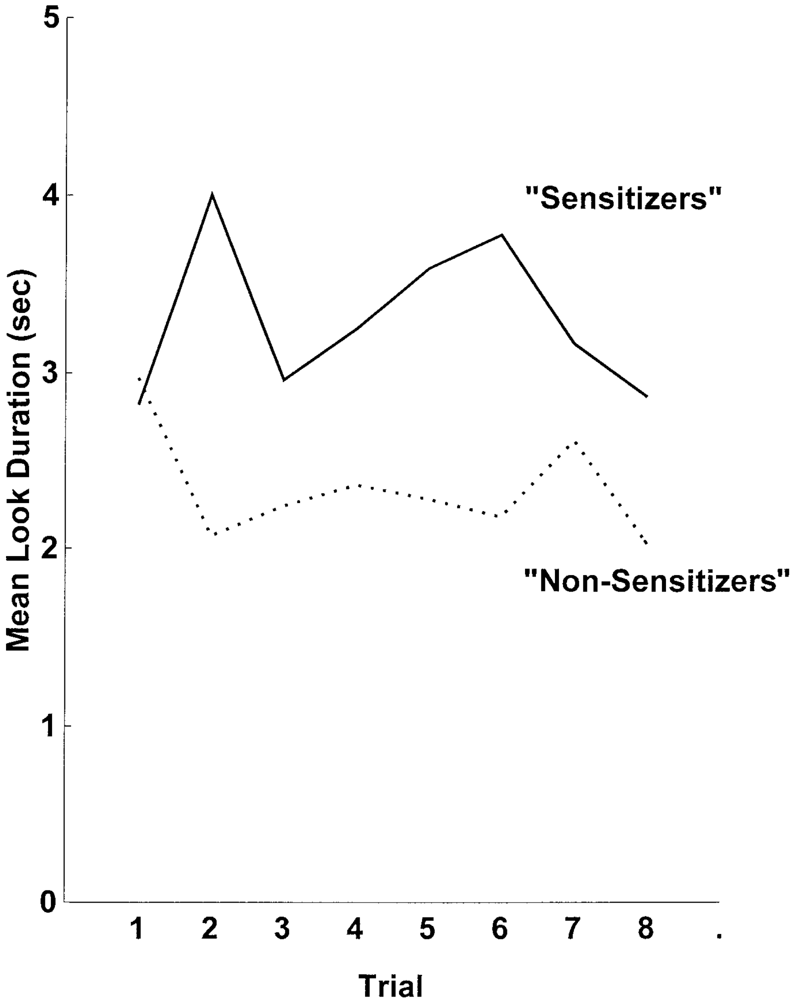

FIG. 6. Average per-trial look duration of infants showing sensitization patterns (''sensitizers'') and those who did not show such patterns (''non-sensitizers'').

30% of the cases, and such classifications did occur up to twice as often with the two complex stimuli (10 × 10 and 20 × 20 checkerboards) than with the simplest one (4 × 4). The luminance of our stimuli was somewhat higher than those used in previous studies (e.g., Kaplan & Werner, 1987), and this may have attenuated the overall stimulus-based sensitization effects that have been previously reported.

Second, we did not observe any effects of ISI on the frequency of sensitization. Thus, we found no support for the hypothesis that sensitization-like patterns of attention in visual habituation might be attributable to the interpretation of a ''blank slide'' as a second stimulus, such that increases in infants' looking across early parts of the habituation sequence might be related to discrepancies between the checkerboard stimuli presented and the second ''blank'' stimulus. Although ISI format did not affect sensitization, it strongly influenced the length of infants' looking to stimuli. Dark ISIs (i.e., ISIs in which the screen and booth were completely dark) evoked significantly more looking overall and longer looks, and tended to diminish the habituation decrement. It is not clear to what this effect is attributable. Simple changes in illumination/luminance across trials may have engendered more looking during the trials themselves. Alternatively, illumination of the infant's surround during periods when a stimulus is not available may have somehow made the checkerboards an increasingly less compelling stimuli when they returned during subsequent trials of the habituation sequence. However, the finding that the amount of ambient light available in ISIs significantly affects infants' looking at stimuli would suggest that investigators might profit from reporting such details routinely in method sections of their studies.

Finally, of most interest to the topic of individual differences in infant visual attention was our finding that infants who showed sensitization responses (defined as increases, rather than decreases, from trial 1 to trial 2 of the habituation sequence) looked longer throughout the subsequent habituation trials, and did not show habituation patterns as robust as those infants who did not show sensitization. This finding may implicate processes of arousal and arousability in individual differences in habituation (i.e., looking time), and raises the possibility that individual differences in sensitization may contribute to differences in the performance of long- and short-looking infants on various cognitive tasks (Colombo et al., 1996; Frick & Colombo, 1996), and may perhaps bear on the continuity of such performance with cognitive status later in life (Colombo, 1993). The next logical step would be to test this possibility with convergent measures of sensitization other than looking.

REFERENCES

Bashinski, H., Werner, J., & Rudy, J. (1985). Determinants of infant fixation: Evidence for a two-process theory. *Journal of Experimental Child Psychology,* **39,** 580–598.

Bornstein, M. H., & Sigman, M. D. (1986). Continuity in mental development from infancy. *Child Development,* **57,** 251–274.

Cohen, L. B. (1988). An information processing approach to infant cognitive development. In L. Weiskrantz (Ed.), *Thought without language* (pp. 211–228). Oxford, UK: Clarendon Press.

Cohen, L. B. (1991). Infant attention: An information processing approach. In M. J. Weiss & P. R. Zelazo (Eds.), *Newborn attention: Biological constraints and the influence of experience* (pp. 1–21). Norwood, NJ: Ablex.

Colombo, J. (1993). *Infant cognition: Predicting later intellectual functioning.* Newbury Park, CA: Sage Publications, Inc.

Colombo, J., Frick, J. E., Ryther, J. S., & Gifford, J. J. (1996). Individual differences in infant visual attention: Four-month-olds' recognition of forms connoted by complementary contour. *Infant Behavior and Development,* **19,** 113–119.

Colombo, J., McCollam, K., Coldren, J. T., Mitchell, D. W., & Rash, S. J. (1990). Form categorization in 10-month-old infants. *Journal of Experimental Child Psychology,* **49,** 173–188.

Colombo, J., & Mitchell, D. W. (1990). Individual and developmental differences in infant visual attention: Fixation time and information processing. In J. Colombo and J. W. Fagen (Eds.), *Individual differences in infancy: Reliability, stability, and prediction* (pp. 193–227). Hillsdale, NJ: Erlbaum.

Colombo, J., Mitchell, D. W., O'Brien, M., & Horowitz, F. D. (1987). Stability of infant visual habituation during the first year. *Child Development,* **58,** 474–489.

Colombo, J., Mitchell, D. W., O'Brien, M., & Horowitz, F. D. (1987). Stimulus and motoric influences on visual habituation at three months. *Infant Behavior and Development,* **10,** 173–181.

Frick, J. E., & Colombo, J. (1996). Individual differences in infant visual attention: Recognition of degraded visual forms by 4-month-olds. *Child Development,* **67,** 188–204.

Groves, P. M., & Thompson, R. F. (1970). Habituation: A dual-process theory. *Psychological Review,* **77,** 419–450.

Horowitz, F. D., Paden, L., Bhana, K., & Self, P. (1972). An infant-control procedure for studying infant visual fixations. *Developmental Psychology,* **7,** 90.

Kaplan, P. S., & Werner, J. (1986). Habituation, response to novelty, and dishabituation in human infants: Tests of a dual-process theory of visual attention. *Journal of Experimental Child Psychology,* **14,** 83–109.

Kaplan, P. S., & Werner, J. (1987). Sensitization and dishabituation of infant visual fixation. *Infant Behavior and Development,* **10,** 183–197.

Kaplan, P. S., Werner, J., & Rudy, J. W. (1990). Habituation, sensitization, and infant visual attention. In C. Rovee-Collier & L. P. Lipsitt (Eds.), *Advances in infancy research* (Vol. 6, pp. 61–109). Norwood, NJ: Ablex.

McCall, R. B., & Carriger, M. (1993). A meta-analysis of infant habituation and recognition memory performance as predictors of later IQ. *Child Development,* **64,** 57–79.

Petrinovich, L. (1984). A two-factor dual-process theory of habituation and sensitization. In H. V. S. Peeke & L. Petrinovich (Eds.), *Habituation, sensitization, and behavior* (pp. 17–55). New York: Academic Press.

Roberts, K., & Horowitz, F. D. (1986). Basic-level categorization in seven- and nine-month-old infants. *Journal of Child Language,* **13,** 191–208.

Sokolov, I. (1963). *Perception and the conditioned reflex.* New York: MacMillan.

Thompson, R. F., Berry, S. D., Rinaldi, P. C., & Berger, T. W. (1979). Habituation and the orienting reflex: The dual-process theory revisited. In H. D. Kimmel, E. H. Van Olst, & J. F. Orlebeke (Eds.), *The orienting reflex in humans* (pp. 21–60). Hillsdale, NJ: Erlbaum.

Thompson, R. F., & Glanzman, D. (1976). Neural and behavioral mechanisms of habituation and sensitization. In T. Tighe & R. Leaton (Eds.), *Habituation: Perspectives from child development, animal behavior, and neurophysiology* (pp. 49–93). Hillsdale, NJ: Erlbaum.

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