

RESEARCH ARTICLES

The Developmental Course
of Habituation in Infancy
and Preschool Outcome

John Colombo

*Department of Psychology and
Schiefelbusch Institute for Life Span Studies
University of Kansas*

D. Jill Shaddy

*Department of Psychology
University of Kansas*

W. Allen Richman

*Schiefelbusch Institute for Life Span Studies
University of Kansas*

Julie M. Maikranz

*Clinical Child Psychology Doctoral Program
University of Kansas*

Otilia M. Blaga

*Department of Psychology
University of Kansas*

A longitudinal sample of 226 infants were tested monthly on habituation and novelty preference tasks, augmented with simultaneous heart rate recording from 3 to 9 months of age. Infants were then administered the Bayley Scales of Infant Development II (BSID) and MacArthur Communicative Development Inventory (MCDI) at

12, 18, and 24 months. Prior findings regarding the decline in look duration with age were replicated. Age-based factors were extracted from the monthly assessments, an early attention factor from 3 to 6 months and a late attention factor from 7 to 9 months. A novelty preference factor, which grouped recognition performance at 4 and 6 months of age, was also derived. The late attention factor correlated negatively with a factor score derived from the BSID mental index, and the novelty preference aggregate was correlated positively with a factor score derived from the MCDI production scores. Two clusters of infants were derived based on the developmental course of change from the early attention to late attention look duration aggregates: One cluster ($n = 150$) decreased strongly, and another ($n = 50$) increased. Infants belonging to these clusters subsequently differed on both the BSID and MCDI outcomes, with the former cluster showing distinct advantages that increased as the outcome assessments progressed from 12 to 24 months of age. This finding was bolstered by subsequent analyses of data from infants who completed all tests run from 3 to 9 months. The results of this study suggest that the developmental course of attention during infancy is an important clue to cognitive and language outcomes in early childhood.

Research on the study of individual differences in infant cognition has increased dramatically over the past two decades. Such interest has been fueled in part by reports indicating that measures of early cognition show modest but significant prediction of intellectual function in childhood and adolescence (Bornstein & Sigman, 1986; Colombo, 1993; Fagan, 1981; McCall & Carriger, 1993; McCall & Mash, 1995). Through the 1970s, the contention that behavioral manifestations in infancy bore little or no relation to mature intellectual function was a widely accepted tenet within the field of developmental psychology. Beginning in the early 1980s, however, measures of preverbal cognition were incorporated into longitudinal studies of long-term developmental outcome (e.g., Fagan & McGrath, 1981; Miller, Spiridigliozzi, Ryan, Callan, & McLaughlin, 1980) as alternatives to traditional standardized infant tests. Individual differences in infants' performance in these paradigms were found to be modestly but significantly correlated with standardized assessments of cognitive, linguistic, and overall intellectual function later in childhood (see reviews by Bornstein & Sigman, 1986; Colombo, 1993, 1997; Colombo & Mitchell, 1990; Fagan, 1984a, 1984b; Fagan & Ohr, 1990; McCall, 1994; McCall & Carriger, 1993; McCall & Mash, 1995; Mitchell & Colombo, 1997; S. A. Rose, 1989).

The history of successful prediction of childhood cognition from measures of habituation in infancy begins with the studies of Miller and her colleagues (e.g., Miller et al., 1977), and extends through the work of Bornstein (see Bornstein, 1984, 1985; Ruddy & Bornstein, 1982; Tamis-LeMonda & Bornstein, 1989) and others (Lewis & Brooks-Gunn, 1981; D. Rose, Slater, & Perry, 1986; Slater, Cooper, Rose, & Morison, 1989). Although the habituation protocol yields many indexes that can be used to characterize attention and cognitive performance,

Colombo and Mitchell (1990) argued that variation in look duration is the primary factor that drives both individual and developmental differences in visual habituation during infancy. This argument is based on the observation that look duration is the only habituation variable (a) to follow a developmental course that is consistent with theoretical underpinnings of the habituation paradigm, (b) to show the most consistent test–retest reliability of all habituation measures, and (c) to contribute to variability in nearly every other parameter of the habituation curve (see Colombo, Mitchell, O'Brien, & Horowitz, 1987a, 1987b). As a result, look duration has also been examined within the context of other paradigms (e.g., fixed-trial accumulation periods, or familiarization periods prior to paired-comparison probes) and used with success in several subsequent longitudinal studies (Jacobson, Chiodo, & Jacobson, 1996; Mitchell, McCollam, Horowitz, Embretson, & O'Brien, 1991; Sigman, 1983; Sigman, Cohen, & Beckwith, 1996; Sigman, Cohen, Beckwith, Asarnow, & Parmelee, 1991; Sigman, Cohen, Beckwith, & Parmelee, 1985, 1986). In the prediction literature, however, two points have been generally overlooked with regard to look duration in infancy.

DEVELOPMENTAL CHANGES IN LOOK DURATION

The first is that look duration changes markedly across the first year of life. Through the 1980s, it was generally held that look duration followed a simple linear decline across the first year (Bornstein, Pecheaux, & Lecuyer, 1988; Colombo & Mitchell, 1990; Mayes & Kessen, 1989). This engendered a relatively straightforward interpretation for both developmental and individual differences in look duration: Shorter looking reflected more rapid stimulus encoding, and those infants who looked for briefer periods than their age-matched cohorts were simply accelerated in their development relative to their longer looking counterparts with respect to this aspect of information processing. This interpretation, of course, was concordant with the reports of modest associations between increased look duration in infancy and less optimal cognitive performance later in childhood.

Recent data, however, have suggested that the developmental course of look duration is not monotonically linear. Both primate (e.g., Reisbick & Neuringer, 1996; Reisbick, Neuringer, Gohl, & Wald, 1997) and human data (e.g., Adams, 1987; Hood, Murray, King, & Hooper, 1996) suggest that look durations increase from the newborn period to about 8 to 10 weeks of age¹ before dropping from 10 weeks onward. In addition, there is strong evidence for a plateau in look

¹In addition, there are some indications that look duration may actually increase toward the end of the first year of life (Kagan, 1971; Saxon, Frick, & Colombo, 1997; see also Colombo et al., 1999).

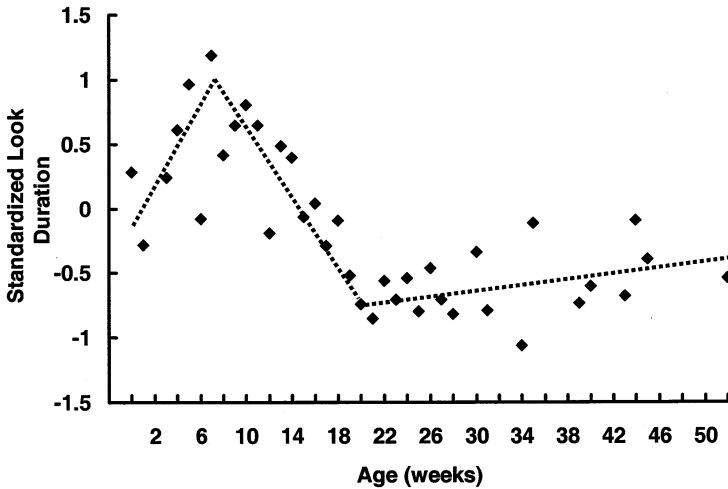


FIGURE 1 Developmental course of look duration, constructed from a meta-analysis of developmental studies of attention in infancy (Colombo, Harlan, & Mitchell, 1999). Points represent averaged standardized measures of look duration plotted by age of assessment. Dotted line represents regression lines for points at different age periods. From "Infant Attention Grows Up: The Emergence of a Developmental Cognitive Neuroscience Perspective," by J. Colombo, 2002, *Current Directions in Psychological Science*, 11, p. 199. Copyright 2002 by Blackwell Publishers. Reprinted with permission.

duration after 6 or 7 months of age (Colombo, Harlan, & Mitchell, 1999; see Figure 1). Thus, the developmental course of look duration from the infant-controlled habituation is complex, which implies that look duration may well reflect different cognitive constructs during the first year and beyond (see Colombo, 2001). In turn, this suggests that the developmental course of look duration would provide important clues for understanding the mechanisms underlying individual differences in visual attention and look duration during infancy, and to the utility of the measures yielded by the habituation paradigm in predicting later cognitive outcome. However, virtually all of the studies of the predictive validity of habituation measures have not made repeated or developmentally sensitive assessments of infant performance, and as such, have ignored the possible effect of systematic developmental change on the assessment of individual differences in infant cognitive performance.

LOOKING AND PROCESSING

The second point with respect to the use of look duration as a predictive measure is that infant looking does not necessarily reflect visual processing. This was implied

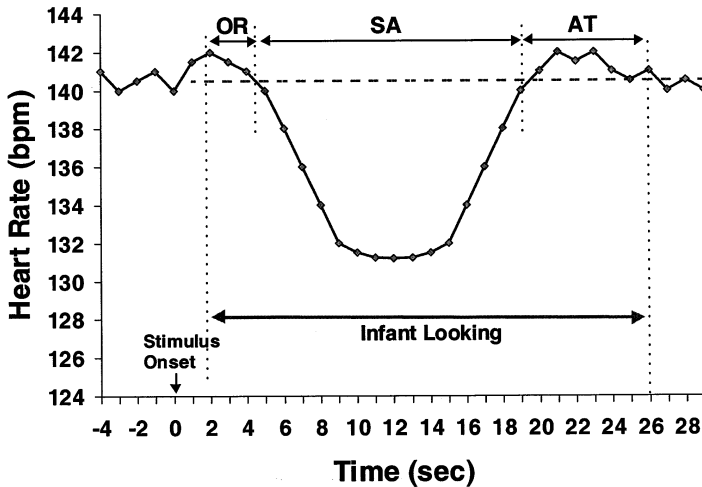


FIGURE 2 Schematic of heart-rate-defined phases of attention, as delineated by Richards (e.g., Richards & Casey, 1992). The dashed horizontal line represents a prestimulus baseline heart rate. Orienting (OR) represents the latency to attainment of a sustained deceleration. Sustained attention (SA) represents the extent of the deceleration, during which encoding and processing presumably takes place. Attention termination (AT) is the perseverance of the look after the end of the deceleration and is thought to reflect facility or difficulty with disengagement of attention. Figure adapted from Colombo, Richman, Shaddy, Greenhoot, and Maikranz (2001). Reprinted with permission of the Society for Research in Child Development.

30 years ago through the existence of terms like *obligatory looking* (Stechler, 1964; Stechler & Latz, 1966), *blank staring* (Greenberg & Weizmann, 1971; Weizmann, Cohen, & Pratt, 1971), or *sticky fixation* (Hood, 1995). However, the point has been made definitively by Richards (Casey & Richards, 1988; Richards, 1985, 1987, 1994; Richards & Casey, 1990a, 1990b, 1991, 1992; Richards & Gibson, 1997; Richards & Lansink, 1997), who used respiratory and cardiac measures in a systematic program of research to investigate different phases of attention that occur during looks (see Figure 2). Looking can be parsed into three distinct phases, based on the topology of the heart rate (HR) deceleration that typically accompanies visual fixation. The period during looking that precedes the attainment of a stable deceleration has been defined as *orienting* (OR). As OR reflects the latency to begin encoding or processing of the stimulus, it is most closely identified with the construct of attentional “engagement.” *Sustained attention* (SA) is defined as the period of HR deceleration that typically occurs during infant looking, and is most closely identified with the construct of encoding or processing of the stimulus. *Attention termination* (AT) refers to the period of the look during which the look persists, despite the fact that the characteristic HR deceleration thought to signify meaningful information processing has ended. AT is most closely identified

with the construct of attentional disengagement (Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001). Despite the fact that these convergent measures have greatly enhanced our understanding of the development of attention in infancy and early childhood, they have never been used in studies of prediction.

SUMMARY AND RATIONALE

In response to these gaps in our knowledge, we have conducted a longitudinal study of the predictive validity of individual differences in the developmental course of look duration to cognitive and language outcome measures. In this article, we report the results of the prediction to measures taken through the second year of life. Simultaneous with the measurement of basic behavioral indexes of attention, we included measures of infants' HR during the habituation phase of the session so that we could independently validate infants' attentional status. In addition, this allowed us to examine parameters of OR, SA, and AT and their association with later cognitive and language outcome.

In addition to the inclusion of measures from infant visual habituation, we also assessed a measure of recognition memory (novelty preference) following the habituation sequence during those ages in infancy. Past research has suggested that novelty preferences are positively correlated with developmental outcome, but such correlations have been observed under conditions where novelty preferences were assessed prior to the attainment of habituation. Because the infant-control habituation technique more closely equates all infants for familiarity with the habituation stimulus, the inclusion of the novelty preference measure here allowed us to test for the predictive validity of novelty preference under conditions where infants' processing of the habituation stimulus is presumably equated. This allows for a test of whether the correlation between novelty preference and outcome is mediated by the infant's rapidity of encoding or by other factors.

METHOD

Participants

Longitudinal Sample

The primary sample for this project was comprised of 226 healthy, full-term infants from the metropolitan and suburban areas of Kansas City, MO. This includes cities and towns that feature populations with a relatively diverse range of backgrounds, including upper middle to lower socioeconomic status (see demographics reported in Colombo, Frick, Ryther, & Gifford, 1996; Frick, Colombo, & Saxon, 1999). The sample was primarily White (91%), but included Asian American (3%),

Hispanic (4%), and African American (2%) participants in proportion to the population sampled. As is typical in longitudinal studies with infants, the number of infants providing complete and usable data at each age varied. Table 1 shows the breakdown of the number of infants tested at each age and reasons for exclusion.

Cross-Sectional Sample

For comparison purposes, a cross-sectional sample was recruited to assess for the effects of repeated testing in the longitudinal sample. A total of 191 additional infants were recruited for this sample from the same population as the longitudinal sample. The breakdown on infants tested in each age group and reasons for exclusion are shown in Table 2. In earlier studies of the developmental course of habituation (Colombo et al., 1987a; Colombo & Mitchell, 1990), no carryover from repeated testings was evident on habituation tasks (i.e., comparison of cross-sectional and longitudinal samples did not yield significant differences). However, because the design of the current project involved a much higher density of assessment during the first year, with particularly short test–retest intervals, we believed the inclusion of these additional groups to be both advisable and worthwhile.

Stimuli

Stimuli were color slides of children's faces. Faces were chosen because they have been used previously with success across the first year of age. Indeed, nearly all of the developmental functions available for infant visual habituation have been derived from work with faces (Bornstein et al., 1988; Colombo & Mitchell, 1990; Mayes & Kessen, 1989). In addition, pilot data (Colombo, Frick, Gorman, & Casebolt, 1997) indicated that faces elicited robust and extended HR decelerations during looking, thus facilitating the delineation of HR-attentional phases (e.g., Richards, 1985) during individual fixations.

Fourteen faces were obtained from commercial sources, with one pair for each of the seven infant attention assessments, matched for ethnicity and hair color. Each pair was comprised of one male and one female face. During habituation, one of the faces from the chosen pair was rear-projected at midline (25° visual angle). During the paired-comparison tests, the pairs were presented (again, each at 25° visual angle) separated by 20° (i.e., each stimulus 10° off midline). So that it remained possible to conduct post hoc stimulus analyses on longitudinal patterns and overall look durations, the longitudinal sample was divided into seven groups (A–G) of approximately 30 infants each. Each group saw a particular order of faces across the longitudinal presentations, balanced in a partial Latin square. In this way, no infant ever saw a face more than once, and the presentation of each stimulus pair was balanced across ages. The gender of the pair presented during

TABLE 1
Longitudinal Sample Testing Details

Age (Months)	Infants Tested ^a	Habituation Session				Paired Comparison Session							
		Complete	State ^b	Parent ^c	Equipment ^d	Other ^e	Complete	State ^b	Parent ^c	Equipment ^d	Lateral Bias ^f	No Shifts	Other ^e
3	203	163	33	4	1	3	116	49	4	3	26	2	3
4	210	196	13	0	0	1	166	19	0	5	15	3	2
5	205	195	9	1	0	0	180	12	1	1	8	3	0
6	199	190	8	1	0	0	177	11	1	2	4	2	2
7	189	176	12	1	0	0	170	15	1	1	1	1	0
8	188	165	19	1	0	3	158	25	3	1	0	0	1
9	191	171	17	2	0	1	160	29	2	0	0	0	0
Totals	1,385	1,256	111	10	1	8	1,127	160	12	13	54	11	8
% of sessions		90.7	8.1	0.7	0.0	0.5	81.3	11.5	0.8	0.9	3.9	0.8	0.5

^aThis total does not include 8 premature infants (gestation less than 37 weeks) who were recruited into the longitudinal sample. These infants were followed along with the full-term sample. ^bIncludes fussiness, sleepiness, and other physiological events common to infancy during session. ^cLaboratory personnel stayed with infants during testing. Parents were encouraged to watch the session from another room. However, all were given the choice of staying with the infant during testing. If they did, parents were seated behind and out of sight of the infant and instructed to not interfere with sessions. On a few occasions, however, parents did speak to their infants during the session, and if this happened, we excluded the session. ^dEquipment failure; in all cases the failure of slides to advance properly. ^eIncludes rare events such as persistent inattention to displays, the infant holding a toy during the session, experimenter error (e.g., incorrect slide setup), or the insertion of a pacifier during a session. ^fIncludes infants who only looked to one lateral position (left or right) across both paired comparison trials. This results in a novelty preference of 0.50 that is not truly attributable to a failure in discrimination or recognition. ^gIncludes infants who looked to one lateral position for one entire paired comparison trial, and to the other lateral position on the other paired comparison trial. That is, the infant never looked to one of the stimuli during the test phase. Such behavior yields novelty preferences of either 0.00 or 1.00, neither of which likely reflects an accurate estimate of performance.

TABLE 2
Cross-Sectional Sample Details

Age	N	Preterm	Habituation Session				Paired-Comparison Session							
			Complete	State ^a	Parents ^b	Equipment ^c	Other ^d	Complete	State ^a	Parents ^b	Equipment ^c	Lateral Bias ^e	No Shift ^f	Other ^d
4	36	1	27	7	0	0	1	20	11	0	1	1	1	1
5	36	2	27	4	1	0	2	26	4	1	2	0	0	1
6	24	0	24	0	0	0	0	24	0	0	0	0	0	0
7	32	3	23	1	3	1	1	23	1	3	1	0	0	1
8	21	0	20	0	1	0	0	20	0	1	0	0	0	0
9	42	0	29	9	0	0	4	26	11	1	0	0	0	4
Total	191	6	150	21	5	1	8	139	27	6	4	1	1	7
%		3.1	78.5	11.0	2.6	0.5	4.2	72.8	14.1	3.1	2.1	0.5	0.5	3.7

^aIncludes fussiness, sleepiness, and other physiological events common to infancy during session. ^bLaboratory personnel stayed with infants during testing. Parents were encouraged to watch the session from another room. However, all were given the choice of staying with the infant during testing. If they did, parents were seated behind and out of sight of the infant and instructed to not interfere with sessions. On a few occasions, however, parents did speak to their infants during the session, and if this happened, we excluded the session. ^cEquipment failure; in all cases the failure of slides to advance properly. ^dIncludes rare events such as persistent inattention to displays, the infant holding a toy during the session, experimenter error (e.g., incorrect slide setup), or the insertion of a pacifier during a session. ^eIncludes infants who only looked to one lateral position (left or right) across both paired comparison trials. This results in a novelty preference of 0.50 that is not truly attributable to a failure in discrimination or recognition. ^fIncludes infants who looked to one lateral position for one entire paired comparison trial, and to the other lateral position on the other paired comparison trial. That is, the infant never looked to one of the stimuli during the test phase. Such behavior yields novelty preferences of either 0.00 or 1.00, neither of which likely reflects an accurate estimate of performance.

habituation was selected randomly for the first visit, and alternated at each subsequent testing.

Procedure

Infants were tested in a 2 m × 2 m room with walls and ceiling painted black. In the wall facing the infant was a 1.0 m × 0.7 m translucent rear-projection screen on which all visual stimuli were presented. Infants were placed in a car seat 0.8 m from the screen. Stimuli were presented with Kodak Ektagraphic carousel slide projectors. At the base of the screen, a Panasonic video camera was positioned to record the infant's face while watching the stimuli. The video feed from this camera was sent to a TV monitor so that an observer could code infants' looks during each of the periods. This feed was also directed to a VCR so that the session could be taped for archival and reliability purposes (discussed later).

Observers blind to stimulus identity during habituation and to the lateral positions of the novel and familiar stimuli on paired comparison trials watched the session on the monitor and coded looks online by pressing buttons that were interfaced with a microcomputer that timed looks, kept track of accumulated time, and controlled the slide projectors. This computer also sent signals to the HR data acquisition package interface (discussed later).

Habituation Protocol

Infants were habituated to stimuli using an infant-control sequence (Colombo et al., 1987a; Colombo, Mitchell, Coldren, & Freesean, 1991; Frick & Colombo, 1996), with a criterion of two consecutive looks at a 50% decrement from the previous longest look. For each trial, the habituation stimulus was presented until a valid fixation (i.e., defined as a look of 1 sec or more in duration) was obtained. The fixation was terminated when the infant looked away for 1 sec or more, at which point the stimulus was turned off. After an interstimulus period of 2 sec (during which the screen was dark), the stimulus was re-presented for the next trial. The look parameters were drawn from Colombo and Horowitz (1985).

Because nearly 40% of infants' habituation patterns are not characterized by a linear or logarithmic decline in looking across trials (see Bornstein & Benasich, 1986; Colombo et al., 1987a; McCall, 1979), a floating-point criterion was used in which the habituation criterion was recalculated if longer looks were encountered later in the habituation sequence.

Reliability for individual looks during habituation was collected on 611 (44%) sessions run by having a second observer (also blind to stimulus identity) code the videotaped session. Pearson correlations were computed within each individual session. These correlations averaged .96 and did not vary significantly across ages.

Paired Comparison Recognition Test

Following habituation, infants were tested for novelty preference in a paired-comparison phase. In each of two choice trials, the habituation stimulus was simultaneously paired with a novel one (the face from the opposite gender from the stimulus pair), with each of the two stimuli presented 10° to the left and right of midline (i.e., separated by a 20° visual angle). The initial positions of the novel and familiar targets were randomly chosen, and then reversed in the second choice trial relative to the first. Infants accumulated 10 sec of total looking in each choice trial at 3 and 4 months of age, and 5 sec of total looking in each choice trial at 5 through 9 months of age. The novelty preference was calculated as the proportion of the total time spent fixating the novel stimulus, relative to the total time spent looking to both the familiar and novel stimuli.

Reliability for novelty preferences was calculated by computing Pearson correlations between the novelty preferences obtained by the online observer and a second observer who coded the paired comparison phase from the videotape of the session. A total of 588 sessions (42%) were coded for reliability, and the mean correlation was .97. Reliability for novelty preference did not vary with age.

Measurement and Reduction of HR

HR was measured with shielded Ag-AgCl electrodes placed on either side of the infant's chest and grounded with an unshielded electrode just above the navel. The electrocardiogram (EKG) was digitized (250 Hz sample rate) through the use of a commercially available data acquisition package interface (BioPac, Inc., Santa Barbara, CA) that was custom configured for psychophysiological recording. The data acquisition interface also received input from a second microcomputer that controlled the timing and presentation of stimuli. In this way, the HR record could be synchronized with stimulus events and the coding of fixations.

Infants' HR was converted into a data file using BioPac software that identified and stored the time code of the *R* waves from the digitized EKG. The time codes from stimulus events (slide onsets and offsets) and infant behaviors (look onsets and offsets) were then interspersed among the *R*-wave time codes to provide a complete sequential record of the infant's session. The sequential file was then analyzed with custom software that parsed infants' looking into categories of OR, SA, and AT based on Richards's (1985) framework for defining different phases of attention from HR. We used Richards's definition of SA as at least 5 consecutive heartbeats below the median HR observed in a prestimulus period. OR was defined as that period of looking prior to the attainment of SA, and AT was defined as looking that continued after sustained attention, but during which HR returned to at least the prestimulus median baseline level.

At each age, infants' HR (taken from intertrial intervals, when no stimulus was present) was observed to increase across trials (all observed *F*s ranged from 9.6 to

40.2, each was significant at the $p < .001$ level, and each showed a linear trend that was significant at the $p < .001$ level). Thus, the use of a single baseline HR value across the entire habituation session for calculation of OR, SA, and AT was not appropriate. As such, we used the prestimulus period prior to the onset of the stimulus as the prestimulus period for each habituation trial. Custom software processed infants' HR during each trial, and was used to calculate the amount of time (in seconds) spent in OR, SA, and AT, and the percentage of time spent in each of these phases during looking. Calculation of this latter variable made it possible to control for expected changes in look duration across age. The computation of each of these phases was based on the attainment of SA during a look; therefore, if SA did not occur during any look, none of the HR-defined phases were classified or counted for that look. It should be noted, however, that every infant showed some SA at some point during every session, and so we were not forced to exclude any infant's session from analysis due to lack of SA. Finer grained analyses of the change of these phases within habituation sessions would have been far too unwieldy to present in this articles; these analyses will be explicated at some later point in a separate report.

Longitudinal Outcome Sessions

After the last habituation measurement at 9 months of age, infants were seen at 12, 18, and 24 months of age and administered the Bayley Scales of Infant Development II (BSID II; Bayley, 1993) and the MacArthur Communicative Development Inventory (MCDI; Fenson et al., 1994). These measures were chosen based on their appropriateness for the ages in question, and also because they had been used successfully as outcome measures in previous work on prediction (e.g., Lewis & Brooks-Gunn, 1981; Ruddy & Bornstein, 1982).

RESULTS

An Outline of the Section

Two primary sets of results are examined in this article. The first concerns the developmental courses of the measures of infant attention from the habituation and paired-comparison phases administered from 3 to 9 months of age. These developmental analyses are presented to determine whether previous findings have been replicated, and to establish normative patterns. The second set of analyses emphasize individual differences and address the primary issues of the study, such as what patterns of covariation exist across ages, and whether aggregate measures are correlated with outcomes at 12 to 24 months of age. We then ask whether particular patterns of change characterize groups of infants, what their concomitants are in

terms of HR-defined phases of attention, and whether these patterns of change in infant attention are related to differential outcomes in the same infants at 12 to 24 months of age.

Preliminary analyses were conducted to determine the effects of gender, stimulus order, stimulus pair, and stimulus gender on the primary dependent measures described next. None of these were statistically significant, and so they are not included as factors in the analyses reported here subsequently.

Developmental Course of Habituation Measures

Habituation Phase

Previous research (e.g., Colombo et al., 1987a) has shown that the duration of the peak, or longest look during the habituation sequence is the variable that drives the variance in most of the other duration measures (e.g., total looking, average looking) as well as all measures of habituation decrement and rate (Colombo & Mitchell, 1990). This measure also has a most robust developmental course and previous studies have reported moderately good psychometric properties. As such, we chose this as the primary duration variable for analysis in this study. Analyses run for total duration of looking, average look duration, and duration of first look yield the same results and inferences as for duration of peak look.

Figure 3 shows the developmental course for the peak, or longest look duration from the habituation sequence for both the longitudinal sample and the cross-sectional comparison samples. Both groups show significant declines in looking. The

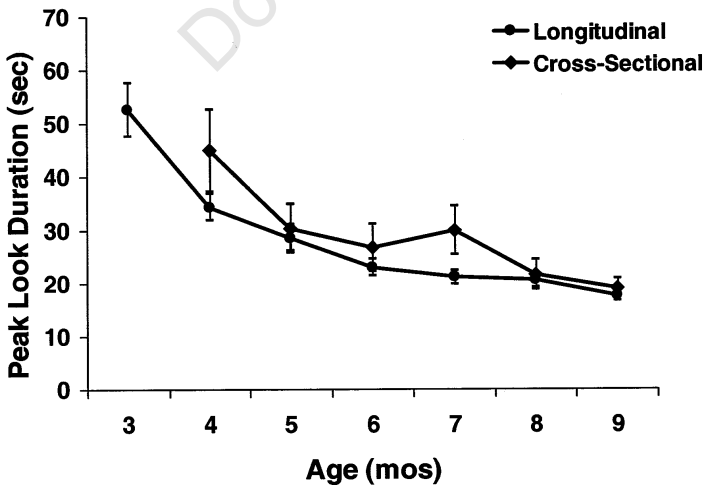


FIGURE 3 Developmental course for duration of peak look from habituation sequence. Bars represent standard errors.

longitudinal sample was tested using a repeated measures analysis using the 81 participants who had complete and usable data across all seven data points from 3 to 9 months. This analysis yielded a significant effect of age, $F(6, 74) = 5.23$, $p < .001$, characterized by significant linear ($p < .001$), quadratic ($p < .01$), and cubic ($p < .05$) trends.² The cross-sectional sample data were subjected to a one-way analysis of variance (ANOVA) with age group as a between-subject factor. This yielded a significant main effect, $F(5, 138) = 2.84$, $p = .016$, characterized solely by a significant linear ($p < .001$) trend. Although the cross-sectional sample tended to show slightly elevated look durations relative to the longitudinal sample, these differences did not attain statistical significance.

One other variable analyzed from the habituation sequence was the number of looks needed for infants to attain the habituation criterion. Neither the longitudinal nor the cross-sectional comparison groups showed significant effects of age on this variable. This finding is in contrast to Colombo and Mitchell's (1990) report that number of looks to criterion significantly increased with age. The mean number of looks to criterion was 6.66 for the longitudinal sample, and 7.08 for the cross-sectional samples, which again did not significantly differ from one another.

Given that the two major variables from the habituation session showed concordance across the longitudinal and cross-sectional samples, we were confident that there were no carryover effects for habituation for the longitudinal group.

Paired-Comparison Phase

Neither the longitudinal nor the cross-sectional comparison groups showed significant effects of age on novelty preference. However, given that the novelty preference can also be tested against an a priori chance expectation of .50, we tested each preference at each age against this value. Table 3 shows the results of these tests.

The two samples show somewhat different patterns of success on the novelty preference task. Infants in the longitudinal sample were not statistically different from chance at 3 months, marginally above chance at 4 months, and then significantly above chance at every other age until 9 months, at which point performance dropped again to chance levels. The overall novelty preference (calculated for infants who had usable data at all seven assessment points) was also significantly greater than chance. The cross-sectional samples showed statistically significant novelty preferences only at 7 and 8 months, but there is some commonality with the longitudinal sample, in that the developmental course

²A mixed-model analysis run with data from all of the participants yielded identical results to this: a significant ($p < .001$) change with age, characterized by highly significant linear and quadratic components, as well as a weaker (but significant, $p < .05$) cubic trend.

TABLE 3
Novelty Preference Results for Both Samples

Age	Longitudinal Sample			Cross-Sectional Sample		
	<i>M</i>	<i>N</i>	<i>t</i> Value vs. Chance (.50)	<i>M</i>	<i>N</i>	<i>t</i> Value vs. Chance (.50)
3	.499	116	0.05			
4	.519	166	1.70 ⁺	.506	20	0.18
5	.558	180	4.62***	.542	26	1.41
6	.544	177	4.04***	.504	24	0.18
7	.529	170	3.24***	.553	23	2.37*
8	.526	158	3.13**	.548	20	2.17*
9	.509	160	1.16	.536	26	1.41
Overall	.525	41	3.00*	.529	139	2.74**

⁺ $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

showed a similar inverted-U function. The changes in performance of the samples do not strictly or logically correspond to changes in the protocol for paired-comparison choice trial length (e.g., performance for young infants should be improved, not depressed, because of longer choice trials). Thus, we are inclined to interpret the developmental function as meaningful, especially for the longitudinal sample. Young infants were unable to discriminate or recognize the faces used, but in the majority of later assessments, infants were successful at this task. Of most interest is the drop-off in performance at 9 months that is evident in both the longitudinal and cross-sectional samples. The difficulty in discriminating or recognizing these faces is surprising, given that these were readily discriminated during the 4 preceding months. This finding suggests that, at these later ages, infants may have been responding to the stimulus class (i.e., “faces”) rather than to the particulars of the individual faces that we used. That is, by 9 months, infants may have been responding to the two faces presented on the choice trials as members of a single category. This interpretation is bolstered by the fact that the novelty preference measure has been previously used with success in tests of discrimination of nonface stimuli with 9-month-old infants (e.g., Jacobs, 2000; Jankowski & Rose, 1997).

Summary

The analyses of developmental course provide replication of some prior findings and some new information. First, the previously reported decline in look duration (Colombo & Mitchell, 1990; Mayes & Kessen, 1989) was robustly replicated here, although the curve for the longitudinal sample adds clear evidence for a plateau after 6 months, given the highly significant quadratic term. Second, prior suggestions of increases in looks to criterion by Colombo and Mitchell were not ob-

served. Although there were minor procedural differences between that study and this one, parsimony suggests simply that what Colombo and Mitchell reported may not be a phenomenon general to the development of habituation. Third, the curvilinear function for novelty preference seen across ages also raises some issues as to whether infants of different ages approach the stimulus pairings in discrimination or recognition tasks in the same manner. These data suggest that although the youngest infants at 3 months may have had difficulty with the face discrimination, infants from 4 to 8 months show fairly robust novelty preferences. The most parsimonious explanation for the disappearance of the discriminative response in the 9-month-olds, however, appears to be that they are responding to the novel exemplar presented during the choice trial as belonging to a general class of stimuli (i.e., “faces”), rather than to the particulars of individual exemplars that provide for discrimination. The fact that the same basic pattern of change appeared for the smaller cross-sectional sample supports this interpretation. If this is true, it has interesting implications for the investigation of categorization and perhaps for the development of face recognition.

Individual Differences

The next set of analyses run concerned individual differences in attention. Our fundamental strategy was to identify key indications of individual differences based on the behavioral variables (i.e., look duration) and then follow up findings of interest with analyses of the HR-defined phases of attention for convergence and validation.

Cross-Age Correlations

The first set of analyses run concerned the cross-age stability of the measures from the habituation and paired-comparison phases. First of all, none of the zero-order age-to-age correlations for number of fixations to criterion during the habituation phase or for infants’ novelty preferences during the paired-comparison phase attained conventional levels of statistical significance. The data for the peak look duration measure, however, did suggest some cross-age stability. Table 4 presents the data for peak look duration (Table 4a), amount of time and percentage of looking spent in OR (Tables 4b–c), amount of time and percentage of looking spent in SA (Tables 4d–e) and amount of time and percentage of looking spent in AT (Tables 4f–g).

Based on capitalization on chance, about one correlation should be significant in each of the matrices presented in Table 4. Each has at least three significant correlations and two matrices have nine. The significant correlations are mostly in the .20s, although some reach into the .40s. However, some patterns of significant stability are evident. For peak look, most of the adjacent ages are statistically significant, and there are five other significant correlations that span beyond 1 month. For

TABLE 4
Cross-Age Correlations

Age	4	5	6	7	8	9
a. Duration of peak look						
3	.21*	.17*	.11	.14	.08	.01
4		.25**	.30**	.08	.17*	.09
5			.04	.09	.08	-.01
6				.21**	.17*	.02
7					.15	.22*
8						.40***
b. Mean time in OR						
3	.06	.03	.02	-.06	.07	-.07
4		.07	.28**	.07	.07	.11
5			.21**	.17*	.01	.04
6				.06	.30**	.01
7					.03	.13
8						.11
c. Percentage of looking time in OR						
3	.05	.08	-.02	.08	.09	.03
4		.10	.08	.24**	.07	-.01
5			.10	.09	.07	.11
6				.24**	.14	.08
7					.16*	.29**
8						.22**
d. Mean time in SA						
3	.31**	.17**	.04	.18**	.02	-.00
4		.09	.24**	.08	.04	-.07
5			.05	.06	.12	.03
6				.29**	.24**	.13
7					.31***	.27***
8						.48***
e. Percentage of looking time in SA						
3	.06	.04	.16*	.00	.00	-.04
4		.04	.08	.03	.09	.00
5			.21**	.15	-.05	-.12
6				.13	.22**	.04
7					.01	.23**
8						.17*
f. Mean time in AT						
3	.27**	.10	.04	.14	.01	-.01
4		.04	.20**	.04	.15	-.12
5			.06	.00	-.04	.10
6				.13	.04	-.06
7					.11	.02
8						.21**

(continued)

TABLE 4 (Continued)

Age	4	5	6	7	8	9
g. Percentage of looking time in AT						
3	-.05	-.09	-.22**	.17	.02	.10
4		.08	.10	.06	.11	-.14
5			.11	.01	.04	.09
6				.16*	.15	-.05
7					.17*	.18*
8						.12

Note. Correlations are computed with all available valid data, so cell sizes vary. The minimum is 118 infants (from 3 to 9 months for some variables), and the maximum is 172 infants (from 4 to 5 months for some variables). OR = orienting; SA = sustained attention; AT = attention termination.

* $p < .05$. ** $p < .01$. *** $p < .001$.

the HR-defined phases of attention, time-based measures show more stability than do percentage-based measures, but the pattern of significance within each suggests the possible existence of some patterns of stability within certain age periods during the first year. At the same time, it is quite obvious that the measures do not show the robust stability common to the psychometric analyses of adult measures of cognition and intelligence.

Data Reduction

Peak look duration factor analysis, aggregates, and clusters. Given that the age-to-age correlations yielded some indications of stability and some suggestion of patterns of stability within certain ages, our next step was to reduce or aggregate the data further to prepare for analyses of predictive validity. Again, we began with the peak look duration, and we subjected the valid data from each age to a factor analysis using a principal components extraction and a varimax rotation.³ The analysis yielded two factors (see Table 5), which quite cleanly joined look durations at months 3, 4, 5, and 6 with one another (we called this factor early attention) and joined look durations at months 7, 8, and 9 together (we called this factor late attention).

Aggregate scores were formed for these age factors from the data available for each infant at these ages. This approach had the distinct advantage of yielding valid developmental data for 200 of the 226 infants enrolled in the study, and thus the greatest power and generalizability. The means for these aggregates showed a drop with age, from 32.82 sec ($SE = 1.78$) for the early factor ages to 19.43 sec ($SE = 0.81$) for the late factor ages. These were statistically significant from one another, $t(199) = 7.33$, $p < .001$, and were correlated modestly but significantly, $r(200) = .165$, $p < .01$.

³The result reported here is robust, irrespective of the rotation chosen to clarify the factors.

TABLE 5
Factor Analysis of Peak Look Duration for the Longitudinal Sample

Age	Factor A: Early Attention ^a	Factor B: Late Attention ^b
3	.563	.008
4	.725	-.073
5	.564	-.057
6	.521	.192
7	.214	.506
8	-.089	.734
9	-.274	.850

Note. This is the pattern matrix resulting from the direct oblimin rotation.

^aEigenvalue = 1.823. ^bEigenvalue = 1.362.

Aggregates were also calculated across these ages for the HR-defined phases of attention, and these are presented in Table 6. Because the ratio of SA to AT has been a variable of interest in past studies (Colombo et al., 2001), we calculated this and included it here as well.⁴ Mean time spent per look in OR and AT significantly decreased across these ages (as might be expected, given that look duration itself decreased), but it was somewhat surprising to observe that time spent in SA did not change. The calculations of percentage of time looking reinforce a picture of look durations becoming more efficient in terms of encoding and information intake as infants got older. Percentage of looking in OR did not change, but percentage of time in AT decreased significantly and percentage of time in SA increased significantly. Thus, given the widely held assumption that SA reflects active, engaged, and voluntarily directed attention, these results suggest that infants spent proportionately more time processing information, at the expense of time spent looking after having disengaged from the stimulus (as represented by the percentage of looking spent in AT). In support of this contention, the SA/AT ratio was observed to significantly increase across these ages. Finally, all variables were modestly but significantly correlated across these ages except for percentage of time in OR, percentage of time in AT, and the SA/AT ratio.

Finally, to examine different patterns of developmental change in these aggregates, we subjected the peak look duration aggregate to a cluster analysis (using Ward's method, with data standardized within cases). Using a series of stopping rules suggested by Green (1990) and the distribution of individual cases among

⁴The calculation of a ratio like this is problematic if the denominator (here, time in AT) is zero. Because some infants did in fact have no AT as part of their profiles at different ages, calculating this ratio without some sort of adjustment produces an inadvertent loss of data. As such, if AT was zero, we set the ratio equal to the value for time in SA (i.e., we set the value of AT in the denominator of the ratio to 1). Given that the actual score for such cases was infinity, this seemed to us to be a conservative practice that salvaged many cases of data over the entire longitudinal set. In any case, the results reported here are unchanged if cases where AT = 0 are excluded from the analysis.

TABLE 6
Means, Standard Errors, *t* Values, and Correlations for Heart-Rate-Defined Phases of Attention as a Function of the Early and Late Attention Factors

Variable	Early Factor (3–6 Months)		Late Factor (7–9 Months)		<i>t</i> (205)	<i>r</i> ^a
	<i>M</i>	<i>SE</i>	<i>M</i>	<i>SE</i>		
Mean time (sec) in OR per look	2.38	0.13	2.29	0.12	0.62	.205**
% of looking spent in OR	26.4	1.02	32.4	1.29	4.15***	.229***
Mean time (sec) in SA per look	6.55	0.37	4.25	0.19	5.98***	.181**
% of looking spent in SA	54.6	0.89	52.8	1.08	1.37	.080
Mean time (sec) in AT per look	3.21	0.26	1.64	0.13	5.70***	.147*
% of looking spent in AT	19.0	0.64	16.6	0.81	2.46**	.115
SA/AT ratio	3.74	0.41	6.52	0.71	3.36***	-.004

Note. OR = orienting; SA = sustained attention; AT = attention termination.

^a*n* = 206.

p* < .05. *p* < .01. ****p* < .001.

clusters as criteria, the best fitting solution yielded two clusters. In the larger cluster (*n* = 150), look duration decreased significantly from the early attention aggregate to the late attention aggregate. Given that this is the normative pattern for the entire sample, this cluster is hereafter referred to as the normative cluster. In the other, smaller cluster (*n* = 50), look duration actually increased from early to late attention ages. Because this is opposite of the normative trend, this group is hereafter referred to as the nonnormative cluster. The means for look durations for these two clusters are shown in Figure 4. It is worth noting that both clusters are significantly different from one another (*p* < .001) at both age points, and both show significant change across ages (*p* < .001). In addition, although the correlation between early and late look duration means for the whole sample accounted for about 4% of the variance (discussed earlier), the correlations between early and late means within clusters were substantially higher, *r*(150) = .37, *p* < .001 for the normative cluster, and *r*(50) = .75, *p* < .001 for the nonnormative cluster.

Novelty preference factor analysis and aggregate. Although none of the cross-age correlations for novelty preference attained statistical significance, we did perform the same factor analysis on novelty preferences that was described earlier for peak look duration. The scree plot suggested that only a single factor (eigenvalue = 1.259) was viable, and this factor was composed of novelty prefer-

ences at 4 and 6 months of age. These two ages loaded .656 and .734 on the factor, respectively; loadings for all of the other ages on this factor were less than .200. As we did for peak look, we formed an aggregate score for this factor from the data available for novelty preferences on each infant at 4 and 6 months of age.

Predictive Analyses

The next set of analyses addressed the degree to which these measures of the developmental course of attention in infancy were related to measures of standardized developmental outcome and language development in the second and third years.

Outcome norms. As noted previously, the outcome measures for this were the BSID II and MCDI. These were assessed at 12, 18, and 24 months of age. The BSID II yields two major scale scores: a mental index and a motor index. Because the MCDI has a somewhat different structure at 12 months than it does at 18 and 24 months, there is a somewhat different mix of measures at these ages. Table 7 shows that infants in this sample were neither particularly advantaged nor disadvantaged on these early outcome measures.

Zero-order correlations. Clearly, given the number of measures and ages at which measures were taken, the number of zero-order correlations available to compute was particularly high for this study. In addition, the examination of such

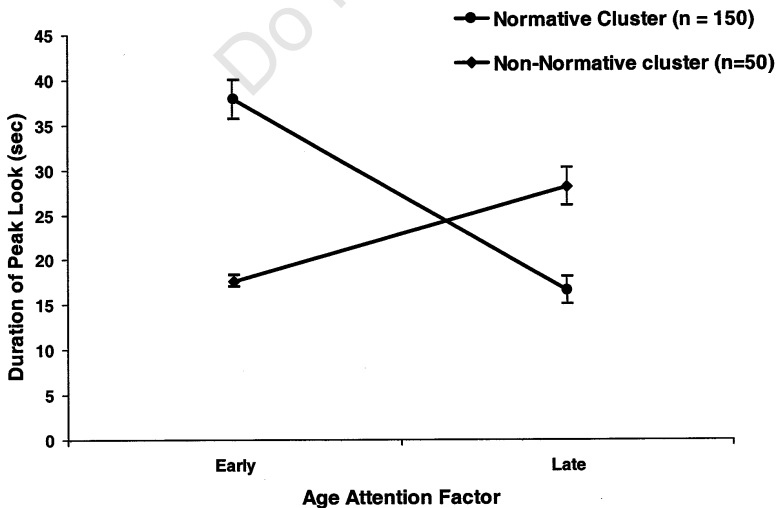


FIGURE 4 Mean peak look durations for normative and nonnormative clusters of infants. Bars represent standard errors.

TABLE 7
Outcome Measures at 12, 18, and 24 Months of Age

Measure	12 Months			18 Months			24 Months		
	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>	<i>N</i>	<i>M</i>	<i>SD</i>
BSID II									
Mental Index	191	99.0	9.52	181	100.8	13.09	167	104.6	13.05
Motor Index	191	95.8	14.39	179	95.0	11.59		99.9	13.25
MCDI: Continuous variables									
Words understood	178	43.6	26.86						
Words produced	178	6.8	7.83	153	81.3	78.92	144	284.8	169.52
Early gestures	178	11.0	2.77						
Later gestures	178	13.2	6.47						
Total gestures	178	24.2	8.43						
Irregular Words				153	0.9	1.42	144	4.6	4.90
Complexity				153	1.2	3.66	145	7.8	9.03
Overregularized words				153	0.2	1.27	144	2.4	7.13
Measure	12 Months			18 Months			24 Months		
	<i>N</i>	"Yes" Count	%	<i>N</i>	"Yes" Count	%	<i>N</i>	"Yes" Count	%
MCDI: Dichotomous variables									
Naming	178	178	100.0						
"No-no"	178	173	97.2						
"Mommy/Daddy"	178	173	97.2						
Imitates?	178	113	63.5						
Labeling?	178	41	23.0						
Refers to past event				153	48	31.4	144	109	75.7
Refers to future event				153	51	33.3	144	109	75.7
Absent object production				153	105	68.6	144	134	93.1
Absent object comprehension				153	143	93.5	144	140	97.2
Absent owner				153	105	68.6	144	136	94.4
Plural ("s")				153	38	24.8	144	99	68.8
Possessive ("s")				153	34	22.2	144	96	66.7
Present progressive ("ing")				153	7	2.8	144	72	50.0
Past tense ("ed")				153	4	1.6	144	44	30.6
Combining?				153	70	45.8	144	130	89.7

Note. BSID II = Bayley Scales of Infant Development II; MCDI = MacArthur Communicative Development Inventory.

zero-order correlations was not the primary focus of this investigation. As such, we sought to examine these in a limited way by examining correlations between aggregates of the infant attention measures suggested by the prior factor analyses reported earlier, and factors formed from a limited set of outcome measures. Three principal components factor analyses were run to create factor scores for the outcome measures to be used in the calculation of these zero-order correlations.

First, we factored the BSID II Mental scale scores at 12, 18, and 24 months. This produced only a single factor, with an eigenvalue of 2.181 and individual loadings of each age assessment above .80 on the factor. Then, we factored BSID II Motor scale scores at the same ages, which also yielded only one factor, with an eigenvalue of 1.82, and individual loadings of .70 for 12 months, and .81 for 18 and 24 months. Finally, we factored the raw language production from the MCDI (the only measure that is repeated across the three ages we tested). This also yielded a single factor with an eigenvalue of 2.15, and loadings above .80 for all three ages.

We then correlated the aggregates calculated for peak look duration (early = 3–6 months; late = 7–9 months) and novelty preferences (4–6 months) with these factor scores. The results are presented in Table 8, and do provide some support for the prior literature on the predictive value of infant attention. The late attention peak look aggregates are significantly and negatively correlated with BSID mental and motor factors, and the novelty preference aggregate is correlated with the MCDI production factor. Although these correlations are statistically significant and are in accord with previous reports linking long looking and lower novelty preferences with less optimal outcomes, these associations do not approach the values of .30 to .60 that have been reported in the prior studies (Colombo, 1993). The correlations reported in Table 8 represent aggregates of both predictor and criterion variables; it should be noted that when correlations are calculated for looking from individual ages during infancy to individual outcomes during toddlerhood, none account for more than 4.2% of the variance, and most do not attain statistical significance.

Predictive value of clusters from developmental course of habituation. The final set of analyses addressed the question of whether the developmental course of habituation measures across the first year were predictive of these outcome measures. To do this, we first examined the clusters formed from the look duration aggregates and how they related to the outcome measures at 12, 18, and 24 months. Because so few of the measures were repeated across all three ages, and

TABLE 8
Zero-Order Correlations Between Look Duration and Outcome Measures

<i>Outcome Measure</i>	<i>Peak Look Duration Aggregates</i>		<i>Novelty Preference Aggregate (4–6 Months)</i>
	<i>Early (3–6 Months)</i>	<i>Late (7–9 Months)</i>	
BSID Mental Index Factor	–.012	–.165*	.034
BSID Motor Index Factor	–.134	–.174*	.075
MCDI Production Factor	.094	–.055	.223*

Note. BSID II = Bayley Scales of Infant Development II; MCDI = MacArthur Communicative Development Inventory.

* $p < .05$.

because there were varying numbers of participants who completed testing, we addressed this using a series of *t* tests for the continuous measures from the BSID and MCDI (see Table 9), and chi-square tests for the dichotomous variables included on the MCDI (see Table 10).⁵

The general pattern of results shows consistently better outcomes for the normative cluster than for the nonnormative cluster. Furthermore, the difference between the clusters appeared to increase with the administration of the later outcome measures at 18 and 24 months. For example, at 12 months, only words produced on the MCDI was different as a function of cluster membership, and only the dichotomous measure of labeling was marginally significant. However, at 18 months, the BSID mental score was significant, as were MCDI production and complexity scores; reference to the absent owner of an object was significant as well, and reference to past events was marginally significant. By 24 months, the two clusters were differentiated by most of the continuous measures: the BSID mental score; MCDI production, irregular words, and complexity; reference to both past and future events; and use of past tense. Use of the present progressive (*-ing* inflection) was marginally significant for the two clusters. Thus, the predictive power of the infant attention measures increased as infants got older.

The data presented clearly indicated that the developmental course of look duration (as characterized by the early and late factor aggregates) identified groups of infants who were to perform at different levels on standardized outcome measures. Although the outcomes for both groups were generally within the normal range for both clusters, the groups were separated quite distinctly by 24 months of age, with the normative cluster scoring (on average) one third of a standard deviation higher on the BSID, and producing (on average) 72 words more on the MCDI than the nonnormative cluster.

Given that these clusters based on the behavioral measures were predictive of later standardized outcomes, the next logical question was whether the clusters were also differentiated by the HR-delineated measures of attention. The data reported in Table 11 show that they were. Age factor (early or late) \times cluster (normative or nonnormative) analyses were run for amount of time per look and percentage of total looking spent in OR, SA, and AT, and the SA/AT ratio.

Each of the analyses for amount of time per look yielded statistically significant Age \times Cluster interactions. For the normative cluster, the amount of time spent in OR, AT, and SA decreased significantly for the normative cluster from early to late attention. For the nonnormative cluster, all three components increased significantly for the nonnormative cluster. However, these are to be expected, given that amount of time spent in these phases will covary with the pattern of change in look duration.

⁵The use of multivariate analyses of variance to conduct repeated measures analysis for BSID or MCDI outcomes reduced the sample size by one half. Although many of the effects observed here still attain statistical significance, we opted to present analyses that used all of the available data.

TABLE 9
Peak Look Duration Aggregate Clusters and Continuous Outcome Measures From the BSID and MCDI

Age	Instrument	Outcome Measure	Cluster A			Cluster B			t Value
			N	M	SE	N	M	SE	
12 months	BSID	Mental Index	139	99.2	0.82	44	97.7	1.36	0.89
		Motor Index	138	96.0	1.26	44	95.7	2.08	0.14
		Phrases	134	13.8	0.53	36	12.8	1.11	0.89
	MCDI	Words understood		79.9	5.12		65.8	9.93	1.27
		Words produced		7.3	0.74		5.2	0.73	2.01*
		Early gestures		11.0	0.23		11.0	0.23	0.37
18 months	BSID	Late gestures		13.0	0.54		14.0	1.28	0.80
		Total gestures		24.0	0.70		25.0	1.72	0.66
		Mental Index	130	101.7	1.11	43	97.2	2.10	1.96*
	MCDI	Motor Index	129	95.4	0.97	42	93.0	1.98	1.18
		Words produced	112	90.5	8.07	35	57.7	8.75	2.76**
		Irregular words		0.93	0.14		0.69	0.19	0.87
24 months	BSID	Overregularized words		0.27	0.13		0.20	0.15	0.27
		Complexity		1.43	0.39		0.49	0.27	1.99*
		Mental Index	123	105.3	1.18	36	100.3	2.12	2.06*
	MCDI	Motor Index	121	100.5	1.18	37	97.6	2.35	1.17
		Words produced	107	296.6	17.17	31	224.7	23.21	2.49**
		Irregular words		5.0	0.52		2.9	0.53	2.82**
		Overregularized words		2.6	0.77		1.9	0.72	0.44
		Complexity		8.7	0.95		4.9	0.98	2.81**

Note. BSID = Bayley Scales of Infant Development; MCDI = MacArthur Communicative Development Inventory.
* $p \leq .05$. ** $p < .01$.

TABLE 10
Peak Look Duration Clusters and Dichotomous Outcome
Measures From the MCDI

Age (in Months)	Variable	Cluster A		Cluster B		$\chi^2(1)$
		No	Yes	No	Yes	
12	Naming	0	134	0	36	—
	“No-no”	4	130	1	34	0.00
	“Mommy/Daddy”	4	130	0	6	1.10
	Imitation	49	85	12	24	0.13
	Labeling	99	35	32	4	3.62+
18	Past events	72	40	28	7	3.03+
	Future events	70	42	26	9	1.64
	Absent object production	32	80	13	22	0.92
	Absent object comprehension	7	105	2	33	0.01
	Absent owner	28	84	18	17	8.66**
	Use of plural (“s”)	82	30	27	8	0.22
	Use of possessive (“’s”)	86	26	28	7	0.16
	Use of present progressive (“ing”)	106	6	34	1	0.37
	Use of past tense (“ed”)	108	4	35	0	1.29
	24	Past events	23	84	12	18
Future events		23	84	12	18	4.22*
Absent object production		7	100	3	27	0.41
Absent object comprehension		3	104	1	29	0.23
Absent owner		5	102	3	27	1.21
Use of plural (“s”)		33	74	11	19	0.37
Use of possessive (“’s”)		37	70	10	20	0.02
Use of present progressive (“ing”)		51	56	20	10	3.39+
Use of past tense (“ed”)		71	36	26	4	4.68*

Note. MCDI = MacArthur Communicative Development Inventory.

+ $p < .10$. * $p < .05$. ** $p < .01$.

The analyses for percentage of time spent in the phases suggest some surprising changes for both the normative and nonnormative clusters. The Age \times Cluster analysis for OR yielded a significant two-way interaction, with OR increasing for the normative cluster but remaining unchanged for the nonnormative cluster. This was somewhat unexpected, and might be taken to suggest that the normative cluster was slower to engage attention than the nonnormative cluster. However, we believe that this might be better viewed in light of the emergence of endogenously driven attentional processes during the end of the first year (see Colombo, 2001). The increased latency to decelerate (relative to look length) may be taken to reflect a more voluntary deployment of attention in the infants from this cluster. That is, infants in the normative cluster may be less likely to be “captured” by the stimulus and automatically engaged (as is typically the case with younger infants), and may

TABLE 11
Heart-Rate-Defined Phases for the Look Duration Aggregate Clusters

Variable	Normative Cluster ^a		Nonnormative Cluster ^b		Age × Cluster Interaction <i>F</i> (1, 196)
	Early Attention	Late Attention	Early Attention	Late Attention	
Amount of time spent per look in					
OR	2.70	2.13	1.85	2.60	13.05***
SA	7.87	3.86	4.28	5.80	44.14***
AT	4.18	1.45	1.56	2.89	44.09***
% of time looking spent in					
OR	25.5	34.0	28.8	27.6	8.70**
SA	54.1	52.9	56.6	52.1	1.10
AT	20.4	14.7	14.6	22.6	45.86***
SA/AT ratio	3.39	7.59	4.80	3.51	8.76**

Note. For amount of time spent per look, all tests for heart-rate-defined phases of attention across ages within clusters (i.e., normative cluster from early to late and nonnormative cluster from early to late) and all tests for heart-rate-defined phases of attention across clusters within ages (i.e., early attention, normative cluster vs. nonnormative cluster; late attention, normative cluster vs. nonnormative cluster) attain the $p < .001$ level of statistical significance. For percentage of time looking, OR increases ($p < .01$) for the normative cluster but does not change for the nonnormative cluster. SA does not change significantly for either cluster, and AT decreases significantly ($p < .001$) for the normative cluster but increases significantly ($p < .001$) for the nonnormative cluster. OR = orienting; SA = sustained attention; AT = attention termination.

^a $n = 150$. ^b $n = 50$.

** $p < .01$. *** $p < .001$.

be involved in some appraisal process prior to an endogenous decision to engage in information processing. This interpretation is reinforced by the fact that the amount of time spent in OR actually follows a curvilinear developmental course, with an increase from 6 to 9 months of age (Colombo, Richman, Shaddy, & Maikranz, 2003). Interestingly, there were no effects for the SA analysis; both clusters spent a majority of their time looking in SA (about 54%) and this remained constant across these ages. However, the developmental courses for percentage of time spent in AT were very different for the two clusters, as the Age × Cluster interaction attained the $p < .001$ level of significance. The percentage of time spent in AT significantly decreased ($p < .001$) for the normative cluster but significantly increased for the nonnormative cluster.

Finally, during early attention, although the SA/AT ratio for the normative and nonnormative cluster did not differ significantly, they did at the later ages; the SA/AT ratio doubled from early to late attention in the normative cluster but did not change for the nonnormative cluster. This suggests overall that the normative cluster became more efficient in their looking across ages, but the nonnormative cluster did not.

Confirmation of effects with complete data sets. These results were important and interesting. They were based on infants' aggregate scores suggested by the factor analysis of peak look duration at different ages; these aggregates were computed under conditions in which infants were missing data at various ages. As such, we sought to confirm the generality and validity of this finding by analyzing the subset of infants ($n = 78$) on whom complete longitudinal sets of data from habituation were available to the same analytic steps. The point of this analysis was to determine whether this analysis would also yield a group of infants with look duration that showed a nonnormative path over the first year, and whether that group would also show less optimal outcomes.

As such, we subjected all of these infants' peak looks from ages 3 to 9 months to a cluster analysis (again, using Ward's method, and standardizing scores within case). A number of roughly equivalent solutions emerged, based on the stopping rules described by Green (1990). The solution that provided most groups and a good distribution of infants was a four-group solution; the mean peak look durations for these four groups are shown in Figure 5. Clusters A ($n = 24$) and B ($n = 15$) most closely conformed to the pattern of the normative cluster from the aggregate analysis described previously, and Cluster D ($n = 18$) resembles the nonnormative cluster from the aggregate analysis. Cluster C ($n = 21$) showed irregular increases and decreases across the first year, although the general trend is toward a decline in looking.

Analyses of these groups' performance on the outcome measures mirrored the finding of the analyses for the clusters derived from the peak look duration aggregates, in that the clusters were not particularly differentiated early on; that is, at 12 months, only the MCDI Phrases measure was significantly different, $F(3, 67) = 3.41$, $p < .05$, with Cluster D lagging behind on this measure. However, at 24 months, a number of significant differences were observed, all favoring Clusters A and B, and showing a clear disadvantage for infants belonging to Cluster D, particularly with respect to language outcomes. Cluster C generally scored in intermediary positions. These included the BSID II Mental scale, $F(3, 59) = 2.85$, $p < .05$, with respective means for Clusters A, B, C, and D of 102.2, 111.9, 102.4, and 96.3; the MCDI production variable, $F(3, 52) = 4.06$, $p < .01$, with respective means of 360.5, 344.3, 239.5, and 173.8; the MCDI irregular words variable, $F(3, 52) = 2.35$, $p < .01$, with means 8.2, 6.2, 3.1, and 1.8; and the MCDI complexity score, $F(3, 52) = 3.21$, $p < .05$, with means 9.8, 14.3, 6.8, and 3.4. In addition, the MCDI overregularized words was marginally significant, $F(3, 52) = 2.35$, $p = .08$, with means of 3.7, 3.9, 0.9, and 1.1.

Thus, these results validate the predictive results observed for the entire sample, in that infants showing a pattern of increasing look duration across the first year performed least well of all the clusters identified. Indeed, at 24 months, Cluster D attained only the 29th percentile for MCDI production, the 29th percentile for MCDI irregular words, and the 36th percentile for the complexity score. In addi-

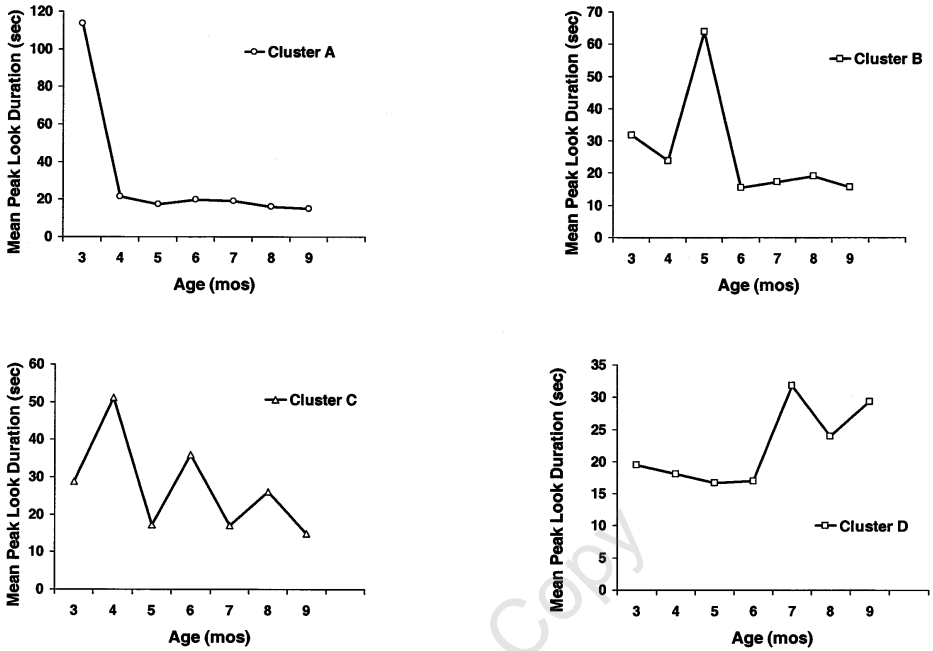


FIGURE 5 Peak look durations for Clusters A, B, C, and D.

tion, however, these results also identify the clusters showing drops to very low levels of look duration toward the end of the first year as having the most advantageous outcomes. On average, Cluster A scored above the 50th percentile on all MCDI variables that could be converted to percentiles, and Cluster B scored close to or above the 60th percentile on these variables.

Summary

The results of the individual difference analyses have revealed several new findings with regard to infant attention and its relation to early cognitive and language outcomes. First, the zero-order cross-age correlations were positive but quite modest in magnitude. A factor analysis of look duration from habituation, however, yielded quite clear evidence of a transition between 6 and 7 months of age. When novelty preference was similarly factored, only one robust factor emerged, which included infants' recognition performance at 4 and 6 months of age. Based on these indications of coherence, we averaged available data for infants from those ages to form aggregate scores, and used them first in correlational analyses that sought to determine their association with outcomes at 12, 18, and 24 months, and then in cluster analyses that sought to determine whether particular changes in the direction of look duration from early to late aggregates were related to the same outcomes.

The correlational analyses yielded significant but again quite modest relations between the look duration and novelty preference aggregates. These generally supported extant reports, in that shorter looking (at least on the late attention aggregate) was related to higher BSID performance, as represented by a factor score calculated from administrations of the BSID at all three ages. Furthermore, higher novelty preference on the 4- to 6-month aggregate was associated with higher language production, again as represented by a factor score calculated from administrations of the MCDI at all three ages. However, the level of prediction offered by the correlation of these static measures was much lower than had been suggested by compilations of previous research reports (e.g., Bornstein & Sigman, 1986; Colombo, 1993; McCall & Mash, 1995).

Cluster analyses identified groups of individual infants whose looking either resembled the normative pattern ($n = 150$) or did not (the nonnormative pattern, $n = 50$). Infants in the normative cluster performed better than infants in the nonnormative cluster on all of the outcome measures on which differences were observed. In fact, the separation between the groups increased appreciably with later outcomes. For example, although the clusters were differentiated on very few measures at 12 months of age, the groups were particularly disparate by 24 months. Analyses of HR-defined phases of attention for the two clusters suggested that attention shown later in the first year by the normative cluster may be more endogenously driven and was much more efficiently organized than that shown by the nonnormative cluster. This general finding was confirmed and extended by the same analytic strategy used for infants who contributed complete data sets from habituation sessions run from 3 to 9 months of age ($n = 78$).

DISCUSSION

This article reports the results of a major prospective study seeking to examine the relation between infant visual habituation and recognition performance with cognitive and language outcome measures in early childhood. It is the first study to incorporate simultaneous measurement of HR with behavioral measures of attention in such an endeavor, and the first to focus on the developmental course of attentional measures as the primary variable in the prediction of later outcomes. The strengths of the study are in its large sample size, its intensive measurement strategy, and its highly standardized protocol. A weakness in this report is that the outcome measures reported to this point only extend to 2 years of age. Furthermore, the outcome measures themselves include the BSID, which is a standardized test with a long-term predictive outcome that is still somewhat uncertain, and the MCDI, which is an instrument for assessing early communicative levels based on parent report.

Normative Analyses

The report of normative developmental functions serves to replicate extant reports on the course of measures from infant visual habituation, but also to provide some new information. The developmental course for look duration (here, represented by the duration of infants' longest, or peak look from the habituation sequence) is much as expected (Colombo & Mitchell, 1990; Mayes & Kessen, 1989), with longer looking on average at 3 months, and a linear drop down to 6 months, after which the course reaches asymptote. Prior reports concerning the existence of an increase in looks to habituation criterion with age (Colombo & Mitchell, 1990) were not replicated.

Analysis of the developmental course of recognition (as measured by novelty preferences) yielded the interesting finding of an inverted-U function. This was unexpected, as prior research had clearly indicated that the paired-comparison method would be appropriate for infants at the upper range of the ages tested here. This finding suggested that novelty preferences reflected different cognitive processes at different points in time. It is our contention that the failure of the youngest infants to show novelty preferences above chance reflects difficulty in discrimination. These early difficulties were subsequently displaced by robust performance above chance, showing that infants readily discriminated stimulus pairs. However, significant novelty preferences disappeared at 8 and 9 months for stimuli that were readily discriminated (according to group-based inferential tests) during the earlier months. This latter phase of responding was most interesting; it is our hypothesis that this apparent random level of responding was not driven by a regression in infants' ability to discriminate targets. Rather, we speculate that this pattern of results was driven by the fact that older infants were responding to the face pairs as a stimulus class or category of "face," rather than as a pair of exemplars to be discriminated. This implies that chance-level responding in older infants tested with the paired-comparison procedure may not necessarily reflect a failure to discriminate or recognize stimuli, especially if stimuli belong to a class with which infants have become overly familiarized.

The discussion of infants' apparent coding of facial stimuli in a categorical or stimulus-class manner at older ages presents an opportunity to caution readers concerning the interpretation of these normative data. All data collected for this article were obtained with facial stimuli. It is worth noting some researchers regard faces as being subject to specialized perceptual processing that may be innately determined to different degrees (e.g., de Haan, Humphries, & Johnson, 2002; Nelson, 2001). The current database does not provide any means for directly testing any hypotheses about face processing, although the developmental trends reported here for faces have also been observed with various nonface stimuli as well (e.g., Colombo et al., 1999).

Individual Differences Analyses

The findings with respect to individual differences in attention and their predictive validity also shed additional light on extant issues, as well as provide new information. Earlier summaries of the literature have suggested that infant attentional measures across the entire first year are moderately correlated with later outcomes. More recent work, however, suggests relations of a far more modest magnitude (e.g., Hood et al., 1996; Laucht, Esser, & Schmidt, 1994). This study generally confirms this latter trend, in that significant correlations were found in the appropriate directions for look duration and novelty preference, but that such correlations were only observed for widely aggregated measures. Furthermore, the magnitude of these correlations was quite modest, in most cases falling at or below .20. As such, these results would argue against the use of measures of infant attention as static psychometric surrogates for childhood IQ. That is, one should not expect that look duration reflects the same underlying constructs at different points in infancy, nor should one expect that the relation from infancy to childhood is attributable to the persistence of a constant, continuous, underlying dimension of cognitive function. Implicit in this conclusion is the corollary that neither should one expect a single measure taken at a single point in time to make a significant prediction of later intellectual or cognitive outcome. This latter must be regarded as a tentative conclusion that will be addressed in subsequent reports that feature more meaningful outcomes in both the cognitive and language domains.

Prediction From the Developmental Course of Habituation

Novel findings from these analyses concern the predictive validity of the developmental function for look duration, and the accompanying functions for Richards's HR-defined phases of attention (i.e., OR, SA, and AT). Essentially, analyses based on aggregate data for 200 of the 226 infants in the longitudinal sample indicate that a nonnormative pattern of increasing look duration from 3 to 9 months is associated with poorer outcomes in early childhood, and that HR-based analyses of attention for infants showing the nonnormative pattern indicate less efficient processing and possibly less endogenously driven attentional processes. The pattern of prediction offered by the developmental course resembles a "sleeper effect," in which clusters were not particularly different at 12 months, but increasingly diverged in developmental outcome as the follow-up assessments progressed to 24 months of age. This pattern was most apparent for the continuous outcome variables (which include both BSID and MCDI subscales and scores), but was also evident to some degree on the dichotomous MCDI items. Further analyses on the 78 infants who successfully completed all seven of the monthly attentional protocols from 3 to 9 months bolster the conclusions drawn from the aggregate data from the entire sample.

The findings for the clustering and predictive validity of the developmental course were somewhat unexpected. The results suggest the existence of two qualitatively different patterns of development, which are related to moderately different outcomes as infants enter early childhood. The look durations for the two clusters show very different patterns of change from the early phase (i.e., 3–6 months) to the later phase (i.e., 7–9 months). The largest cluster shows the expected normative trends of look duration decreasing over time. Analysis of concomitant HR patterns indicates that the decrease in look duration is associated with increased facility in disengagement of attention (i.e., decreases in the amount and proportion of time spent looking in AT), decreases in the amount of time spent encoding the stimulus (i.e., decreases in the time spent in SA), and perhaps the emergence of voluntary control over the engagement of attention (i.e., increases in the proportion of time spent in OR). On the other hand, the behavior of a smaller cluster of infants (which was confirmed in an analysis of babies who successfully completed all attention assessments from 3–9 months) shows a significant increase in looking across infancy. The HR data do not definitively identify the particular attentional components responsible for this. The amount of time spent in OR, SA, and AT all show significant increases for this cluster; when considered in terms of proportion of look duration, only AT changes (increases) significantly. It is tempting to simply characterize this cluster's information processing as becoming less efficient over time (this is suggested by the SA/AT ratio), needing more time to encode and more time to disengage attention during looks, but it is somewhat difficult to reconcile this with the fact that the nonnormative cluster showed less of both SA and AT than the normative cluster during early attention.

Alternative interpretations of the mechanisms at work within the nonnormative cluster would, at this point, rest within the realm of speculation. One possibility, however, is that the constructs of attention that we have analyzed and characterized actually represent different processes for the normative cluster than for the nonnormative cluster. For example, we have interpreted brief looking as representing rapid encoding for the normative cluster. However, for the nonnormative cluster, brief looking seen during early attention may represent some difficulty in coming to or maintaining an attentive state, similar to the attentional difficulties posited to occur for very young infants (Colombo, 2001, 2002). If that is true, then the increase seen for the nonnormative cluster from the early to late attention factors may actually represent some extension of the initial increase in look duration represented by the far left-hand portion of the developmental course represented in Figure 1.

SUMMARY AND CONCLUDING REMARKS

In both predictive analyses involving clusters characterized by specific developmental courses, trends toward more efficient processing were associated with

more optimal outcomes in the second year of life. This outcome implies that a purely psychometric approach to infant attention and its predictive validity is probably untenable. Instead, an approach involving a developmental systems model (e.g., Colombo, 2002; Colombo, Shaddy, & Richman, 2000) might be more appropriate for both conceptualization of prediction and its analysis. If this is the case, such a model would necessarily involve the measurement of the environment in tandem with the measurement of the infant (Colombo & Saxon, 2002), and this would appear to be the clearest direction for future studies. This has been done to some degree in the past (e.g., Tamis-LeMonda & Bornstein, 1989), but not to the intensive degree suggested by the current data set; nor has it been done from a developmental framework (e.g., see Saxon, Colombo, Robinson, & Frick, 2000).

ACKNOWLEDGMENTS

This research was funded by Grant R01 HD35903 to John Colombo and supported in part by the University of Kansas Center for Research. We are grateful first and foremost to the 417 families who participated in this project, and then to the staff of the University of Kansas Regents Center at the Edwards Campus for their assistance with this research. Andrea Greenhoot provided statistical consultation. Les Cohen, Janet Frick, Paul Atchley, Jim Juola, and Joan McDowd made various suggestions concerning interpretation and analysis at various points in this process. Christa Anderson and Kathleen Kannass assisted us with data coding and entry. Steven Warren, Director of the Schiefelbusch Institute for Life Span Studies, unfailingly supported our research program during some difficult and trying times. Finally, we are especially grateful to John E. Richards for his time and assistance with analysis of the heart-rate-defined phases for this project.

REFERENCES

- Adams, R. (1987). An evaluation of color preference in early infancy. *Infant Behavior and Development, 10*, 143–150.
- Bayley, N. (1993). *Manual for the Bayley Scales of Infant Development* (2nd ed.). San Antonio, TX: Psychological Corporation.
- Bornstein, M. H. (1984, April). *Infant attention and caregiver stimulation: Two contributions to early cognitive development*. Paper presented at the biennial International Conference on Infant Studies, New York.
- Bornstein, M. H. (1985). How infant and mother jointly contribute to developing cognitive competence in the child. *Proceedings of the National Academy of Sciences (USA), 82*, 7470–7473.
- Bornstein, M. H., & Benasich, A. A. (1986). Infant habituation: Assessments of short-term reliability and individual differences at five months. *Child Development, 47*, 87–99.
- Bornstein, M. H., Pecheaux, M. G., & Lecuyer, R. (1988). Visual habituation in human infants: Development and rearing circumstances. *Psychological Research, 50*, 130–133.

- Bornstein, M. H., & Sigman, M. D. (1986). Continuity in mental development from infancy. *Child Development, 57*, 251–274.
- Casey, B. J., & Richards, J. E. (1988). Sustained visual attention in infants measured with an adapted version of the visual preference paradigm. *Child Development, 59*, 1514–1521.
- Colombo, J. (1993). *Infant cognition: Predicting childhood intellectual functioning*. Newbury Park, CA: Sage.
- Colombo, J. (1997). Individual differences in infant cognition: Methods, measures and models. In J. Dobbins (Ed.), *Developing brain and behavior: The role of lipids in infant formulas* (pp. 339–385). London: Academic.
- Colombo, J. (2001). The development of visual attention in infancy. *Annual Review of Psychology, 52*, 337–367.
- Colombo, J. (2002). Infant attention grows up: The emergence of a developmental cognitive neuroscience perspective. *Current Directions in Psychological Science, 11*, 196–199.
- Colombo, J., Frick, J. E., Gorman, S. A., & Casebolt, K. (1997, April). *Heart rate patterns during infant-controlled habituation sessions*. Paper presented at the annual meeting of the Society for Research in Child Development, Washington, DC.
- 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., Harlan, J. E., & Mitchell, D. W. (1999, April). *The development of look duration in infancy: Evidence for a triphasic course*. Paper presented at the annual meeting of the Society for Research in Child Development, Albuquerque, NM.
- Colombo, J., & Horowitz, F. D. (1985). A parametric study of the infant control procedure. *Infant Behavior and Development, 8*, 117–121.
- Colombo, J., & Mitchell, D. W. (1990). Individual and developmental differences in infant visual attention. In J. Colombo & J. W. Fagen (Eds.), *Individual differences in infancy* (pp. 193–227). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Colombo, J., Mitchell, D. W., Coldren, J. T., & Freese, L. J. (1991). Individual differences in infant attention: Are short lookers faster processors or feature processors? *Child Development, 62*, 1247–1257.
- Colombo, J., Mitchell, D. W., O'Brien, M., & Horowitz, F. D. (1987a). 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. (1987b). Stimulus and motoric influences on visual habituation at three months. *Infant Behavior and Development, 10*, 173–181.
- Colombo, J., Richman, W. A., Shaddy, D. J., Greenhoot, A. F., & Maikranz, J. (2001). HR-defined phases of attention, look duration, and infant performance in the paired-comparison paradigm. *Child Development, 72*, 1605–1616.
- Colombo, J., Richman, W. A., Shaddy, D. J., & Maikranz, J. M. (2003, April). *Heart-rate defined phases of attention during visual habituation across the first year: What habituates in habituation?* Poster presented at the meeting of the Society for Research in Child Development, Tampa, FL.
- Colombo, J., & Saxon, T. (2002). Infant attention and the development of cognition: Does the environment moderate continuity? In H. Fitzgerald, K. Karraker, & T. Luster (Eds.), *Infant development: Ecological perspectives* (pp. 35–60). Washington, DC: Garland.
- Colombo, J., Shaddy, D. J., & Richman, W. A. (2000). Cognition, development, and exceptional talent in infancy. In R. Friedman & B. Shore (Eds.), *Talents unfolding: Cognition and development* (pp. 123–148). Washington, DC: American Psychological Association.
- de Haan, M., Humphreys, K., & Johnson, M. H. (2002). Developing a brain specialized for face perception: A converging methods approach. *Developmental Psychobiology, 40*, 200–212.
- Fagan, J. F. (1981). Infant intelligence. *Intelligence, 5*, 239–243.
- Fagan, J. F. (1984a). The intelligent infant: Implications. *Intelligence, 8*, 1–9.

- Fagan, J. F. (1984b). The relationship of novelty preferences during infancy to later intelligence and recognition memory. *Intelligence*, 8, 339–346.
- Fagan, J. F., & McGrath, S. K. (1981). Infant recognition memory and later intelligence. *Intelligence*, 5, 121–130.
- Fagen, J. W., & Ohr, P. S. (1990). Individual differences in infant conditioning and memory. In J. Colombo & J. W. Fagen (Eds.), *Individual differences in infancy* (pp. 155–192). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., & Pethick, S. J. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development*, 59(Serial No. 242).
- 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.
- Frick, J. E., Colombo, J., & Saxon, T. F. (1999). Individual and developmental differences in disengagement of fixation in early infancy. *Child Development*, 70, 537–548.
- Green, J. (1990). Analyzing individual differences: Correlations and cluster analysis. In J. Colombo & J. W. Fagen (Eds.), *Individual differences in infancy: Reliability, stability, and prediction* (pp. 77–112). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Greenberg, D. J., & Weizmann, F. (1971). The measurement of visual attention in infants: A comparison of two methodologies. *Journal of Experimental Child Psychology*, 11, 234–243.
- Hood, B. M. (1995). Shifts of visual attention in the human infant: A neuroscientific approach. In L. Lipsitt & C. K. Rovee-Collier (Eds.), *Advances in infancy research* (Vol. 9, pp. 163–216). Norwood, NJ: Ablex.
- Hood, B. M., Murray, L., King, F., & Hooper, R. (1996). Habituation changes in early infancy: Longitudinal measures from birth to 6 months. *Journal of Reproductive and Infant Psychology*, 14, 177–185.
- Jacobs, S. E. (2000). Visual recognition memory for objects in six- and nine-month-old infants. *Occupational Therapy Journal of Research*, 20, 271–285.
- Jacobson, S. W., Chiodo, L. M., & Jacobson, J. L. (1996, April). *Predictive validity of infant recognition memory and processing speed to 7-year IQ in an inner-city sample*. Paper presented at the biennial International Conference on Infant Studies, Providence, RI.
- Jankowski, J. J., & Rose, S. A. (1997). The distribution of visual attention in infants. *Journal of Experimental Child Psychology*, 65, 127–140.
- Kagan, K. (1971). *Change and continuity in infancy*. Oxford, England: Wiley.
- Laucht, M., Esser, G., & Schmidt, M. H. (1994). Contrasting infant predictors of later cognitive functioning. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 35, 649–662.
- Lewis, M. E., & Brooks-Gunn, J. (1981). Visual attention at three months as a predictor of cognitive functioning at two years of age. *Intelligence*, 5, 131–140.
- Mayes, L., & Kessen, W. (1989). Maturation changes in measures of habituation. *Infant Behavior and Development*, 12, 437–450.
- McCall, R. B. (1979). Individual differences in the pattern of habituation at 5 and 10 months of age. *Developmental Psychology*, 15, 558–568.
- McCall, R. B. (1994). What process mediates prediction of childhood IQ from infant habituation and recognition memory? Speculations on the roles of inhibition and rate of information processing. *Intelligence*, 18, 107–124.
- 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.
- McCall, R. B., & Mash, C. (1995). Infant cognition and its relation to mature intelligence. In G. Whitehurst (Ed.), *Annals of child development* (Vol. 11, pp. 27–56). New York: JAI.
- Miller, D., Ryan, E., Short, E., Ries, P., McGuire, M., & Culler, M. (1977). Relationships between early habituation and later cognitive performance in infancy. *Child Development*, 48, 658–661.

- Miller, D., Spiridigliozzi, G., Ryan, E., Callan, M., & McLaughlin, J. (1980). Habituation and cognitive performance: Relationships between measures at four years of age and earlier assessments. *International Journal of Behavioral Development*, 3, 131–146.
- Mitchell, D. W., & Colombo, J. (1997). Infant cognition and general intelligence. In W. Tomic & J. Kingma (Eds.), *Advances in cognition and educational practice: Reflections on the concept of intelligence* (pp. 101–119). Greenwich, CT: JAI.
- Mitchell, D. W., McCollam, K., Horowitz, F. D., Embretson, S. E., & O'Brien, M. (1991, April). *The interacting contribution of constitutional, environmental, and information processing factors to early developmental outcome*. Paper presented at the annual meeting of the Society for Research in Child Development, Seattle, WA.
- Nelson, C. A. (2001). The development and neural bases of face recognition. *Infant and Child Development*, 10, 3–18.
- Reisbick, S., & Neuringer, M. (1996). Maturation of average look duration in rhesus monkey infants: Repeating patterns. *Developmental Psychobiology*, 29, 295.
- Reisbick, S., Neuringer, M., Gohl, E., & Wald, R. (1997). Visual attention in monkeys: Effects of dietary fatty acids and age. *Developmental Psychology*, 33, 387–395.
- Richards, J. E. (1985). Respiratory sinus arrhythmia predicts heart rate and visual responses during visual attention in 14 and 20 week old infants. *Psychophysiology*, 22, 101–109.
- Richards, J. E. (1987). Infant visual sustained attention and respiratory sinus arrhythmia. *Child Development*, 58, 488–496.
- Richards, J. E. (1994). Baseline respiratory sinus arrhythmia and heart-rate responses during sustained visual attention in preterm infants from 3 to 6 months of age. *Psychophysiology*, 30, 235–243.
- Richards, J. E., & Casey, B. J. (1990a). Development of sustained visual attention in the human infant. In B. A. Campbell, H. Hayne, & R. Richardson (Eds.), *Attention and information processing in infants and adults* (pp. 30–60). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Richards, J. E., & Casey, B. J. (1990b). *Visual fixation patterns and recognition memory in the paired-comparison paradigm in infants: Effects of attention phases, age, and respiratory sinus arrhythmia*. Unpublished manuscript, University of South Carolina, Columbia.
- Richards, J. E., & Casey, B. J. (1991). Heart-rate variability during attention phases in young infants. *Psychophysiology*, 28, 43–53.
- Richards, J. E., & Casey, B. J. (1992). Development of sustained visual attention in the human infant. In B. A. Campbell, H. Hayne, & R. Richardson (Eds.), *Attention and information processing in infants and adults: Perspectives from human and animal research* (pp. 30–60). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Richards, J. E., & Gibson, T. L. (1997). Extended visual fixation in young infants: Look distributions, heart rate changes, and attention. *Child Development*, 68, 1041–1056.
- Richards, J. E., & Lansink, J. M. (1997). Heart rate and behavioral measures of attention in six-, nine-, and twelve-month-old infants during object exploration. *Child Development*, 68, 610–620.
- Rose, D., Slater, A., & Perry, H. (1986). Prediction of childhood intelligence from habituation in early infancy. *Intelligence*, 10, 251–263.
- Rose, S. A. (1989). Measuring infant intelligence: New perspectives. In M. H. Bornstein & N. A. Krasnegor (Eds.), *Stability and continuity in mental development: Behavioral and biological perspectives* (pp. 171–188). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Ruddy, M. G., & Bornstein, M. H. (1982). Cognitive correlates of infant attention and maternal stimulation over the first year of life. *Child Development*, 53, 183–188.
- Saxon, T. F., Colombo, J., Robinson, E. L., & Frick, J. E. (2000). Dyadic interaction profiles in infancy and preschool intelligence. *Journal of School Psychology*, 38, 9–25.
- Saxon, T. F., Frick, J. E., & Colombo, J. (1997). A longitudinal study of maternal interactional styles and infant visual attention. *Merrill-Palmer Quarterly*, 43, 48–66.

- Sigman, M. (1983). Individual differences in infant attention: Relations to birth status and intelligence at five years. In T. Field & A. Sostek (Eds.), *Infants born at risk* (pp. 271–293). New York: Grune & Stratton.
- Sigman, M., Cohen, S., & Beckwith, L. (1996, April). *Why does infant attention predict adolescent intelligence?* Paper presented at the biennial International Conference on Infant Studies, Providence, RI.
- Sigman, M., Cohen, S., Beckwith, L., Asarnow, R., & Parmelee, A. (1991). Continuity in cognitive abilities from infancy to 12 years of age. *Cognitive Development, 6*, 47–57.
- Sigman, M., Cohen, S., Beckwith, L., & Parmelee, A. (1985, April). *Infant attention in relation to intellectual abilities in childhood.* Paper presented at the meeting of the International Society for the Study of Behavioral Development, Tours, France.
- Sigman, M., Cohen, S., Beckwith, L., & Parmelee, A. (1986). Infant attention in relation to intellectual abilities in childhood. *Developmental Psychology, 22*, 788–792.
- Slater, A., Cooper, R., Rose, D., & Morison, V. (1989). Prediction of cognitive performance from infancy to early childhood. *Human Development, 32*, 137–147.
- Stechler, G. (1964). Newborn attention as affected by medication during labor. *Science, 144*, 315–317.
- Stechler, G., & Latz, E. (1966). Some observations on attention and arousal in the human infant. *Journal of the American Academy of Child Psychiatry, 5*, 517–525.
- Tamis-LeMonda, C. S., & Bornstein, M. H. (1989). Habituation and maternal encouragement of attention in infancy as predictors of toddler language, play, and representational competence. *Child Development, 60*, 738–751.
- Weizmann, F., Cohen, L. B., & Pratt, R. J. (1971). Novelty, familiarity, and the development of infant attention. *Developmental Psychology, 4*, 149–154.