Developmental Differences in Infants' Visually-Defined and Heart Rate-Defined Attention to Unimodal and Multimodal Displays

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Abstract

Although developmental research on infants' attention to visual (V) events is extensive, comparatively less work has been conducted on attention to auditory (A) events in the absence of V input, and to combined AV events. The purpose of this study was to examine developmental changes in 14-, 20-, and 26-week-old infants' behaviorally- and psychophysiologically-defined attention to unimodal and bimodal A and V events. An infant-controlled procedure was used during which heart-rate (HR) activity controlled both the onset and offset of events. Three kinds of V events were compared: computer generated forms, adult-directed face (AD), and infant-directed face (ID). Three kinds of A events were compared: instrumental music, AD speech, and ID speech. Each infant experienced events twice, both unimodally (A or V) and bimodally (AV). Greater HR-defined sustained attention and longer looking times to AV events were evident at all ages, with greater attention to ID events in the 14- and 20-week-old infants. However, sustained attention (both in terms of HR and behavior) was greatest to ID and computer-generated AV events in the 26-week-olds. These results corroborate and extend other findings that infants' attention is better elicited and maintained by complex, multimodal events, especially those involving dynamic face+voice information that is typical of their interactions with caretakers (i.e. infant-directed).

Developmental Differences in Infants' Visually-Defined and Heart Rate-Defined Attention to Unimodal and Multimodal Displays

Infants process information differently depending on their level of attention engagement. When attending more 'casually', infants do not process extensive detail and do not encode events to an extent that facilitates recognition at later points in time. In contrast, when attention is 'focused', infants process specific details about events, are less distractible, and more likely to show subsequent memory for the event (Colombo, 2001; Oakes, Tellinghuisen, & Tjebkes, 2000; Richards, 1997; Ruff, Capozolli, & Saltarelli, 1996). It is beneficial to the study of perceptual, social/emotional, and/or cognitive development in infancy to incorporate methods that are sensitive to level of attention to better interpret both successes and failures in infant performance.

However, the behavioral assessment of attention is most conducive to tasks in which the orientation of sensory receptors is apparent (e.g., looking directly at an object). Receptor orientation is less apparent in the case of *auditory attention* in that one can process a speaking voice without looking at the speaker, or even 'orienting' the ears in some focal plane. Moreover, tasks that yoke looking to listening (e.g., fixation on a visual target results in some auditory event) are not necessarily accurate in measuring attention because infants can maintain visual fixation during *inattentive* states (Richards, 1997). This makes the study of auditory attention in infants a special challenge. The primary purpose here was to systematically compare developmental changes in infants' attention to auditory and visual events of a speech (face/voice) and non-speech (object/music) nature, through the use of both behavioral and psychophysiological indices of attention. We used a heart-rate (HR) controlled procedure to index infants' interest in both uni- and bi-modal auditory+visual (AV) events because HR has been shown to add important information about attention beyond that gleaned from behavior alone (Reynolds & Richards, 2005; Richards & Casey, 1992; Richards & Lansink, 1998).

Developmentally, attention is best regarded as a multicomponential process (Richards, 1985; Richards & Casey, 1992; Ruff, 1986; Ruff & Rothbart, 1996) undergoing substantial change during infancy. 'Multicomponential' implies that attention is not a single act, but rather successive phases of information processing that involve activity at different levels of organization, including overt focusing, motor quieting, autonomic responsivity, and cortical effort. In the context of infant development, it is often useful to define different phases of attention according to visual, facial, and motor activity (Ruff, 1986). However, the operationalization of attention in infants has primarily been done in the context of visual responses, and not other sensory systems. For example, Colombo (2004) longitudinally examined visually- and HR-defined patterns of attention in infants as they looked at photographs of faces, and found a linear decrease in overall visual attention across age (i.e., as infants get older, they attended for shorter periods of time). However, these authors also found an interesting change in the proportion of HR defined attention phases; although looking duration decreased with age, older infants maintained HR decelerations for a greater proportion of each look (sustained attention) as well as the time to this deceleration (orientation) but decreased acceleration time (attention termination). These results most likely reflect the increased coupling and integration of behavior and physiology that infants attain as they become more experienced perceivers, as well as concurrent changes in neurophysiological mechanisms of attention control (Richards, 2006; Frick, Colombo, & Saxon, 1999).

More recently, Courage, Reynolds, and Richards (2006) examined changes in infants' attention to static *and* dynamic visual events across the first postnatal year. They gave infants at 5 ages (14, 20, 26, 39, and 52 weeks) a random series of visual events to view, and recorded both visual and heart-rate defined attention. The dynamic and static visual events elicited different attention patterns across age: from 14- to 26 weeks of age, visual attention declined to all events, but older infants (39- and 52-week-olds) increased attention (both in terms of looking time and sustained HR decelerations) to dynamic events (especially faces and an animated video) but not the static ones. Thus, the nature of the event is important when characterizing attention during infancy, a finding recently supported by preliminary work in R. Panneton's lab (McIlreavy, Bhullar, Panneton, & Aslin, 2006). In this study, 3-, 6-, and 9-month-olds experienced four silent visual events in three separate blocks: two events were static (a bullseye and a female face) and two events were dynamic (expanding geometric forms and a female speaking to an infant). Both in terms of visual- and HR-defined measures, infants attended less to static, but more to dynamic events over age, with greatest attention to the dynamic female talker in the 9-month-olds. These data complement those of Courage, Reynolds, and Richards (2006) in that infants' attention increases with age, but only to dynamic events (attention to static events decreased over age). Moreover, animated faces of adult speakers become particularly potent in terms of eliciting and maintaining attention in older infants.

Although it is important to understand changes in *visual* attention over age, the assessment of attention in other modalities (Bahrick & Lickliter, 2000; Lewkowicz,

2003) is also important, especially regarding attention to auditory events such as speech (Burnham, 1993; Gogate, Bahrick, & Watson, 2000; Locke, 1998) and music (Trehub & Trainor, 1998). Attention to speech is essential for vocal language learning, but also for other aspects of social, emotional, and/or cognitive growth (Fogel & Thelen, 1987; Patterson & Werker, 2002; 2003). Infants' attention to speech changes across speech type and age. For example, younger infants attend more to speech that is acoustically exaggerated in pitch, pitch variability, amplitude, tempo/rhythm, and duration; often referred to as 'infant-directed speech' (IDS; Cooper & Aslin, 1990; Fernald, 1985; Fernald & Kuhl, 1987; Pegg, Werker, & McLeod, 1993; Papousek, Papousek, & Symmes, 1991). The ability of IDS to elicit and direct infant attention may stem largely from its association with vocal emotion (Kitamura & Burnham, 1998; Singh, Morgan, & Best, 2002; Trainor, Austin, & Desjardins, 2000), and it may be less attention-eliciting in older infants (Bergeson, Spisak, & Houston, 2006; Panneton, Kitamura, Mattock, & Burnham, 2006). Regardless, it is clear that one benefit of heightened attention to IDS is in infants' access to important aspects of native language structure (Fisher & Tokura, 1996; Christophe, Gout, Peperkamp, & Morgan, 2003; Morgan & Saffran, 1995). So it is necessary to not only investigate speech to infants and its properties that affect learning, but to also study the process of attention to speech itself, and the ways in which speech attention changes with age and experience.

Because it is difficult to assess auditory attention directly, infants' interest in IDS is typically measured via visual fixation. That is, a visual event is presented, and fixation of that event results in the presentation of a speech event (e.g., IDS). Because the sound continues for the length of the fixation that produced it, the primary measure is average looking time as a function of speech type (e.g., Cooper, Abraham, Berman, & Staska, 1997; Cooper & Aslin, 1994; Pegg, Werker, & McLeod, 1993). Often, it is assumed that length of a look is equivalent to the duration of attention. Interestingly, the general length of individual looks to a visual event decrease in duration over infant age (Colombo & Mitchell, 1990) such that younger infants typically look longer at static, two-dimensional visual events than older infants. However, this does not mean that younger infants are *attending* more; rather, they may have difficulty terminating and/or shifting attention given immaturities in cortical control of resource allocation (Colombo, 1995; Hood, 1995; Johnson, 1997; Reynolds & Richards, 2006). Potentially, this means that younger infants can fixate events without active processing (Richards, 1985).

Thus, using 'looking' measures to assess infants' attention to speech may yield only a partial view of information processing, bypassing internal factors that reflect the functioning of infants' general arousal systems (Oakes, Tellinghuisen, & Tjebkes, 2000). This nonspecific arousal system helps to initiate attention, sustain attention, and maintain a vigilant state (Richards, 2001), and changes throughout the first postnatal year (Lansink & Richards, 1997). To date, no research has focused on how IDS impacts infants' attention on a psychophysiological level, and how general arousal systems operate during attention to speech. One way to do so is to complement existing behavioral measures with the addition of those that reflect the internal activity of central and autonomic nervous systems. HR is one psychophysiological measure for studying infant attention (Shaddy & Colombo, 2004; Reynolds & Richards, 2006; Richards, 2001) and is reflective of the influence of the arousal system via parasympathetic nervous system control.

Cardiovascular activity varies in attention-relevant ways across the course of exposure to an event (Berg & Richards, 1997; Richards & Casey, 1992). At event onset, the orienting phase (OR) is considered “reactive attention” (Richards, 1985), reflecting the evaluation of event novelty and some preliminary decision to allocate attention toward the source. With event onset, HR typically decelerates, with the level of deceleration influenced by aspects of the event (e.g., relative novelty/saliency). After OR, infants transition into a phase of sustained (or focused) attention (SA), and HR remains decelerated for some unrestricted period of time, depending on degree of engagement (e.g., extent of cortical resource allocation). In this sense, the duration of SA is infant-controlled, and reflects more detailed information-processing than OR. Finally, infants transition into attention termination (AT) during which time HR returns to pre-event levels and information processing begins to wane, although the infant may continue to fixate the event before terminating attention altogether.

This attention model has been validated in infants of various ages (14-, 20, and 26-week-olds) as they are engaged with both visual (Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001; Maikranz, Colombo, Richman, & Frick, 2000; Richards, 1985; 1997) and auditory (Richards, 2000; Shaddy & Colombo, 2004) events, but has not been applied to infants’ attention to speech. Because HR changes are reflective of the general arousal system, HR activity can shed light on how attention is modulated and regulated in the context of speech, especially face+voice events.

In the current study, we examined differences in infants’ attention to auditory alone (instrumental music vs. voices), visual alone (computer generated moving forms vs. dynamic female face), and auditory/visual (music + geometric forms vs. dynamic face+voice) events in order to assess whether the model of HR defined attention described above is complementary across modalities (vision and audition), and across sensory conditions (unimodal vs. bimodal). We also compared infants' auditory, visual, and AV attention to speech-relevant events (faces with voices) and speech non-relevant events (objects with music) to see whether attention was differentially affected by the nature of the events themselves (e.g., if infants would engage in longer sustained attention to speech compared to non-speech). Lastly, we compared infants' attention to both infant-directed (ID) and adult-directed (AD) information in auditory alone, visual alone, and AV conditions to see if the nature of infants' processing of ID speech and faces changed across age.

Separate groups of infants were tested at three ages: 14-, 20-, and 26-weeks. These ages were chosen because distinct changes in visual- and HR defined attention phases have been found across this general age range (Courage et al., 2006; Richards, 1985; 1987). In the Courage et al. (2006) study, infants across this age span showed linear decreases in attention to both static and dynamic visual events (although their older infants showed greater attention to dynamic events; see also Ting, Bergeson, & Sech, 2006). However, all of the visual events in these studies were silent, so it is unknown whether the availability of concomitant auditory information (which is also dynamic) will modify developmental differences in infants' attention. Given our preliminary data, along with the literatures on infants' attention to speech, and attention to bimodal AV events, we expected the following outcomes: (i) linear decreases in both looking time and sustained attention to unimodal events across age; (ii) higher overall levels of attention to bimodal over unimodal events at all ages, but a linear decrease in attention to bimodal computer events and AD events across age, and (iii) an increase in looking time and sustained attention to bimodal face+voice ID events across age.

Method

Participants. Three separate age groups were studied: 16 14-week-olds (M = 100.0 ; SD = 6.1), 16 20-week-olds (M = 146.2; SD = 7.4), and 16 26-week-olds (M = 184.7; SD = 3.1). All infants were recruited from birth announcements published in Columbia, South Carolina. All participating infants were considered full term and of normal birth weight (at birth), with no pre- or perinatal health problems (by parental report). Twelve additional infants were tested but not included due to fussing or equipment failures and who did not receive at least two trials of each type.

Apparatus and Stimulus Events. Each infant was held in his or her parent's lap (facing forward) approximately 55 cm from the center of a 49 cm color monitor. Two Radio Shack Realistic loud speakers were located adjacent to this monitor, behind black material which shrouded the entire area surrounding the monitor. A Panasonic VHS camcorder was mounted directly above the monitor, positioned downward for a full frontal view of the infant (subtending a visual angle of 44^{0}). This video camera functioned in two ways: (1) it provided an online view of the session during which an observer in an adjacent room monitored the infant's behavior, and (2) it transmitted a record of the entire session to a separate computer that then stored the digital video record along with a time code for further offline coding and synchronization with physiological data.

Three different kinds of visual/auditory events were constructed for this experiment (all could be unimodally or bimodally specified). One was a dynamic, computer-generated pattern (successively expanding/constricting series of concentric circles) with a soundtrack of an instrumental version of "White Christmas" (Form+Music). The second was a short (25 sec) digital movie of an adult female speaking to an adult interviewer (AD Face+Voice). The third was a short (25 sec) digital movie of the same female speaking directly to her 6-month-old infant (ID Face+Voice). Each of these stimulus events was presented either unimodally (e.g., the ID Face alone with no soundtrack; Music alone with no visual track) or bimodally. Additionally, a digitized movie segment of Sesame Street's "Follow That Bird" was used to initiate each block of the session.

Measurement of HR change. Heart rate (HR) was continuously recorded during each session with two Ag-AgCl electrodes placed on the infant's sternum (left and right), and a third reference electrode placed on the infant's right rib cage. The electrodes were connected to a Biopac amplifier via shielded cables. HR was digitized at 1000 Hz (each ms) on a computer, and online changes in the inter-beat intervals (IBIs) between R-waves of the QRS complex were used to determine trial length (explained below). The IBI is the reciprocal of heart rate so that the lengthening of IBIs reflects a deceleration in HR and shortening of IBIs refers to a return to baseline HR and/or a HR acceleration. IBI Artifact correction was conducted online using algorithms and offline visual inspection of the electrocardiographic record.

Procedure. When the infant was in an alert and quiet state, he/she sat on the parent's lap, facing the TV monitor. One experimenter attached electrodes to the infant's chest, while the second experimenter monitored the infant's activity and all recording equipment from an adjacent room. The "Sesame Street" video was then presented for approximately 10 seconds to direct the infant's attention to the TV monitor. Once the infant was oriented to the TV, one of 9 stimulus events was presented (Block 1): Form, AD Face, ID Face, Music, AD Voice, ID Voice, Form+Music, AD Face+Voice, or ID Face+Voice. These events were presented in random order (without replacement), with the stipulation that not more than 2 events of the same class (visual alone, auditory alone, visual+auditory) could occur in sequence. After completing this first blocked sequence, "Sesame Street" was again presented for approximately 10 seconds, and a second block of the same 9 events (Block 2) was repeated so that each infant saw/heard a total of 18 events.

Trials were initiated whenever the infant was calm, and looking toward the blank monitor. Once an event began, the duration of each trial was infant-controlled, but instead of using infant looking to determine attention, we used infant HR change. That is, each stimulus event remained on until the infant showed two HR decelerations, interleaved by their respective accelerations (deceleration1 -> acceleration1 -> deceleration2 -> acceleration2). HR deceleration was defined online as five successive IBIs that were each longer than the median of the five successive IBIs that preceded event onset. Likewise, HR acceleration was defined as 5 successive IBIs that were each shorter than the median of the pre-event HR measure. Ideally, each event remained on for the duration of the first deceleration+first acceleration+second deceleration+second acceleration. However, if 20 sec elapsed from the onset of the event with no change in HR, the trial terminated. Likewise, after the first acceleration, if 20 sec elapsed with second deceleration, the trial ended.

Data preparation. Two streams of activity comprised the dependent measures for subsequent analyses. The length of time that an infant looked at the TV monitor was calculated as a function of the different events by re-coding the infants' digitized videos offline. A coder watched each session on the computer (with no sound track, and no access to the visual event on the TV) and recorded the amount of time that an infant was looking at the monitor during each trial. These looking times were synchronized with each infant's ongoing HR activity.

A continuous stream of HR activity was also recorded, digitized and stored for each session. Each HR file was viewed offline for any artifact (individual beats that were not marked erroneously marked as beats). Attempts were made to manually correct such mistakes in the ECG record, and if not possible, unreadable portions of the record were deleted.

Results

There are different ways in which changes in HR activity can be measured to see if patterns of deceleration (attention) and acceleration (attention termination) correspond to the presentation of perceptual events. We explored several of these options (individually discussed below), with the consistent expectation that the most substantial HR decelerations would accompany the bimodal female ID movie, particularly in older infants.

Total trial duration. Trial length was one measure of interest because it was determined by individual infants' HR patterns (rather than looking time, as in most typical preference studies). That is, each trial lasted for the duration of the first HR deceleration, first HR acceleration, second deceleration (if there was one), and second acceleration. Generally, events that recruit more attention should result in longer trials, especially if the event evokes greater periods of sustained attention (slower HR over time). Total trial duration was analyzed with an Age (3: 14, 20, 26 weeks) x Mode (3: Auditory (A), Visual (V), AV) x Event (3: Computer, Adult-Directed, Infant-Directed) ANOVA (Footnote 1). The only significant effect was for Mode: F (2, 78) = 9.71, $p < .001$, with total trial duration for AV (M = 22.9 s, SD=11.1) being longer than that associated with either A or V trials (M = 19.2 and 19.8 s, SD = 9.1 and 8.4, respectively). There were no significant effects of age or event on trial duration.

HR Deceleration Time. Another measure of interest was the total HR-deceleration time during a given trial. This is an informative measure because two trials of equal duration are not necessarily composed of equal deceleration and acceleration periods; in one trial, HR may have decelerated quickly but then returned slowly (i.e., accelerated) to pre-trial levels whereas in another, HR may have decelerated and stayed slow for a longer period, and then accelerated quickly. Thus, HR-deceleration time was analyzed with an Age (3: 14, 20, 26 weeks) x Mode (3: A, V, AV) x Event (3: Computer, AD, ID) ANOVA. There was a significant main effect of Event: F (2, 78) = 3.75, $p < .04$, which was superseded by a significant Mode x Event interaction: F (4, 78) = 2.55, $p < .05$. Figure 1A shows the average HR deceleration time for each mode and event type, collapsed across age. For the A mode, the computer-generated event (i.e., an instrumental melody) elicited the longest HR deceleration (compared to either AD or ID speech), whereas during the AV mode, the computer-generated and ID events produced longer HR decelerations than the AD event. HR deceleration time was not significantly different across events in the V mode. Additionally, there was a significant Age x Mode interaction: F (4, 78) = 2.45, $p < .05$, with both the 20- and 26-week-old infants showing longer HR deceleration time to the AV events but the 14-week-old infants showing equal decelerations to the V and AV events (see Figure 1B). All three ages groups showed the least HR deceleration time (i.e., low sustained attention) to the A events (recall that during A only trials, no visual event was present).

Taken together, these first two measures (trial duration; total HR deceleration time) indicate that the AV events produced the longest trials, with sustained HR deceleration accounting for more of the trial length when the AV event involved computer-generated and ID presentations compared to AD presentations. However, there was little evidence for any systematic age-related effects, as predicted, other than the finding that the youngest infants showing more equivalent attention to both V and AV events, whereas the older infants responded most to AV events.

Interbeat Interval Change from Event Onset. Another informative way to compare differences in attention to events is in changes in average interbeat interval (IBI) size, with increases in IBI indicating the magnitude of the HR deceleration (or the depth of focused attention). First, the average IBI change across each trial, timed from the onset of the event, was analyzed with an Age (3: 14, 20, 26 weeks) x Mode (3: A, V, AV) x Event (3: Computer, AD, ID) ANOVA. The only significant effect was for Mode: $F(2, 90) = 6.57$, $p < .002$, with the AV events producing significantly greater increases in IBI length than the A and V events (see Figure 2). However, this analysis made clear that IBI changes tended to be more pronounced in longer compared to shorter trials. In other words, shorter trials (overall) were less likely to show differences in IBI change as a function of mode (A, V, AV) in interaction with either event and/or age, whereas longer trials showed more differentiated IBI change patterns. Thus, IBI changes (in msec) were further analyzed for successive 10 s intervals (Footnote 2), with an Age (3: 14, 20, 26 weeks) x Mode (3: A, V, AV) x Event (3: Computer, AD, ID) x Intervals (5: 0-10s; 11-20s; 21-30s; 31-40s; > 41s) ANOVA. As with the analysis above, there was a main effect of Mode (again, AV events produced greater IBI change than A or V events), and also a statistically significant main effect of Intervals: F (4, 163) = 17.69, $p < .0001$. The intervals effect was due to the finding that the shortest trials show relatively small IBI changes, the trials lasting 20 to 30 s showed steep IBI changes followed by a rapid return to pre-event levels, and the trials lasting 30 to 40s, and beyond showed large initial IBI changes and sustained lowered heart rate throughout the trial (see Figure 3).

Because the above analyses on HR deceleration were timed from event onset, the degree of HR slowing includes the initial orientation phase (see Richards & Casey, 1992), which typically does not vary much from one kind of event to another. However, we were primarily interested in whether the *degree* and *duration* of HR deceleration was a function of the mode (A, V, AV) and/or age of infant. Thus, we next analyzed IBI change from the onset of HR-defined sustained attention, rather than the onset of the event. Timing the analysis from HR deceleration onset effectively removes stimulus orientation time from the measure, and also allows for ascertaining different degrees of deceleration as a function of the mode of presentation, type of event, and age of infant. The IBI change during the entire deceleration interval was analyzed with an Age (3: 14, 20, 26 weeks) x Mode (3: A, V, AV) x Event (3: Computer, AD, ID) ANOVA. Only a significant main effect of mode was found: F (2, 90) = 9.75, $p < .0001$. As with the IBI change timed from Event onset, the initial HR response to the V and A events were similar, whereas the response to the AV event was significantly larger (Figure 4 shows the IBI change timed from the onset of the first deceleration and for as long as the deceleration continued, that is, until criterion for return of heart rate to pre-event levels was met).

Next, we analyzed IBI changes during heart rate deceleration for several intervals in the deceleration period (similar to the interval analysis discussed earlier, but in trial length rather than deceleration length), with an Age (3: 14, 20, 26 weeks) x Mode (3: A, V, AV) x Event (3: Computer, AD, ID) x Intervals (4: 0-5s; 6-10s; 11-20s; > 21s) ANOVA (Footnote 2). The main effect for Intervals was statistically significant: F (3, 122) = 4.61, $p < .005$. However, unlike HR timed from event onset, there was a steady decrease in HR over the entire period the deceleration was ongoing. Although the Mode main effect and Mode x Age interaction were only marginally significant, the Intervals x Mode x Age interaction was statistically significant: F (12, 136) = 2.05, $p < .03$; (see Figure 5a). In the beginning of the deceleration phase, 14-week-olds showed approximately the same IBI change in all three presentation modes, 20-week-olds showed slightly larger IBI changes to the AV events, and 26-week-olds showed the largest distinction between the AV and unimodal (A and V) presentations. As the deceleration period progressed, all three age groups showed larger IBI changes and more extended deceleration episodes to the AV events.

Moreover, there was a significant Intervals x Event x Age interaction: F (12, 141) = 1.99, $p < .03$. Figure 5b shows the IBI changes that occurred during heart rate deceleration separately for the three event types and ages. Although IBI changes at the beginning of heart rate deceleration were similar for all ages and all Event types, ID speech resulted in the largest and most extended heart rate deceleration for the 14- and

20-week-old infants. For the 26-week-olds, all three Event types produced similar levels of IBI change during the periods of extended heart rate deceleration.

The results illustrated in Figure 5b imply that the youngest two age groups had extended periods of heart rate deceleration (particularly for ID events), even though the analyses presented earlier that were conducted from event onset did not find that the duration of heart rate deceleration was significantly affected by the Event factor. However, the results in Figure 5 suggest that the interaction between event type and age was present only on select trials, particularly with trials of extended duration.

Attention Measured via Looking Time. In addition to HR, we were also interested in infants' patterns of looking during each trial, even though looking was not required for the presentation of any particular event (e.g., on A trials, the monitor was actually blank). Nonetheless, we coded looking time (offline from digital recordings) for all event types. Look duration (i.e., time spent looking toward the monitor) was analyzed with an Age (3: 14, 20, 26 weeks) x Mode (3: A, V, AV) x Event (3: Computer, AD, ID) ANOVA. This analysis resulted in a significant main effect of Mode: F (2, 78) = 60.87, $p < .0001$, and a Mode x Age interaction: F (4, 78) = 3.58, $p < .02$ (see Figure 6). Not unexpectedly, the shortest looking times toward the monitor occurred during the A presentations (given that the screen was blank), and this effect did not differ by age. The looking time during V presentations was at an intermediate level between the A and AV trials, with a significant decline in total looking time to V over age (the mode x age interaction). The total looking time during AV presentations was the longest, and it did not differ across age. Although this pattern of looking time closely complements the data presented in Figure 1B on HR deceleration duration, it is clear that low levels of looking on A trials did not necessarily mean that infants were not attending to the speech and/or music (i.e., although not to the same extent as on V and AV trials, HR did decelerate to the sounds alone).

Discussion

The main purpose of this study was to assess developmental changes in 14-, 20-, and 26-week-old infants' attention to dynamic visual and auditory events and included computer generated geometric forms, female ID and AD faces, instrumental music, and female AD and ID voices. Also, the events occurred either unimodally (A, V) or bimodally (A+V). We predicted that the AV bimodal events (face+voice), particularly when involving ID stimulation, would induce the most attention, and in the oldest infants. This prediction was partially supported in that we found that AV events, irrespective of their composition, engendered more attention from infants at all ages, and that ID events, irrespective of their mode, engendered more attention in the 14- and 20-week-old infants. However, the most pronounced age-related effect was with respect to the ability of AV computer-generated and ID events to promote sustained attention in the oldest infants, but not the AD events.

Increased attention to AV events at all three ages was apparent in longer trial durations, which were determined by the infant's own HR deceleration/acceleration pattern. However, when looking at total HR deceleration time (within any given trial duration) different attention effects emerged depending on the mode of presentation. For A presentations, music elicited longer HR decelerations than either speech type, which is interesting because on these trials there was no visual event present that infants could fixate (resulting in low looking times to the blank monitor). Thus, longer HR decelerations to music on such trials may reflect infants' ability to focus their attention on ambient sound, but more so if it is complex and perhaps novel (as compared to speech). For V presentations, there was no difference in attention across the event types. To some extent, this finding corroborates others that have shown consistently higher levels of attention to dynamic V over static V events (Courage et al., 2006; McIlreavy et al., 2006; Shaddy & Colombo, 2004; Ting, Bergeson, & Sech, 2006).

However, in the current study, the addition of a sound-track (music) to a computer generated display or a voice to a talking face increased attention even further. Colombo, Harlan, and Mitchell (1999; see also Colombo, 2001) proposed a tri-phasic model of infant visual fixation patterns, with fixation length initially increasing in early infancy (as behavioral state organizes around the availability of perceptual information) and then linearly decreasing with age (looks become shorter but more efficient as sustained attention increases and attention termination decreases). This pattern, though, may be relevant only for infants' attention to static, simple visual events, and not to events that are more complex and ecologically-relevant. The increasing attention to AV events with age found in the current study is more consistent with developmental changes in fixation to simple vs. complex events over age (Courage et al., 2006; Richards & Anderson, 2004; Richards, 2004). Generally, such studies have found (similar to Colombo et al., 1999) that fixation duration decreases over infant age to simple, low-complexity stimuli, but actually increases with age as complexity increases. Given that the AV events in the current study were by definition more complex than their A or V counterparts, the finding of increased sustained attention with age falls in line with this other work.

The second general finding was that for the ID events, all ages showed larger and extended HR decelerations in the longer trials, suggesting that attention to ID events is not only immediate, but also sustained for longer intervals of time. This was especially the case in the younger two age groups compared to the oldest group. This is consistent with the literature on newborn and young infants' preferences for ID over AD speech (Cooper & Aslin, 1990; Fernald, 1985; Pegg, Werker, & McLeod, 1992) but also somewhat surprising in that the general facilitating effect of ID stimulation on attention was not as strong in the oldest age group (which was predicted). The ability of ID stimulation to elicit and sustain attention in this older sample was highest when the event involved both a face and voice (and less to A and V). There has been little research extending preferences for ID speech into older aged infants (with the possible exception that many speech perception studies with older infants obtain better results when using ID-generated stimuli). The fact that attention to ID events in general was less in the oldest infants in this study suggest that a simple ID speech preference may not be maintained with age, but that it gets integrated into infants' emerging biases for more complex, multimodal experiences (Lewkowicz, 2000), especially talking faces. This increasing attention to bimodal ID is also consistent with findings from Colombo, Shaddy, Richman, Maikranz, and Blage (2004), who conducted a longitudinal study on infants' attention to faces. The primary result in their study was in increasing sustained attention and decreasing attention termination with age, with little developmental change in the orientation response (see also Shaddy & Colombo, 2004). However, a more recent study found no differential attention to ID and AD face+voice displays in separate groups of 6- and 24-month-old infants, although preferences for ID face+voice recordings was found in 4-month-olds (Bergeson, Spisak, & Houston, 2006). Because there have been relatively few studies exploring infants' attention to ID information in the latter part of the first postnatal year, it is not clear whether early preferences can be generalized across infant development, and calls for more empirical studies on a potential reorganization in infants' attention to ID vocal and facial information as native language learning progresses.

Another interesting finding was that the magnitude of attention effects was not uniform across trial time, with shorter trials showing less differentiation in attention than longer trials, as a function of event type, presentation mode, and age (see similar findings in Richards & Anderson, 2004; Richards & Cronise, 2000; Tellinghuisen, Oakes, & Tjebkes, 1999). In the current study, the ability of the computer-generated events (regardless of mode) to sustain attention in all age groups decreased across trial length. One interpretation of this finding is that the effect of dynamic moving objects and music on infants' attention is powerful, but immediate, and does not manifest itself across longer intervals of time. This is also consistent with the inability of computer-generated events to sustain attention as infants get older (Richards & Anderson, 2004). A similar pattern was found for the AD events in the younger infants, although there were more extended decelerations to AD events in the longer trials in the 14- and 20-week-olds than in the oldest group. ID events were much more likely to sustain attention (to result in extended deceleration periods) in longer trials for all ages, but particularly in younger infants. This was true only for the bimodal ID event in the older age group.

In sum, we found evidence that dynamic events differentially affect infant attention depending on their mode of presentation, their content, and infants' ages. ID events (voices and/or faces), compared to computer-generated and AD events, generally produce more sustained attention, but more so in younger than older infants. In older infants (26-week-olds), sustained attention was most pronounced for AV presentations that involved moving objects and music, or a moving face and ID speech. However, in general, AV events were better at eliciting and maintaining infants' attention than either A or V alone events, irrespective of age. These results support a view of the development of attention as involving the progressive coordination of information across multiple sensory modalities (Bahrick & Lickliter, 2000; Lickliter & Bahrick, 2001), particularly as this involves the processing of complex, dynamic event information (Courage, Reynolds, & Richards, 2006; Richards, 2001).

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Footnotes.

1. All duration variables were transformed by the log function to account for skewed distribution of duration variables. The analyses were done with the general linear models approach to ANOVA.

2. The default minimum trial length was 20 seconds, so all participants had heart rate data for the first 20 s. There was less data for the remaining intervals, so this analysis was done with the general linear models approach that reflected different numbers of data in the successive testing intervals. For the IBI change from the onset of the deceleration, the intervals were chosen to get approximately equal numbers of data points in each interval; the general linear models approach was used.

Figure Captions

Figure 1. Average heart-rate (HR) deceleration time (sec), summed across total trial time spent in a deceleration (i.e., 5 consecutive inter-beat intervals (IBI) less than the median of the 5 IBIs preceding event onset). In 1A) HR dec time is plotted as function of mode (A, V, AV) and event (C, AD, ID), collapsed across age. In A mode, the music produced longer HR dec times than either AD or ID voices; In AV mode, however, both C forms+music and ID face+voice produced longer HR dec times. In 1B), HR dec time is plotted by mode and age (14-, 20-, and 26-week-olds). Significantly greater HR dec time was present in AV mode (independent of event), but only in the 20- and 26-week-olds.

Figure 2. Average inter-beat interval (IBI) change (msec) across trial duration (successive 1 sec periods) from the onset of the event; IBI change is plotted as a function of mode (A, V, AV), with significantly greater IBI change (sustained attention) to the AV mode.

Figure 3. Similar to Figure 2, average IBI change (msec) is plotted over trials of different durations (sec; 0-20, 0-30, 0-40, 0-50); trials of longer duration were more likely to show different degrees of HR change as a function of mode (A, V, AV) than those of shorter durations.

Figure 4. Average IBI change (msec) plotted from the onset of the first HR deceleration (rather than event onset); AV mode produced significantly greater IBI change (sustained attention) than A or V modes.

Figure 5. Average IBI change (msec) from the onset of the first HR deceleration. In (A) IBI change is plotted by age (14-, 20-, and 26-week-olds) as a function of mode (A, V, AV); AV mode produced significantly more IBI change (sustained attention) than either A or V modes at each of the three ages. In (B), IBI change is plotted by age (14-, 20-, and 26-week-olds) as a function of event (Computer, AD, ID); AD and ID events produced significantly more IBI change (sustained attention) across different trial lengths in the youngest two age groups, but this effect was not evident in the oldest group (26-week-olds).

Figure 6. Average looking time (sec) plotted by age (14-, 20, 26-week-olds) and mode (A, V, AV). There was no difference in looking times A or AV events, with visual attention to AV events higher than A or V. There was a significant decline in visual attention to V events over age.

Figure 1.

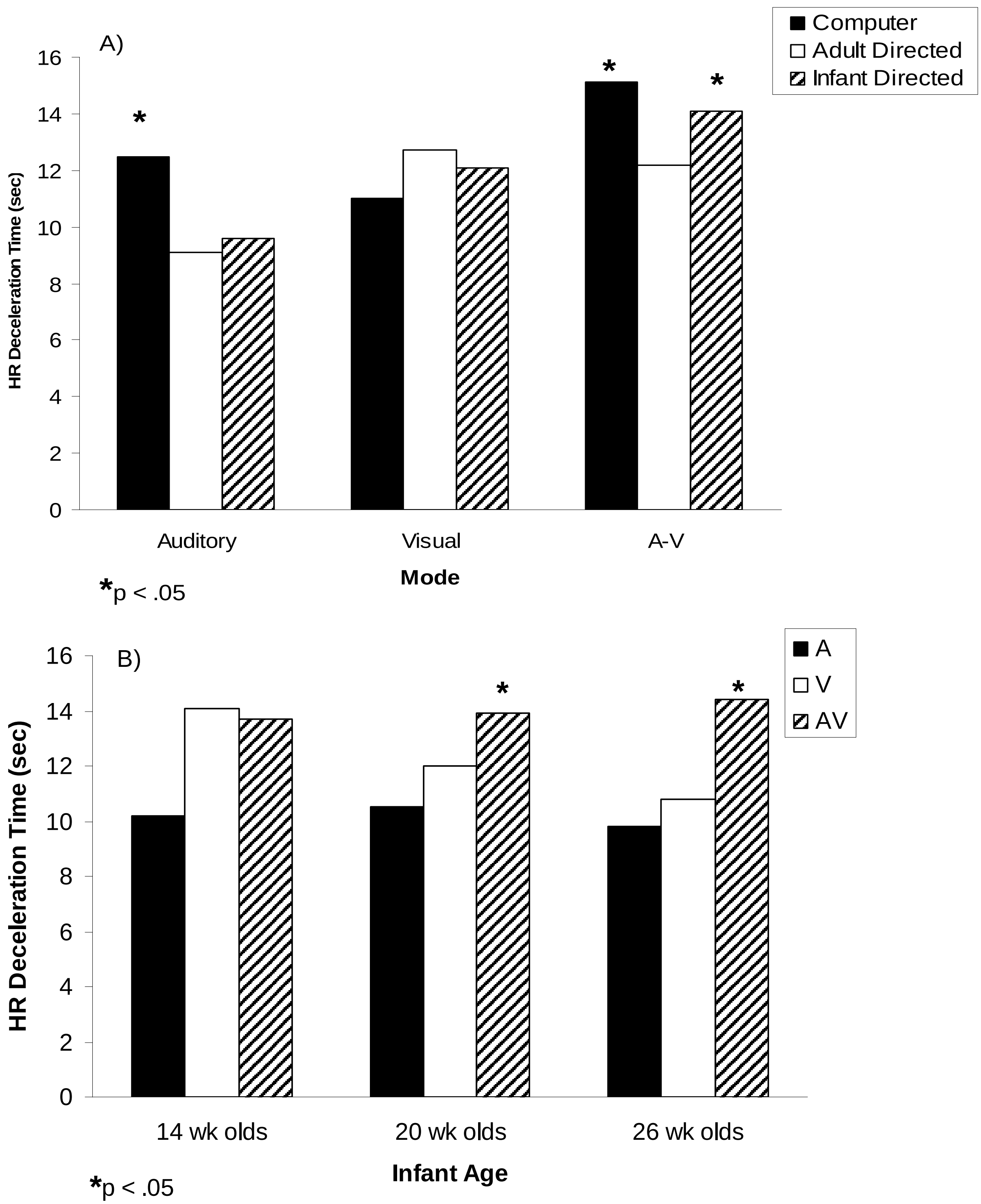

A)
Computer
Adult Directed
Infant Directed
HR Deceleration Time (sec)
0
2
4
6
8
10
12
14
16
*
*
*
Auditory
Visual
A-V
Mode
*p < .05
B)
A
V
AV
HR Deceleration Time (sec)
0
2
4
6
8
10
12
14
16
*
*
14 wk olds
20 wk olds
26 wk olds
Infant Age
*p < .05

Figure 2.

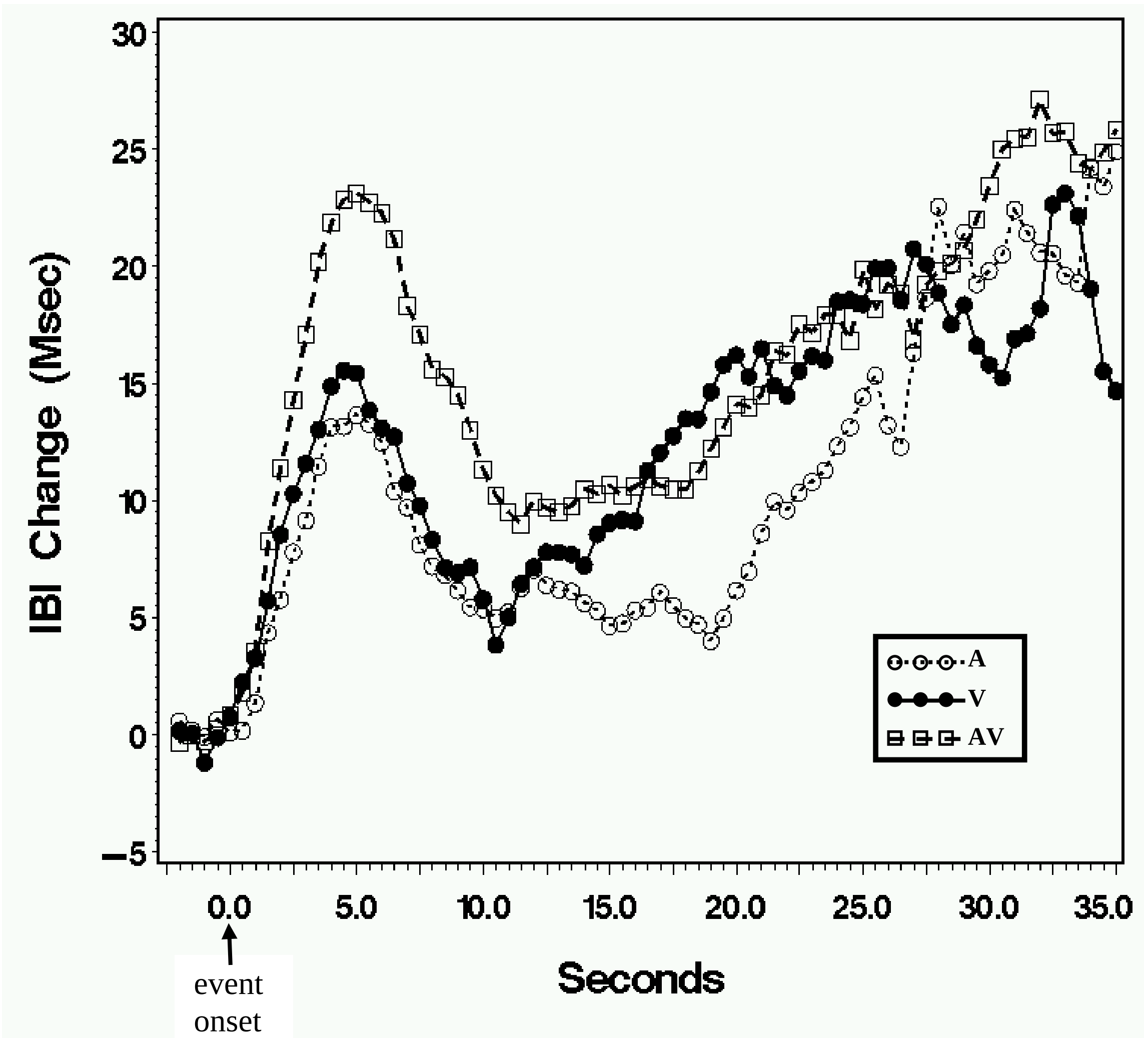

IBI Change (Msec)
30
25
20
15
10
5
0
−5
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
Seconds
event
onset
A
V
AV

Figure 3.

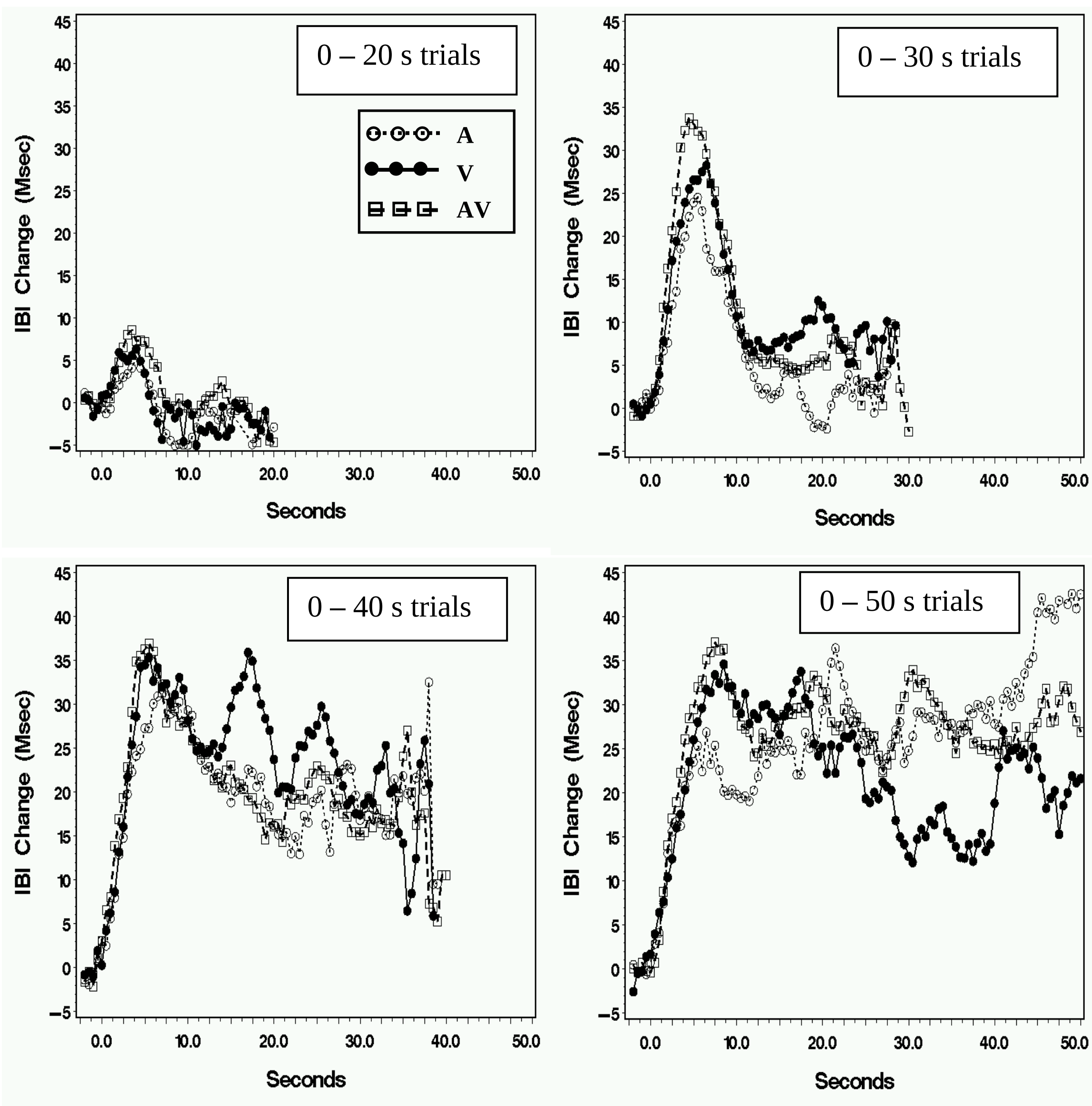

0 – 20 s trials
A
V
AV
IBI Change (Msec)
Seconds
0 – 30 s trials
0 – 40 s trials
0 – 50 s trials

Figure 4.

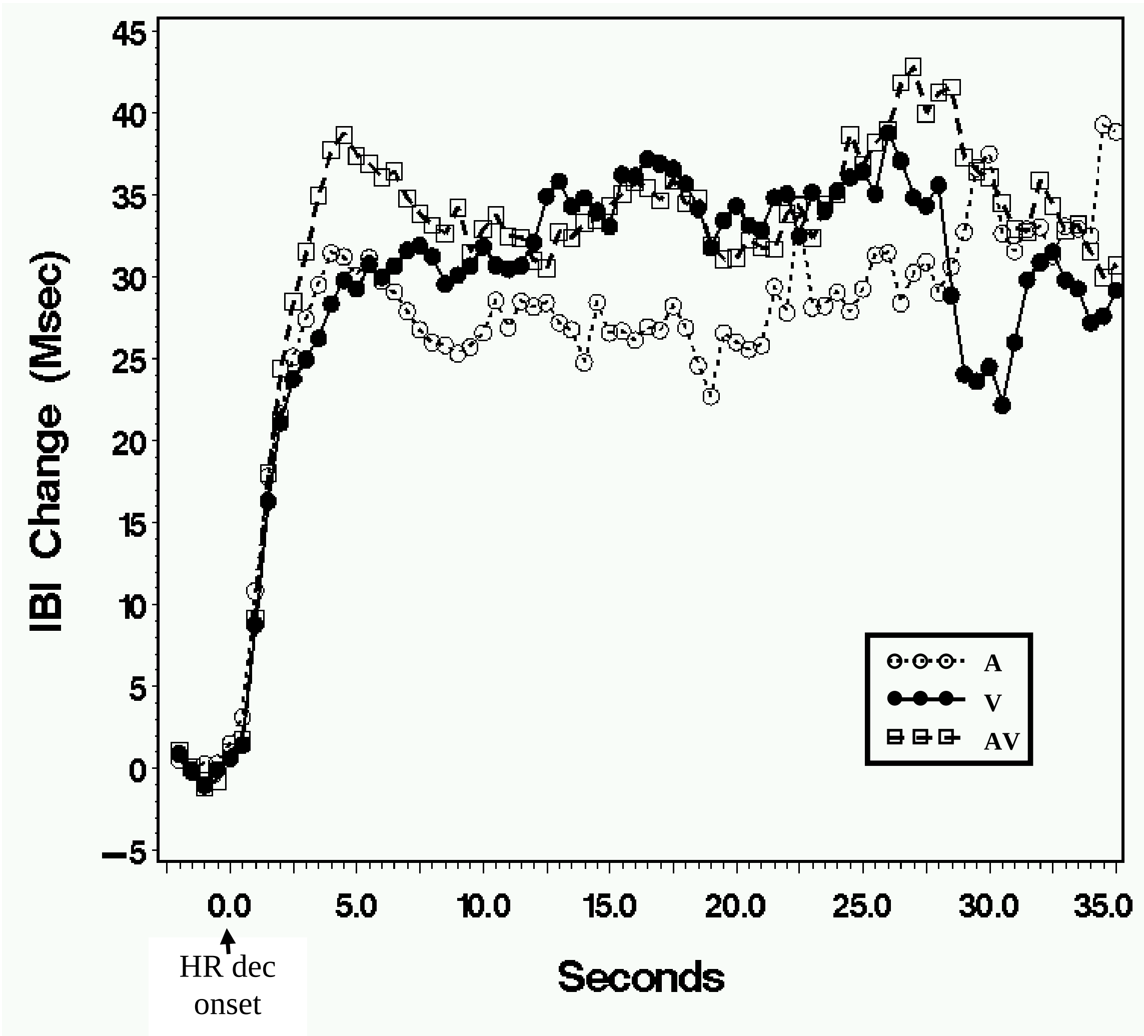

45
40
35
30
25
20
15
10
5
0
−5
IBI Change (Msec)
0.0
5.0
10.0
15.0
20.0
25.0
30.0
35.0
Seconds
HR dec onset
A
V
AV

Figure 5A.

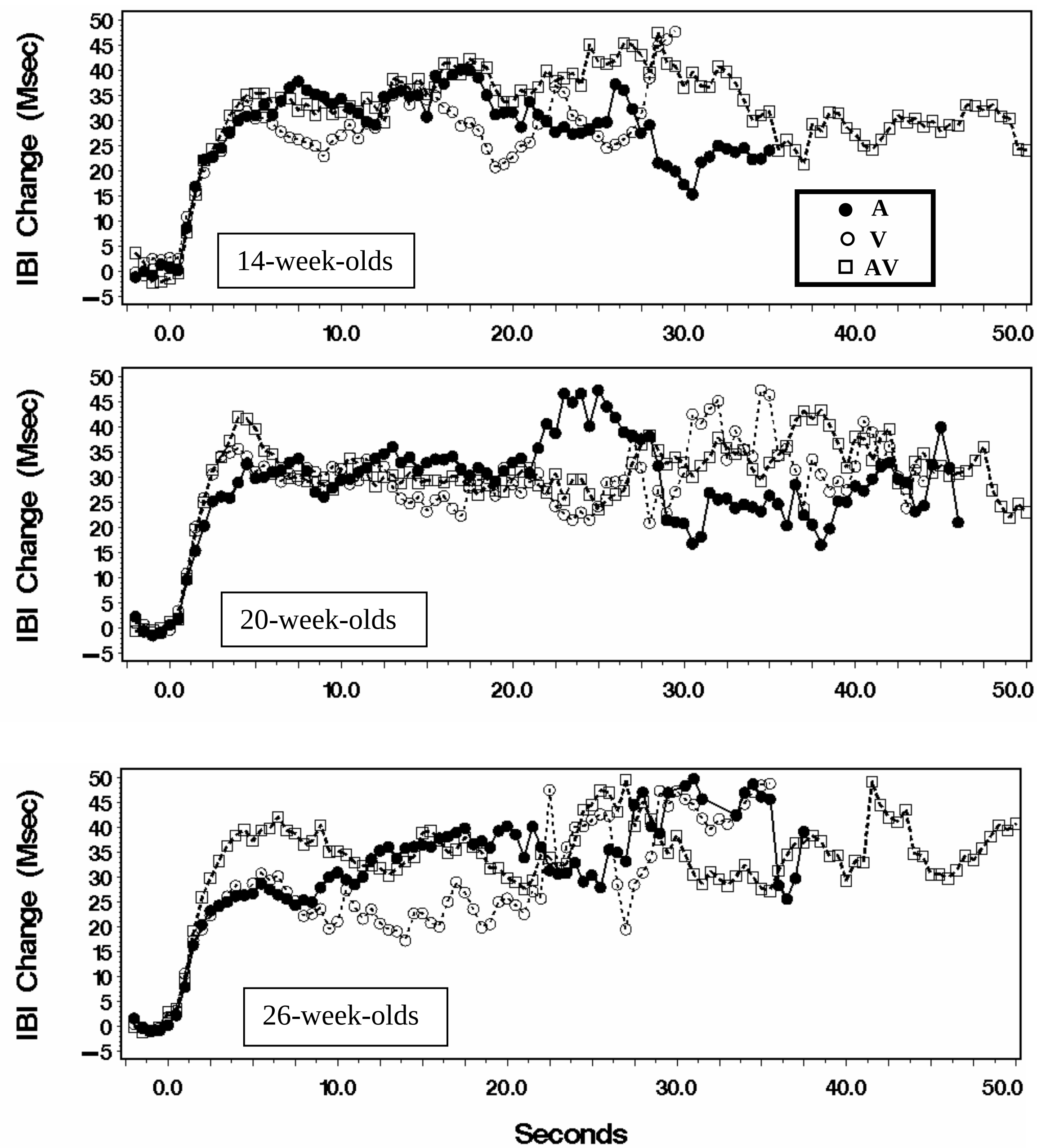

IBI Change (Msec)
14-week-olds
20-week-olds
26-week-olds
A
V
AV
-5
0
5
10
15
20
25
30
35
40
45
50
0.0
10.0
20.0
30.0
40.0
50.0
Seconds

Figure 5B.

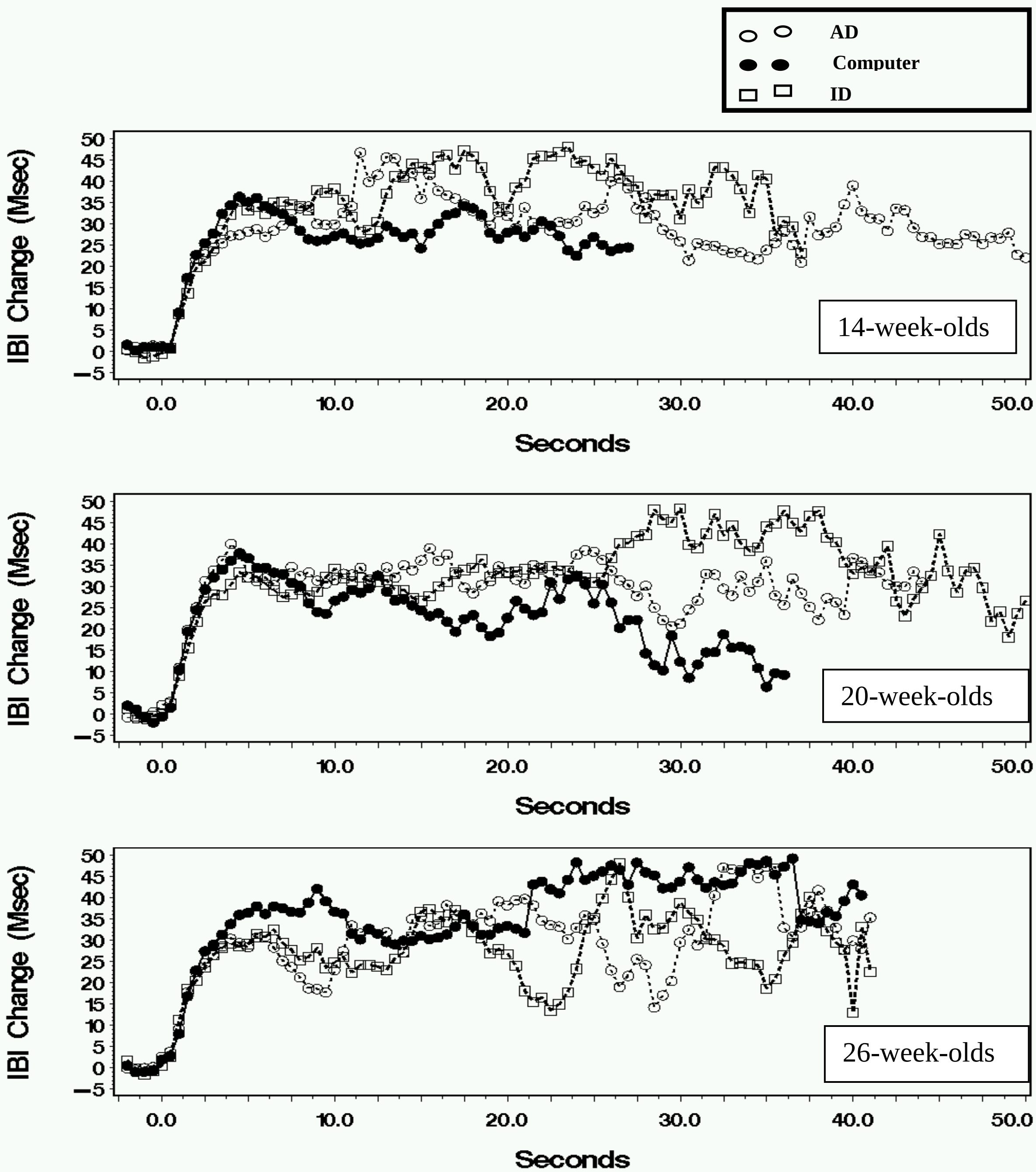
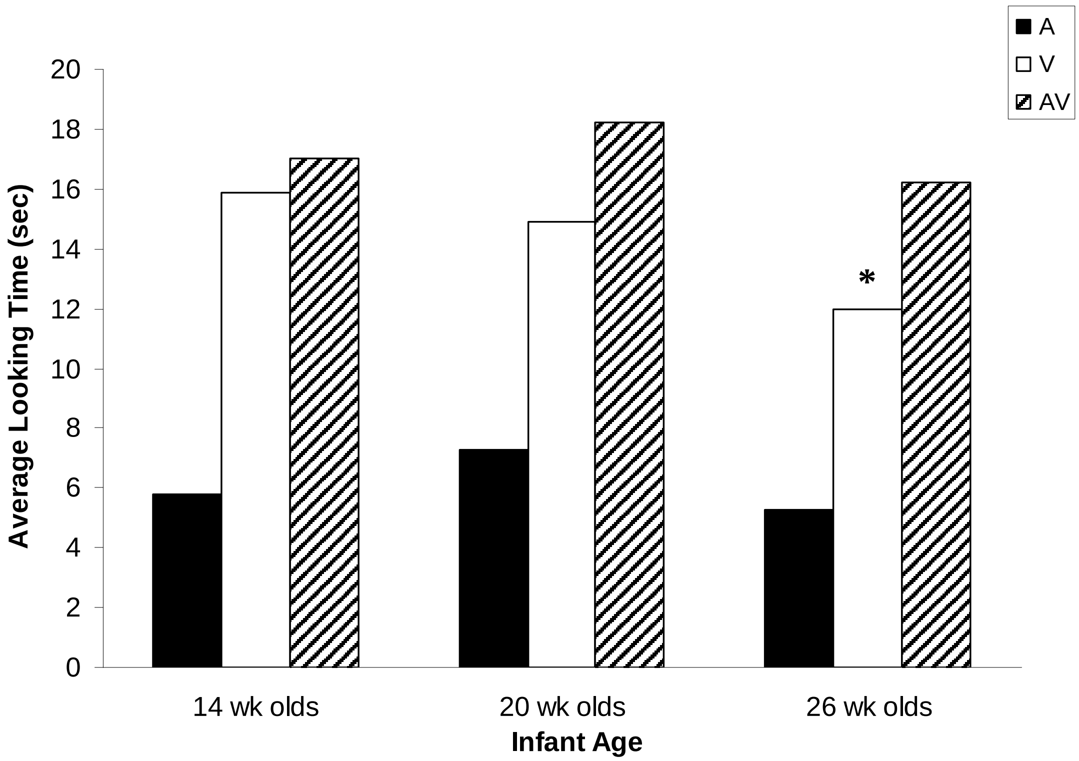

AD
Computer
ID
IBI Change (Msec)
50
45
40
35
30
25
20
15
10
5
0
−5
0.0
10.0
20.0
30.0
40.0
50.0
Seconds
14-week-olds
20-week-olds
26-week-olds

Figure 6.


A
V
AV
20
18
16
14
12
10
8
6
4
2
0
Average Looking Time (sec)
*
14 wk olds
20 wk olds
26 wk olds
Infant Age

$p < .05$