THE ROLE OF AUDITORY-VISUAL SYNCHRONY IN CAPTURE OF ATTENTION AND

INDUCTION OF ATTENTIONAL STATE IN INFANCY

By

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Submitted to the graduate degree program in Psychology and the Graduate Faculty of the University of Kansas in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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Date Defended: September 6, 2013

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Chairperson Dr. John Colombo

Date approved: December 4, 2013

Abstract

This study was designed to examine the types of events that are most effective in capturing infant attention and whether these attention-getting events also effectively elicit an attentional state and facilitate perception and learning. Despite the frequent use of *attention-getters* (AGs) – presenting an attention-grabbing event between trials to redirect attention and reduce data loss due to fussiness – relatively little is known about the influence of AGs on attentional state. A recent investigation revealed that the presentation of AGs not only captures attention, but also produces heart rate decelerations during habituation and faster dishabituation in a subsequent task, indicating changes in the state of sustained attention and enhanced stimulus processing (Domsch, Thomas, & Lohaus, 2010). Attention-getters are often multimodal, dynamic, and temporally synchronous; such highly redundant properties generally guide selective attention and are thought to coordinate multisensory information in early development. In the current study, 4-month-old infants were randomly assigned to one of three attention-getter AG conditions: synchronous AG, asynchronous AG, and no AG. Following the AG, infants completed a discrimination task with a partial-lag design, which allowed for the assessment of infants' ability to discriminate between familiar and novel stimuli while controlling for spontaneous recovery. Analyses indicated that the AG condition captured and induced an attentional state, regardless of the presence of temporal synchrony. Although the synchronous and asynchronous AG conditions produced similar patterns of attention in the AG session, during familiarization infants in the asynchronous AG condition showed a pattern of increasing HR across the task and had higher overall HR compared to the synchronous AG and no AG conditions. Implications of the effect of attention-getters and temporal synchrony on infant performance are discussed.

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Eliciting and maintaining a state of attention is a common concern for researchers of infant perception and cognition. As interest and attention wane, infants often become fussy, which can result in a significant loss of data. Over the last decade, an increasing number of infant studies have employed a methodological technique to address this concern – the presentation of an *attention-getter* (AG) between each trial to redirect attention to the task. Researchers have used AGs in a variety of tasks: habituation (Cohen & Cashon, 2001; Domsch, Thomas & Lohaus, 2010; Panneton & Richards, 2011), categorization (Kovack-Lesh, Oakes, & McMurray, 2011), preference (Brand & Shallcross, 2008), statistical learning (Fiser & Aslin, 2002), and eye-tracking to redirect point of gaze (Johnson, Amso, & Slemmer, 2003 ; Johnson, Davidow, Hall-Haro, & Frank, 2008).

Although attention-getting events vary from study to study, they are typically dynamic and multisensory, often with corresponding visual and auditory stimuli. For example, Kovack-Lesh and colleagues (2011) presented infants with a looming gray circle accompanied by a whistle. Similarly, Domsch and colleagues (2010) paired a baby toy sound with a blue dot that grew in size and appeared to be looming. In addition to being multimodal and dynamic, AGs can also be temporally synchronous, with visual stimuli that loom and contract simultaneously with a rhythmic sound (Cohen & Cashon, 2001; Johnson et al., 2008). Richards and his colleagues (Frick & Richards, 2001; Panneton & Richards, 2011; Richards, 1997) commonly present Sesame Street video clips as AGs. When shown briefly at various points prior to and during testing, these Sesame Street video clips produced changes in infants' heart rate (HR) that are associated with the different phases of attention (Frick & Richards, 2001; Richards, 1997). This

work found that infants who were in a sustained attention phase (induced by the Sesame Street video AG) when the task started processed the stimuli more completely than infants who were in other attentional phases. In other words, by inducing a sustained attention phase in some infants, the AG affected subsequent stimuli processing.

Until recently, researchers had not considered the influence of AGs on performance – beyond using them as a tool for refocusing attention to the task and reducing fussiness. Expanding on the work of Richards and his colleagues (Frick & Richards, 2001, Richards, 1997), Domsch and colleagues (2010) compared habituation-dishabituation performance of infants in two conditions: Attention-getter (AG) and non-attention-getter (NAG). They found that infants in the AG condition had decreased HR and shorter looking times during habituation (habituated more quickly) and increased dishabituation response, indicating a state of sustained attention and enhanced stimulus processing, compared to infants in the NAG condition. These results demonstrate that the brief presentation of events with attention-getting properties not only capture attention, but also induce a state of attention in infancy, which can enhance perception and learning.

It is important to note the methodological implications of these findings – brief presentations of AGs between trials for the purposes of redirecting infant attention to the task, may also lead to unanticipated changes in the infant's attentional state, which may in turn affect performance. Thus, the variability in the types of events used as AGs across studies is cause for concern. If certain types of stimuli naturally attract infant attention, as the substantial literature on infant preferential looking suggests, some AGs may capture attention and induce a state of attention more effectively than other AGs, which may yield performance differences across studies. In addition, with the increased use of AGs as a tool for refocusing attention, it is

essential that researchers understand the effects of different AGs on infant performance. The purpose of this study is to examine the types of events that are most effective in capturing infant attention and whether these attention-getting events also effectively elicit an attentional state and facilitate perception and learning.

Varieties of Attention

Attention is typically characterized as a process that involves focusing on or selecting certain objects or events from the environment for further processing or action. Although the psychological literature widely employs the term *attention*, it is quantified in many ways and there remains no single definition. Over a century ago, in *Principles of Psychology*, William James (1890) introduced the notion of the existence of *varieties of attention*; researchers continue to recognize the multifaceted nature of attention by identifying several broad categories of the neural and behavioral processes related to the general construct of attention (Colombo, 2001; Parasuraman & Davies, 1984; Ruff & Rothbart, 1996).

In the most comprehensive model of adult attention, Posner and his colleagues (Fan, McCandliss, Sommer, Raz, Posner, 2002; Posner & Petersen, 1990) divided attention into three networks with differing functions, anatomical locations and neurochemical modulators: orienting, alerting, and executive. In line with the adult literature, developmental models of attention, including Ruff and Rothbart's (1996) theoretical work on attention in early development and Colombo and colleagues' (Colombo 2001, 2002; Colombo & Cheatham, 2006) developmental taxonomy of early visual attention, highlight selection (orienting), attentional state (alerting), and endogenous or executive attention as important processes in the development of early attention. The current study will focus on selection and attentional state (see table 1).

Table 1

Varieties of Attention

Selection/ Orienting		The selection of specific information from a wide range of stimuli (while filtering out potential distractors) for enhanced processing. It involves engagement, disengagement, shifting/moving and reengagement of attention.
	Exogenous Selection	Automatic selection, driven by external stimulus characteristics, which *capture* attention
	Endogenous Selection	The higher-level ability to resolve conflict among responses and voluntarily orient attention to enhance processing of events or objects that are related to behavioral goals
Attentional State		A state of readiness or preparedness for incoming stimulation often linked to arousal.

Attentional Selection

Our senses are subject to large amounts of information or stimulation in the environment every day; however, we can only attend to a limited number of objects or events. The selective aspects of attention allow for the narrowing of information from a wide range of stimuli to a single response or a select set of stimulus responses, while filtering out potential distractors and promoting processing of desired stimuli. Even young infants are selective in their looking behavior, with certain stimulus properties (e.g. events that are multisensory, dynamic, and temporally synchronous) naturally attracting attention (Bahrick, 1988; Blossom & Morgan, 2006; Dodd, 1979; Panneton & Richards, 2011; Shaddy & Colombo, 2004; Spelke, 1979; Volkmann & Dobson, 1976),

A fundamental question in the adult literature on selective attention is the extent to which selection is controlled endogenously, by the goals and expectations of the observer or

exogenously, by stimulus properties (Rauschenberger, 2003; Ruz & Lupianez, 2002; Theeuwes, 2010). Proponents of endogenously controlled selective attention argue that attention can be oriented voluntarily to enhance processing of events or objects related to behavioral goals (Folk, Remington, & Johnston, 1992). For example, when talking to a friend in a noisy restaurant, you will focus your attention on her voice, while filtering out irrelevant noises. Although these top-down or endogenous influences can help guide the focus of attention, some events may attract attention regardless of goals or expectations (Theeuwes, 1991, 1992, 1994). This exogenous selection is automatic and driven by external stimulus characteristics, which capture attention (Theeuwes, 1992). For example, if a fire truck drives by, you will likely turn toward the lights and noise automatically. Abrupt changes in the environment are important, perhaps to survival, and such signals might be missed if attention were strictly endogenous or controlled by goals.

Although the debate continues in the adult literature about whether selection is voluntary or automatic, infant researchers are more interested in determining the developmental course of exogenous and endogenous attention. In the first year, infant behavior and attentional state/alertness shift from being exogenous or externally driven to being more endogenous or internally driven (Colombo & Cheatham, 2006; Ruff & Rothbart, 1996). During the first 6 months, attention is largely captured and held by external characteristics, such as specific stimulus properties (Shaddy & Colombo, 2004) or the environment (Atkinson, Hood, Wattam-Bell, & Roddick, 1992; Saxon, Colombo, Robinson, & Frick, 2000; Saxon, Frick, & Colombo, 1997). However, toward the end of the first year, infants become capable of voluntarily allocating or inhibiting attention (Colombo & Cheatham, 2006). This study is designed to examine the properties of events that are effective in capturing attention and producing an

attentional state in early infancy, so the remainder of this paper will focus on exogenous rather than endogenous attention.

For over 30 years, researchers have investigated the conditions under which stimulus characteristics control selective attention in an exogenous way (see Rauschenberger, 2003; Ruz & Lupianez, 2002; Theeuwes, 2010 for reviews). This stimulus-driven orienting of attention, independent of an observer's goals and intentions, is known as attentional capture (Folk & Remington, 1998; Theeuwes, 1991). Although the paradigms used to assess attentional capture vary, most tasks take the form of an adapted visual search task, which measures the effects of an irrelevant, novel or salient event on performance in a primary task (Folk & Remington, 1998; Simons, 2000; Theeuwes, 1991). Slowed performance on the primary task in the presence of an additional event indicates attentional capture.

The majority of attentional capture studies have focused on visual attention in the spatial domain; however, recent investigations have explored capture in the auditory modality (Dalton & Lavie, 2004) as well as the influence of temporal stimulus properties on exogenous attention (von Muhlenen, Rempel, & Enns, 2005). Extensive work on attentional capture has produced a long list of stimulus properties that grab attention. Several of these are relevant to the present study, as they mirror the types of stimuli that have been shown to attract and hold infant attention: novelty, dynamic events, saliency, faces, emotional facial expressions, and temporal synchrony.

Several theories have been proposed to explain how these stimulus features capture attention. According to the *new-object hypothesis*, attention is only captured by the sudden appearance of new objects (Yantis & Hillstrom, 1994; Yantis & Jonides, 1984). For example, the appearance of a deer running across a previously empty field is likely to capture attention.

Alternatively, the *transient hypothesis* suggests that sensory transients (e.g. luminance and motion) that occur when there is a salient change in a stimulus capture attention regardless of whether or not the object is new (Franconeri, Hollingworth & Simons, 2005; Franconeri & Simons, 2003; Jonides & Yantis, 1988; Yantis & Jonides, 1984). Following the previous example, the same deer, which is not a new object, running back across the field would create a motion transient that would capture attention. The *saliency capture hypothesis* states that a stimulus that is salient or distinctive from other objects in color, form or luminance will capture attention (Becker & Horstmann, 2011; Theeuwes, 1991; Turatto & Galfano, 2000). For example, a red flower would be more likely to grab an observer's attention in a field of green grass than in a field of orange flowers.

Recent work by von Muhlenen and his colleagues (2005) revealed that events are most likely to capture attention when they are both spatially and temporally unique. The *unique-event hypothesis* states that as long as they are temporally unique, abrupt color or motion changes and the abrupt onset associated with new events are effective in capturing attention (von Muhlenen, et al., 2005). For example, changes in color, from gray to red, are more likely to capture attention when they occur 150 ms before or after a display transition than changes that occur at the same time as a display transition (von Muhlenen et al., 2005). The next two sections briefly describe two specific types of exogenous attention observed in infancy: exogenous visual orienting, and spontaneous, stimulus-driven visual preferences.

Attentional selection in infancy. The phenomenon of attentional capture has also been applied in a literature on infant selective attention (Dannemiller, 2000, 2001, 2005; Ross & Dannemiller, 1999). However, the definition of capture differs for infants compared to adults, because, unlike adults, infants cannot follow verbal instructions to attend to a primary target.

Instead, an infant views moving target bars and static bars while an observer makes decisions about where the infant orients his or her attention. Specifically, Dannemiller and his colleagues examined the processes by which infants orient to salient visual stimuli with varying stimulus properties (e.g. contrast, movement, size, and color) that appear unexpectedly. Investigations of what captures infant attention are not limited to this specific exogenous visual orienting task. Another widely used methodology that can assess attentional capture in infancy is preferential/selective looking.

For over 50 years, researchers have taken advantage of infants' tendency to preferentially look at (selectively attend to) some events in the environment rather than others to study the development of perceptual and cognitive abilities in infancy. However, these studies have not generally invoked attention as a factor in such preferences. The position here is that visual or auditory preferences in early infancy reflect exogenous selection. In his early work on form perception, Fantz (1958; 1961) measured preferential looking by simultaneously presenting two stimuli with different levels of complexity, on opposite sides of the midline, while an observer recorded the number and duration of looks to the each stimulus. Using this technique, Fantz (1961) found that young infants spent more time looking at complex patterns and stimuli with high contrast and large features compared to solid colors. In addition, infants also preferred curves over straight lines (Fantz & Miranda, 1975) and looked longer at face-like patterns than the same face-like pattern with the features rearranged (Fantz, 1961). Fantz (1964) was also the first demonstrate the phenomenon of infant preference for novel events rather than familiar ones. In this classic work, he presented infants with multiple trials of two stimuli, to the left and right of midline. During the task, one stimulus was always the same (familiar), while the other was

always different (novel). Over the course of the task, infants spent more time looking at the novel stimulus and away from the familiar one.

Fantz's preferential looking technique and its many variants remain the primary methods for assessing infant attentional preferences. There exists an extensive literature demonstrating the types of events to which infants preferentially attend: multisensory (Panneton & Richards, 2011), dynamic (Panneton & Richards, 2011; Shaddy & Colombo, 2004; Volkmann & Dobson, 1976), temporally synchronous (Bahrick, 1988; Blossom & Morgan, 2006; Dodd, 1979; Spelke, 1979), predictable (Nakata & Mitani, 2005), and "social" – faces (Dannemiller & Stephens, 1988; Fantz, 1961; Gliga, Elsabbagh, Andravizou, & Johnson, 2009), infant directed speech (Fernald, 1985) and infant-directed sign language (Masataka, 1996). Multisensory events that are dynamic and temporally synchronous are most germane to the current study, because these types of events are most often used as attention-getters in infant studies.

If attention is driven exogenously, especially in early infancy, then it follows that environmental conditions or manipulations can induce or trigger attentional states that contribute to learning. Based on the review of the selective attention literature thus far, multimodal, dynamic, and temporally synchronous events capture attention. It remains unclear, however, whether the stimulus properties that effectively grab attention are also able to induce an attentional state and enhance processing, learning, and discrimination.

Attentional State

Attention is often characterized by a state of readiness for stimulation that is associated with alertness, arousal (Pribram & McGuinness, 1975), and psychophysiological responses (Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001; Richards & Cameron, 1989); this readiness presumably has positive consequences for learning, perhaps through the promotion or

facilitation of synchronized neural activity (Eckhorn, Gail, Bruns, Gabriel, Al-Shaikhli, & Saam, 2004; Niebur, Hsaio, & Johnson, 2002; Roy, Steinmetz, Hsaio, Johnson, Niebur, 2007). The current belief is that the attentional state is regulated by ascending pathways from the brainstem that mediate higher-order brain structures through neurotransmitters (Robbins & Everitt, 1995). Early work by Moruzzi and Magoun (1949) proposed the existence of a brainstem reticular activating system (RAS) that plays a crucial role in regulating cortical arousal and maintaining an alert state and mediating transitions from periods of wakefulness to states of high attention. In addition to mediating attentional state, these brainstem systems are also related to autonomic and physiological functions including cardiac, respiratory systems, pupillary responses and the modulation of sleep/wake cycles, which make measures of autonomic function ideal indicators of attention (Colombo et al., 2001; Richards & Cameron, 1989). Finally, four ascending neurotransmitter pathways from the brainstem to neocortical areas of the brain are often associated with attentional function: noradrenergic, cholinergic, dopaminergic, and serotonergic pathways (Parasuraman, Warm, & See, 1998; Robbins & Everitt, 1995).

The noradrenergic system is the most closely related to attention and readiness for stimulus input (Aston-Jones, Rajkowski, Kubiak, & Alexinsky, 1994; Parasuraman et al., 1998). At the center of this system is the locus coeruleus (LC), which shows greater activity during periods of alertness and is associated with increased norepinephrine in the cortex (Aston-Jones et al 1994; Moore & Bloom, 1979; Parasuraman et al., 1998). The reported increase in lapses of attention following the administration of clonidine (an alpha-2 adrenoceptor agonist that acts presynaptically by reducing the release of noradrenaline; Parasuraman et al., 1998), offers further support for the link between the noradrenergic system and attention. The cholinergic system also originates in the brainstem, specifically in the pontine tegmentum and the basal forebrain, which

are related to a variety of cognitive functions, including sustained attention (Sarter, Givens, & Bruno, 2001). The cholinergic system plays an important role in cortical activity, including the sleep-wake cycle (Datta & Siwek, 1997; Moruzzi & Magoun, 1949), motor function and arousal (Steckler, Inglis, Winn & Sahgal, 1994). Less is known about the relationship between attentional state and the other two neurotransmitter pathways. The dopaminergic system is associated with activation of behavior (Brown & Robbins, 1991; Koob, 1992), while the serotonergic pathway is concomitant with inhibition of behavior (Robbins, 1998).

As a function of attaining an attentional state, the saliency of an attended to stimulus or event increases through the amplification of stimulus properties or a reduction of external or internal noise (Blaser, Sperling, & Lu, 1999; Dosher & Lu, 2000; Yeshurun & Carrasco, 1998). This increase in salience enhances the likelihood that stimulus properties are associated or bound together through increased coordinated neural activity (Engel & Singer, 2001; Usher & Donnelly, 1998; Tallon-Baudry, Bertrand, Delpuech & Pernier, 1996), which in turn promotes learning. Recent research suggests that neural synchrony, indicated by increased EEG gamma-band oscillations, represents an underlying state of attention and other cognitive processes including learning, memory, and perception (Doesburg, Roggeveen, Kitajo, & Ward, 2008; Neibur, et al., 2002; Roy, et al., 2007; Ward, 2003). Although neural synchrony is often described as an indicator of attentional state, it is also important to note that external stimuli can induce that neural synchrony (Basar-Eroglu, Struber, Schurmann, Stadler & Basar, 1996; Kaiser & Lutzenberger, 2003).

Attentional state in infancy. The ability to attain an attentional state develops gradually over the first few months of life. During the first month, infants spend less than 20% of their time in an alert, attentive state (Colombo & Horowitz, 1987; Thoman, 1975; Wolff, 1965). For infants

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younger than 2-3 months, behavior is often state-dependent, with external events or lower order mechanisms of arousal influencing attention (Karmel, Gardner, & Magnano, 1991). Manipulations of arousal, through feeding and/or swaddling, affect visual preferences, discrimination, and memory recognition in very young infants. For example, 1-month-old infants in an aroused state who completed a visual preference task prior to being fed and swaddled preferred lower temporal frequency (less stimulation) compared to higher temporal frequency (more stimulation), whereas less aroused infants who were tested after feeding while swaddled showed the opposite preference (Gardner & Karmel; 1984; Geva, Gardner, & Karmel, 1999). The amount of time spent in an alert state increases over the first 10-12 weeks of life, with 3-month-old infants being able to attain and maintain alert, attentive states more often (Berg & Berg, 1979). Having more control over their internal state allows infants to inhibit responses based on internal stimulation/arousal and focus attention on external characteristics of stimuli in the environment (Geva et al., 1999; Maurer & Lewis, 1979).

Measuring Attention in Infancy

Given the benefits of the attentional state – increased saliency, enhanced processing, and the promotion of learning – it is important to understand how the attentional state is attained. According to Ruff and Rothbart (1996), state and selectivity are overlapping processes. Prior to reaching an attentional state, the infant must select a focus of attention. The infant first orients toward interesting and potentially important sources of information. Following orienting, the infant selects sufficiently novel and/or salient events for further exploration and learning resulting in a state of sustained attention (Ruff & Rothbart, 1996).

Investigators of selection/orienting and a state of sustained attention employ several types of measures: behavioral (e.g. looking, facial expressions and motor activity), physiological (e.g.

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heart rate (HR), respiration, pupillometry, and galvanic skin response), and electrophysiological (electroencephalogram (EEG) and event related potentials (ERPs)). Relevant to the current study is the behavioral measure of look duration and the psychophysiological measure of HR. Measures of look duration comprise two separate processes – attention-getting and attention-holding (Cohen, 1972). In the current study, attentional capture is analogous to the process of attention-getting. An event that effectively captures attention increases the speed with which an infant orients to a stimulus. A common behavioral measure of attention-getting is the latency to turn toward a stimulus (Cohen, 1972). Attention-holding is reflected in the amount of time an infant spends looking at a stimulus. While there is valuable information in measures of the amount of time an infant spends looking at a stimulus, adding additional measures such as HR allows for a better understanding of attentional processes, especially attentional state.

Lewis, Kagan, Campbell, and Kalafat (1966) first observed the relationship between HR and attention over 40 years ago. Recently, researchers have taken advantage of the association between arousal and attentional state by supplementing behavioral data with measures of heart rate to obtain a more accurate measure of infant attentional state (Colombo, et al., 2001; Elsner, Pauen, & Jeschonek, 2006; Frick & Richards, 2001; Lansink, Mintz, & Richards, 2000; Maikranz, Colombo, Richman, & Frick, 2000; Richards, 1985; 1997; Shaddy & Colombo, 2004). Richards and Casey (1991, 1992) identified three heart rate defined phases of looking that reflect different levels of information processing that occur over time when an infant attends to an event: Orienting, sustained attention, and attention termination (see Figure 1). At the onset of an event, the infant begins orienting (OR) toward potentially important sources of information. If the infant selects a novel or salient event for further exploration and learning, OR is followed by the sustained attention (SA) phase, which is marked by infant looking accompanied by a

deceleration of heart rate. The SA phase often reflects cognitive activity and can indicate that the infant has reached an attentional state (Graham & Clifton, 1966; Richards, 1985). This phase of decelerated HR is maintained until the infant is no longer in an engaged attentional state. The attention termination (AT) phase, defined by the return of HR to pre-event levels although looking may continue, signifies the disengagement of attention.
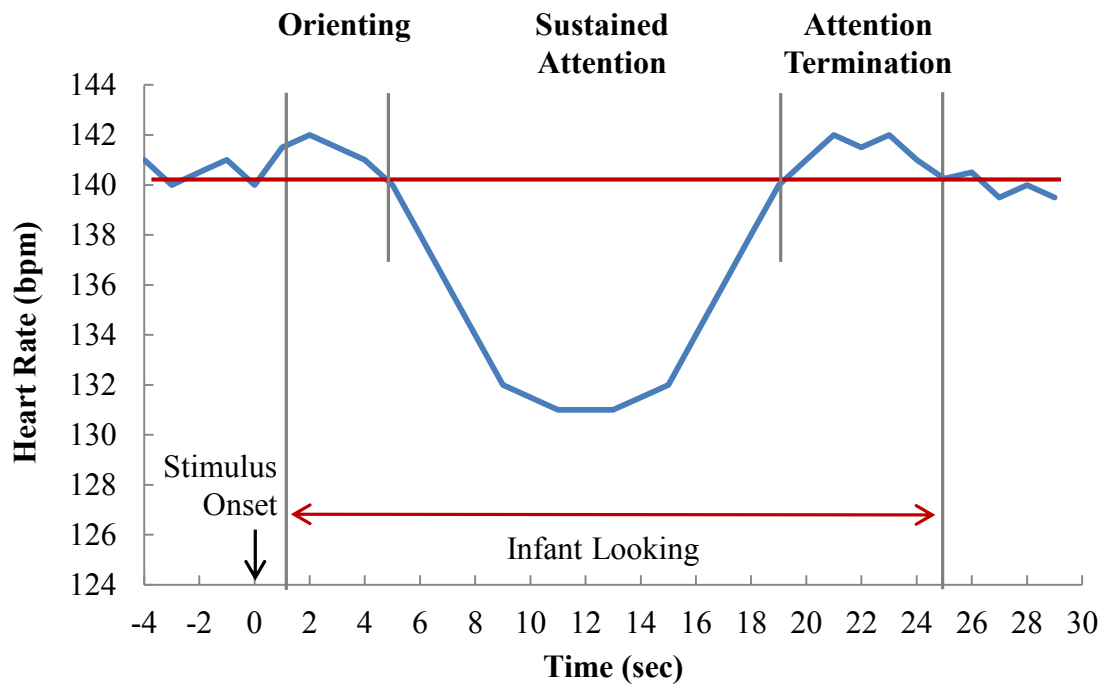
Figure 1. Heart rate-defined phases of attention (after Richards & Casey, 1992).

Intersensory Processing

Attention-getting events used in infant research are often multisensory and dynamic, as these events are better able to elicit infant attention and produce greater sustained attention – HR and looking – than auditory or visual events alone (Panneton & Richards, 2011). Attention to multisensory events, which make up most of human perception experience, requires intersensory processing. This highly redundant, often temporally synchronous, information guides selectivity

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at the expense of non-redundant information and, as a result, facilitates perception, learning, and discrimination (Bahrick, Lickliter, & Flom, 2004; Lewkowicz & Kraebel, 2004). Although multisensory information arrives simultaneously through separate sensory channels, it is integrated into a stable, coherent experience. A fundamental issue in the infant literature is how multimodal stimulation is processed and integrated into a unitary perception. Historically, research on the development of this ability was driven by two opposing theoretical views of intersensory perception: early integration (also known as differentiation) and late integration (see Bahrick & Pickens, 1994; Lewkowicz, 1994; Lewkowicz, 2000 for a review, Robinson & Sloutsky, 2010).

According to the early integration view, intersensory perceptual abilities are present at birth (Bower, 1974; E. J. Gibson, 1969; J. J. Gibson, 1966; Werner, 1973). An extreme version of the early integration view argues that at birth there is a single, completely merged sensory system, which makes it difficult for infants to differentiate stimulation from different modalities (Bower, 1974; Werner, 1973). A less extreme example of the early integration view is E. J. Gibson's (1969) *invariance detection theory*. According to Gibson, infants have an innate ability to detect invariant or amodal properties of events or objects. Characteristics represented redundantly across different modalities (e.g., synchrony, rhythm, tempo, intensity) are considered amodal. The capacity to detect invariant information continues to develop over time, as infants are able to differentiate finer and more complex information (see Bahrick & Pickens, 1994 for review). In contrast to the early integration view, the late integration view (Birch & Lefford, 1963, 1967; Friedes, 1974; Piaget, 1952) suggests that the sensory systems are independent at birth. Because of this independence, young infants are unable to process

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intersensory stimulation. According to this theory, the senses gradually integrate as infants and young children learn to process and coordinate multimodal stimulation.

A more recent explanation of infants' capacity to pick up overlapping, amodal information from objects and events in our environment, is Bahrick and Lickliter's (2000) *intersensory redundancy hypothesis* (*IRH*). Intersensory redundancy, the presentation of spatially coordinated and temporally synchronous information across two or more senses, directs attention and perception of multisensory stimulation. Specifically, during early development infants selectively attend to redundant, amodal information rather than non-redundant, modality-specific information.

Intersensory redundancy hypothesis makes four empirically supported predictions about multimodal processing in infancy. (1) Multimodal information engages attention and facilitates processing of redundant, amodal events more effectively than unimodal information (Bahrick & Lickliter, 2000; Bahrick, Flom & Lickliter, 2002; Flom & Bahrick, 2007; Lickliter, Bahrick & Honeycutt, 2002, 2004). (2) Unimodal information engages attention and facilitates processing of modality-specific events more effectively than multimodal information (Bahrick, Lickliter & Flom, 2006; Flom & Bahrick, 2010). (3) With experience, perceptual processing becomes increasingly flexible, allowing perceivers to detect both amodal and modality-specific properties in unimodal and multimodal presentations (Bahrick & Lickliter, 2004; Flom & Bahrick, 2007; Lickliter, Bahrick & Markham, 2006). (4) Intersensory redundancy is most pronounced when cognitive load or task difficulty is high and perceiver expertise is low (Bahrick Lickliter, Castellanos and Vaillant-Molina, 2010).

Attention to temporal synchrony. A preponderance of evidence suggests that temporal synchrony is an important attribute used to coordinate multisensory information in early

development (Bahrick, 1988, 2001; Lewkowicz, 1986). As early as 2 months of age, infants can integrate auditory and visual information based on temporal synchrony (Bahrick, 1988; Lewkowicz, 1986; Spelke, 1979) and detect changes the temporal synchrony in auditory-visual events (Bahrick & Lickliter, 2002; Lewkowicz & Kraebel, 2004). Research has also demonstrated that infants prefer to attend to events presented synchronously compared to events presented asynchronously (Bahrick, 1988). For example, 4-month-old infants prefer to look at a visual event (e.g., a bouncing green disk) that has a rate of surface impact that corresponds to the rate of the sound (Spelke, 1979; Spelke, Born & Chu, 1983). Very young infants are also aware when voice and lips do not match. They attend significantly longer to in-synchrony face-voice events compared to face-voice events that are out-of-synchrony (Dodd, 1979). Temporal synchrony also plays a crucial role in intersensory matching. At 6 months of age, infants are able to detect temporal relationships between moving auditory and visual events, but only if the events are temporally synchronous. When the relationship between the auditory and visual events is asynchronous, intersensory matching is no longer possible (Bahrick, 1987; Lewkowicz, 1986).

The effects of temporal synchrony have also been measured using heart rate and event-related brain potentials (ERPs). As previously discussed, decelerations in HR while the infant is looking at an object or event indicate cognitive processing and a state of sustained attention. Researchers of sustained attention and engagement report that increased vagal tone reflects slower HR (HR decelerations) and increased HR variability. Conversely, low vagal tone is related to faster HR and decreased HR variability (Bozhenova, Plonskaia, & Porges, 2001). Pizur-Barnekow, Kraemer, and Winters (2008) conducted a pilot study with 5-month-old infants examining the relationship between visual attention and HR responses to synchronous and

asynchronous events. Although visual behavior did not differ for synchronous and asynchronous events, vagal tone was significantly lower during the asynchronous condition compared to the synchronous condition. These findings suggest that auditory and visual events presented in synchrony are more likely than asynchronous events to elicit an attentional state in infants.

Examining the neural basis of face-voice synchrony in 5-month-old infants, Hyde, Jones, Flom, and Porter (2011) report that synchronous speech presented with a static face compared to asynchronous speech, presented with the same static face with a 400 ms delay, produced a greater early (auditory N1/P2) response, indicating an initial synchrony bias. The asynchronous condition produced a greater negative component (Nc) response, indicating attentional processing, than the synchronous condition. The authors explain this unexpected finding – synchronous events are more familiar, and therefore less interesting than the asynchronous event. Further, dynamic, auditory-visual synchrony elicited a greater positive slow wave (PSW), which is related to memory recognition, compared to the asynchronous condition. Kopp & Dietrich (2013) extended this work by examining 6-month-old infants' discrimination of and ERP responses to synchronous and asynchronous videos of a woman clapping her hands. The asynchronous stimuli elicited significantly longer latencies in auditory N1/P2 and Nc responses than did the synchronous stimuli. In addition, asynchronous compared to the synchronous stimuli produced greater negative amplitudes of Pb, an ERP component related to stimulus expectancy. Taken together, these studies demonstrate differential effects of synchronous and asynchronous stimuli on infant ERP modulations related to processes of perception, attention, memory recognition, and expectancy.

Temporal synchrony presumably plays a significant role in attention during early infancy, making it an important factor to consider when designing attention-getters (Bahrick, 1988, 2001;

Lewkowicz, 1986). For example, events presented asynchronously may be less effective in eliciting and maintaining an attentional state, because they lack the redundant multisensory information that facilitates perceptual processing and learning in early infancy.

Pilot Study on Attention to Synchrony

Data collected recently in the KU Infant Cognition Lab provided support for the use of dynamic, synchronous events/stimuli in attracting attention and eliciting an attentional state in infants (Curtindale, Bahrick, Lickliter, & Colombo, 2011). The study investigated whether synchronous stimuli more effectively induce attention in infants than stimuli characterized by asynchrony. It was predicted that synchronous compared to asynchronous stimuli would produce longer looking and more time spent in a state of sustained attention, evidenced in deep heart rate decelerations strongly coordinated with looking. Eighty 4-month old (N = 38; M = 3.9 months) and 8-month old (N = 42; M = 8.1 months) full term (i.e., gestational lengths of more than 37 weeks) infants were shown 2-minute, multimodal synchronous or asynchronous video clips of a woman speaking in infant-directed speech or a toy hammer tapping a rhythm. During the task, look duration and heart rate (HR) were measured. HR was evaluated using measures of beats per minute (bpm) and three HR-defined phases of attention: Orienting (OR), Sustained Attention (SA) and Attention Termination (AT).

Mirroring the results of Pizur-Barnekow and colleagues (2008) and a recent study by Reynolds, Zhang, and Guy (2013), there were no effects of temporal synchrony condition on measures of look duration. However, HR results revealed significantly different patterns of attention for the synchronous and asynchronous conditions. These results highlight the importance of supplementing behavioral data with physiological measures. Percentages of looking time and HR for each phase were analyzed across the 2-min period. Analyses of the

percentage time spent in each HR phase (OR, SA, AT) yielded a significant Condition x HR

Phase interaction, $F(2, 62) = 3.17$, $p = .049$. The synchronous condition produced faster HR

decelerations (less OR) and a longer state of sustained attention than the asynchronous condition

(see Figure 2).
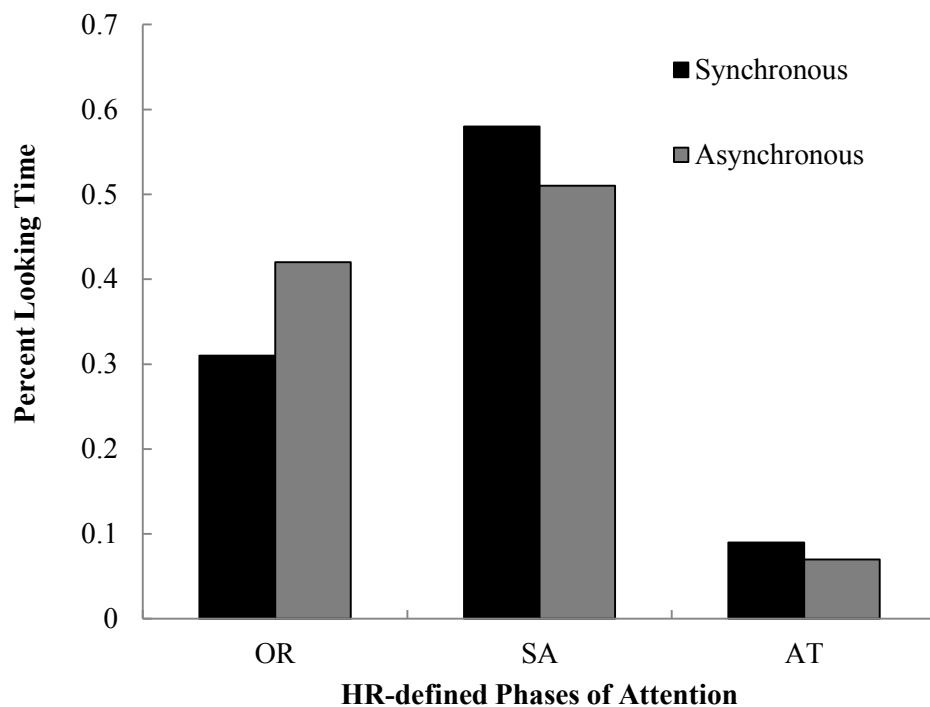
Figure 2. Percentage of looking time as a function of each HR-defined phase of attention for the
synchronous and asynchronous conditions from the Curtindale et al. (2011) study.

Results for 4-month-olds, the age of interest in the current study, were similar to those

presented above. Infants had nearly the same first look duration to the synchronous ($M = 30.65$,

$SD = 34.17$) and asynchronous ($M = 21.24$, $SD = 27.20$) stimuli, $t(33) = .07$, $p = .948$. However,

significantly less of that time was spent in an OR phase of attention for the synchronous ($M = $

0.09, $SD = 0.24$) compared to the asynchronous condition ($M = 0.51$, $SD = 0.50$), $t(24.60) = 3.26$,

$p = .003$. Percentage of time spent in an OR phase of attention, particularly during the first look,

reflects the effectiveness of a stimulus is in capturing or getting attention. Infants also spent more time in a SA phase of attention during the synchronous ($M = 0.72$, $SD = 0.44$) compared to the asynchronous condition ($M = 0.40$, $SD = 0.32$), $t(31.21) = -2.47$, $p = .019$. Four-month-old infants oriented more quickly and spent more time in an attentive state during the synchronous compared to the asynchronous condition, indicating that temporal synchrony was effective in capturing attention and inducing an attentive state.

Aims of this Research

This study was designed to extend previous research on the influence of attention-getting events on infant attention, perception, and learning. Specifically, behavioral and physiological measures of attention were used to examine whether a brief exposure to temporally synchronous events was effective in capturing attention and bringing an infant to an attentive state. It was hypothesized that the presentation of a dynamic, multimodal AG, especially one featuring temporal synchrony, would capture infant attention and elicit an attentional state more effectively than the no AG, control condition. The second aim of this study was to examine how the presumed induction of the attentional state affected performance on a discrimination task administered after exposure to the AG. It was expected that effects of the AG would extend to the discrimination task, with infants who experienced a temporally synchronous AG performing significantly better in than infants in the asynchronous AG and no AG control conditions.

<div align="center">

Method

</div>

Participants

Fifty-two 4-month-old infants were recruited from an area of reasonable driving distance from the KU Edwards Campus (including towns of Lenexa, Prairie Village, Overland Park, Olathe, Shawnee, DeSoto, Gardner, Stillwell, Leawood, etc.). This population is predominantly

upper-middle class and the sample had the following ethnic composition: White, Non-Hispanic, (84%), Hispanic (4%), and other/more than one ethnicity (12%). Prospective participants' names were first obtained from public birth notices (newspapers, word of mouth, etc.). After screening for mortality, information about these births was placed in a password-protected database. In addition to public birth notices, a list of families willing to participate in KU research projects from the Participant Recruitment and Management Core (PARC) was obtained. Families living in the recruitment area were mailed an introductory letter and then contacted via phone, when possible, to answer any questions that the parent had about the study, and schedule a visit. Of the 52 infants tested, eight were excluded due to prematurity ($n = 4$) or computer/experiment error ($n = 4$). The forty-four infants included in the final sample, 27 females and 17 males, were full term (i.e., gestational lengths of more than 37 weeks) and had no medical history that involved visual or auditory problems.

Table 2

Demographic Information

	M	*SD*
Infant		
Age at Testing (days)	127.13	13.28
Maternal		
Age (years)	30.79	3.85
Education (years)	16.28	2.03
Paternal		
Age (years)	31.81	5.70
Education (years)	16.52	2.16

Apparatus

Testing set-up. During testing, infants were seated in a car seat approximately 112 cm away from a 30-inch (76 cm) monitor to complete an attention-getter session (visual angle of

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approximately 6.5°), followed by a discrimination task (visual angle of approximately 9.7°). All stimuli were presented in the center of the monitor using Windows Media Player. A video camera, placed at the base of the monitor, recorded and transmitted an image of the infant's face, specifically the eyes, to an adjacent room. A trained observer coded the direction and duration of infants' looks to the stimulus by pressing a button that timed looks, recorded accumulated time, and interfaced with the HR data acquisition package (see below). All sessions were recorded on DVD. Parents remained with the infant in the testing room, but were instructed to stand behind the car seat to avoid distracting the infant.

Measurement of heart rate. Infants' HR was measured with shielded Ag-AgCl electrodes placed on either side of the chest and grounded with an unshielded electrode just above the navel. The electrocardiogram (EKG) was digitized using a data acquisition interface and a second computer running software from a commercial data acquisition package (BioPac, Inc., Santa Barbara, CA) configured for psychophysiological recording, with a sampling rate of 250 Hz. The data acquisition interface also received input from the button being used to record looking data and mark stimulus onset, so that the HR record was synchronized with stimulus events and the coding of visual fixations.

Procedure

When the parent and infant arrived at the lab, the experimental procedures were explained in detail and informed consent was obtained. Parents then completed a demographic and health questionnaire. Prior to beginning the task, electrodes were placed on the abdomen and chest of the infant to obtain a baseline measure of HR.

Attention-Getter. The attention-getter session included exposure to a multisensory and dynamic synchronous or asynchronous AG for 10 seconds, or a no AG (control) condition

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matched on duration. The temporally synchronous stimulus consisted of a green dot on a white background that loomed and contracted in synchrony with a rhythmic beep (170 ms). The beep occurred each time the circle reached the largest point and appeared to change direction, at a rate of 0.5 Hz. Infants, randomly assigned to the asynchronous condition, were presented with the same looming and contracting green dot and sound; however, each auditory event was shifted so that it preceded each change in direction by 400 ms – a value that was carefully chosen from the literature on infant perceptions of temporal synchrony (see Figure 3).

Perceptions of temporal synchrony do not require that the auditory and visual events occur at precisely the same. Rather, there is an intersensory temporal synchrony window (ITSW) that marks the point at which an individual first begins to perceive asynchrony. Events that occur within the window or in what is referred to as the "psychological present" (Fraisse, 1982) are perceived as belonging together; whereas events that occur outside the window are considered temporally separate (Lewkowicz, 1996). Adults report perceptions of temporal asynchrony when the auditory event precedes the visual event by 65-78 ms. However, when the visual event precedes the auditory event, temporal synchrony is not perceived until 112-187 ms (Dixon & Spitz, 1980; McGrath & Summerfield, 1985; Lewkowicz, 1996). Relevant to the current study is the size of the ITSW in infancy. Infants, 2 to 8 months of age, can accurately detect changes in synchrony when the sound precedes the visual event by 350 ms and when the visual event precedes the sound by 450 ms (Lewkowicz, 1996). In the synchronous condition, a beep marked each direction reversal of the looming and contracting green dot. The infant should have perceived the auditory event and the visual event as occurring simultaneously. In the asynchronous condition, the beep preceded the change in direction by 400 ms, which is outside

of the ITSW for 4-month-old infants. Therefore, the infant should have perceived the auditory

and visual events as temporally separate and asynchronous.
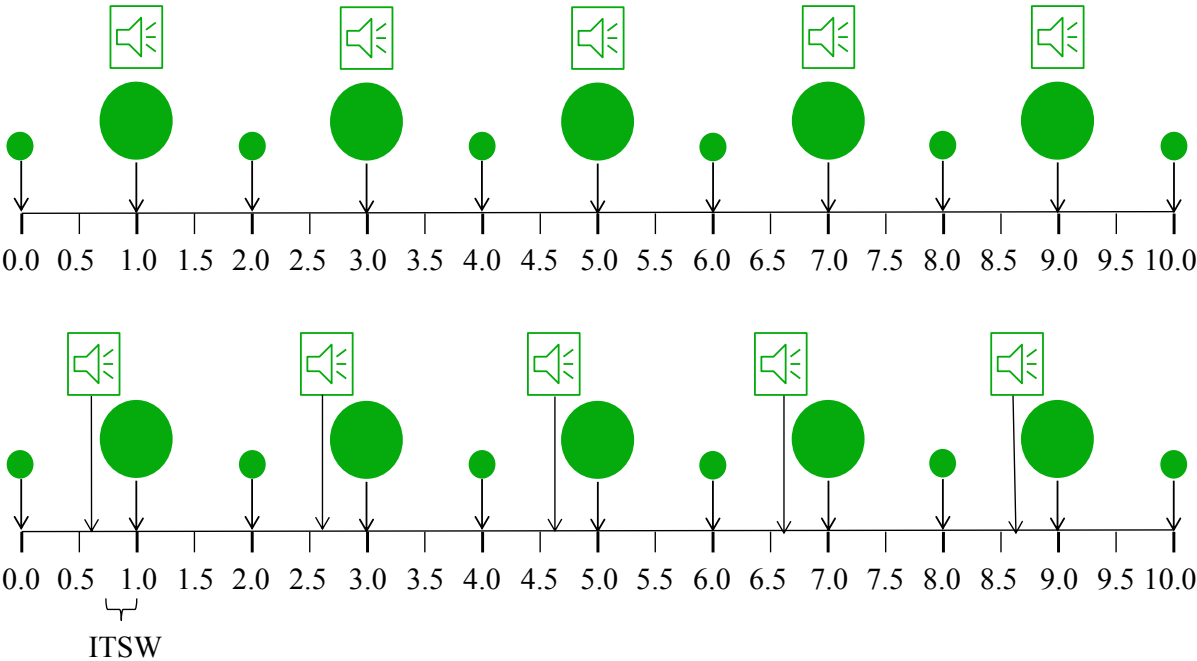
Figure 3. Temporal breakdown of events for the synchronous and asynchronous attention-getter conditions.

Evaluation of attentional capture and attentional state focused on three dependent

measures: look duration, heart rate (beats per minute), and proportion of time spent in HR-

defined phases of attention. Effectiveness of an event in capturing or getting attention is reflected

in the speed with which an infant orients to a stimulus. A common behavioral measure of how

quickly an infant orients is latency to turn toward a stimulus (Cohen, 1972). In the current study,

it was not possible to assess latency, because the task did not begin until the infant was looking

at the screen. This was done to ensure that infants looked at the display at least once during the

AG session. Physiologically, attentional capture or attention-getting can be evaluated using the

OR phase of attention, with attention-getting events yielding less time spent in an OR phase of

attention. Attentional state is reflected in deeper/longer HR decelerations associated with infant looking (Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; Colombo et al., 2001).

Discrimination task. In order to assess whether the preliminary stimulus exposure had any carry-over effects beyond the initial induction, a discrimination task was administered following the AG session. It was hypothesized that the induction of an attentional state by one or more of the AGs would, in turn, yield better performance on the discrimination task. A common technique for assessing infant perception and cognition is to first provide infants with the opportunity to process and encode a stimulus by using a familiarization procedure. Following familiarization, infants are presented with test trials to assess discrimination related to the stimulus that was encoded. Successful discrimination is typically indicated by systematic preference for or increased looking to the novel stimulus. Researchers have argued that a preference for the novel stimulus indicates complete encoding of the familiar stimulus, while a preference for the familiar stimulus reflects incomplete encoding during familiarization (Colombo, 1993; Sophian, 1980).

Familiarization. Infants were first presented with a fixed 30-second familiarization block consisting of a bright, colorful stimulus (see Figure 4). The fixed familiarization was chosen over an infant-controlled familiarization (e.g., habituation) because fixed familiarization provides an experimenter-controlled assessment of individual differences in the rate of encoding during a brief amount of time, and thus allowing the measurement of the differential influences of AG type.

Test. Following familiarization, infants were tested for discrimination of the familiarized stimulus from a novel stimulus using a partial-lag design test condition (see Bertenthal, Haith, & Campos, 1983). This design allows for the assessment of infants' ability to discriminate between

familiar and novel stimuli while controlling for the spontaneous recovery (i.e., increased looking following familiarization, regardless of stimulus novelty). Normally, tests for discrimination involve presenting infants with a change to stimuli following familiarization, and this usually requires a no-change control condition (as a control for spontaneous recovery in looking) that increases the sample size without contributing to the statistical power of the study for detecting infants' ability to discriminate. Given certain assumptions, the partial-lag design theoretically allows testing for and correction of spontaneous recovery while still providing access to discrimination data in all infants tested.

Four test trials were presented in alternating order, two with the familiar stimulus (F) and two with the novel stimulus (N). Half of the infants were immediately presented with the novel stimulus (i.e., immediate change condition – NFNF), while the other half saw the familiar stimulus for one more trial immediately after familiarization (i.e., lagged change condition – FNFN). This partial-lag design is illustrated in Figure 4. To ensure infants' ability to discriminate between the familiar and novel stimuli, the shape was varied (e.g., square pattern containing a vs. a circular, sun-like pattern). The use of an additional presentation of the familiar stimulus in the lagged change condition allows for the assessment of spontaneous recovery. The expected response pattern was for infants to increase looking to the novel presentations, irrespective of whether they occur immediately or are lagged for a trial. It was also expected that infants would not increase looking to the familiar stimulus during the additional familiarization trials in the lagged condition. The procedure thus controlled for spontaneous recovery between-subjects (by comparing recovery in the immediate and lagged conditions), while allowing for the potential use of all subjects for evidence of recognition (by computing recovery to the novel stimulus collapsed across both conditions).

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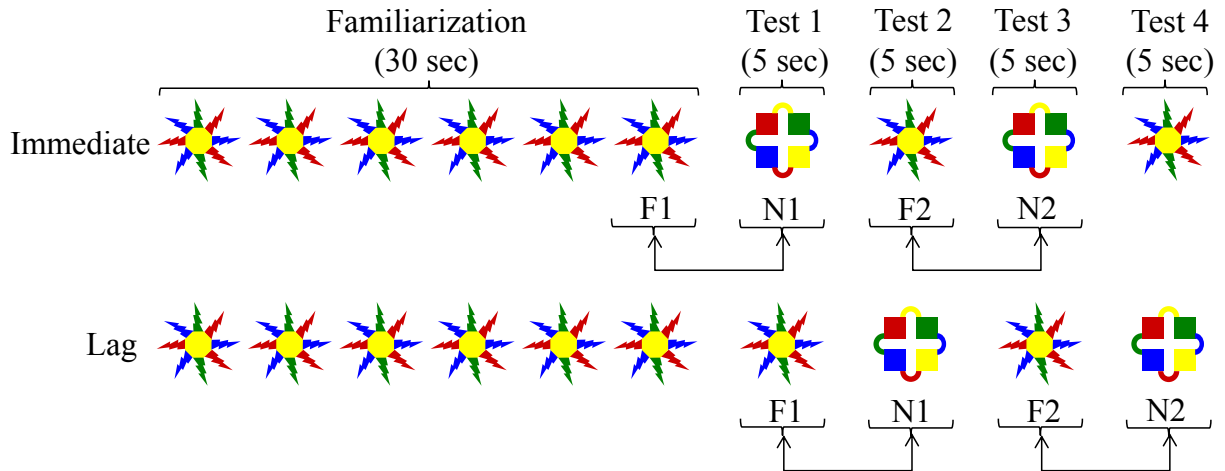
Figure 4. Familiar and novel stimuli for the immediate and lagged change conditions.

Data Reduction: Heart Rate-Defined Phases of Attention

Infants' HR was converted from graphical representation of the *qrst* EKG complex into a numerical data file for analysis using BioPac, Inc. software that identifies and stores the time code of the R waves from the digitized EKG. The time codes from stimulus events onset and infant behaviors (look onsets and offsets) were interspersed among the R-wave time stamps to provide a complete sequential record of the infant's session. The sequential file was analyzed on a beat-by-beat basis. Infants' looking was parsed into categories of OR, SA, and AT using Microsoft Excel.

Typically, SA is defined as looking accompanied by at least five consecutive beats below the median HR observed in a prestimulus baseline period (Richards, 1997). The relatively short look durations in the current study made calculations of SA for any beat below the median HR observed in the prestimulus period a necessity. Orienting was defined as that period of looking prior to the attainment of SA, and AT was defined as looking that continues after SA, but during which HR has returned to at least the prestimulus median baseline level. Pre-AG median HR,

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collected prior to the AG, served as the prestimulus baseline for both the AG session and the discrimination task. This baseline HR measure was ideal in the present study, because it was unaffected by AG type. A simple AG type (synchronous, asynchronous, vs. control) ANOVA on pre-AG median HR revealed no significant differences, $F(2, 41) = 1.93$, $p = 0.16$. However, HR did vary significantly across the task. When median HR was entered into a prestimulus baseline type (pre-AG, post-AG, and post-familiarization) x AG type (synchronous, asynchronous, vs. control) mixed-model ANOVA, there was a significant main effect of baseline type, $F(2, 82) = 19.42$, $p < .001$. A significant interaction between baseline type and AG type, revealed that median HR varied across the session as a function of AG type, $F(4, 82) = 6.52$, $p < .001$. Refer back to Figure 1 for an example of how these phases will be coded within the context of a single look. The amount of time observed in each of the phases within the AG and familiarization periods were summed to create the variables used in the analyses.

Results

The analyses were carried out in two stages to address the aims of the study. The first set of analyses addressed the question: does a multimodal AG, especially one with synchronous auditory and visual input, effectively capture attention and elicit an attentional state in infancy? The second set of analyses addressed the question: does the brief presentation of a multimodal AG, especially one with synchronous auditory and visual input, produce carry-over effects resulting in superior performance in a discrimination task?

Attention-Getter

Behavior. To determine whether the temporally synchronous AG was more effective in attracting and maintaining attention behaviorally (i.e. longer look durations) compared to the asynchronous and control AGs, we conducted a simple AG type (synchronous, asynchronous, vs.

control) ANOVA on total look duration. Look duration varied significantly as a function of AG type, $F(2, 41) = 11.59$, $p < .001$. Fisher's Least Significant Difference (LSD) comparisons indicated that infants spent significantly less time looking in the no AG, control condition ($M = 2.99$, $SE = 0.72$) compared to the synchronous ($M = 7.44$, $SE = 0.72$), $p < .001$, and asynchronous ($M = 7.00$, $SE = 0.72$), $p < .001$, conditions, but looking in the synchronous and asynchronous AGs did not vary from one another ($p > .05$). It was not surprising that looking was similar in the synchronous and asynchronous AG conditions. Previous studies on the effects of synchrony on infant attention have reported the physiological rather than behavioral differences (Curtindale, et al. 2011; Pizur-Barnekow, et al., 2008; Reynolds, et al., 2013).

Heart rate. The effect of AG type on HR, measured in beats per minute, was assessed in two ways: 1) median HR two seconds before and two seconds after the AG session; 2) overall, average HR across the 10-second AG session. First, to examine whether the temporally synchronous AG was effective in eliciting an attentional state (i.e. a decrease in HR), we compared HR before and after the AG session in an AG type (synchronous, asynchronous, vs. control) x baseline (before AG, after AG) mixed-model analysis of ANOVA was performed. This analysis revealed a significant main effect of baseline $F(1, 41) = 23.07$, $p < .001$ and a marginally significant main effect of AG type $F(2, 41) = 3.20$, $p = .05$. These effects were qualified by a significant interaction between AG type and baseline HR $F(2, 41) = 8.28$, $p = .001$ (see Table 2). Simple effects tests to explore the nature of this interaction indicated that HR decreased significantly following the synchronous $F(1, 41) = 24.97$, $p < .001$ and asynchronous $F(1, 41) = 14.08$, $p = .001$ AGs, while there was no significant decrease in HR in the control condition $F(1, 41) = 0.21$, $p = .65$.

Table 3

Means and Standard Deviations of Median Heart Rate

| | HR Before AG (bpm) | | HR After AG (bpm) | |
AG Type	*M*	*SD*	*M*	*SD*
Synchronous	143.33	12.22	134.14	13.36
Asynchronous	153.86	11.92	144.38	15.04
Control	148.26	7.19	149.39	10.04

The influence of the AG on HR was further investigated with a simple AG type (synchronous, asynchronous, vs. control) ANOVA on average HR. As expected, there was a significant effect of AG type on average HR, $F(2, 41) = 3.74$, $p =.032$. Fisher's LSD comparisons indicated that HR was significantly lower in the synchronous AG condition ($M = 136.69$, $SE = 3.30$) compared to the asynchronous ($M = 146.35$, $SE = 3.36$), $p = .045$, and no AG, control ($M = 148.47$, $SE = 3.24$), $p = .014$, conditions, but HR in the asynchronous and control conditions did not vary from one another ($p > .05$). It is important to note that these differences in HR were not present prior to the AG session. A simple AG type (synchronous, asynchronous, vs. control) ANOVA on median HR revealed that at the start of the AG session HR was similar across all AG types, $F(2, 41) = 1.93$, $p = 0.16$.

We explored the potential changes in HR across the 10-second AG session by plotting HR as a function of beats separately for each infant. The HR curve of each infant was then fit with a quadratic function ($y = ax^2 + bx + c$). This yielded an intercept, linear term, and quadratic term for every infant. These variables were entered into separate AG type (synchronous, asynchronous, vs. control) ANOVAs. The intercept varied significantly as a function of AG type, $F(2, 39) = 3.43$, $p = .042$. Fisher's LSD comparisons indicated that the intercept in the no AG, control condition ($M = 146.60$, $SE = 2.06$) was significantly lower than the intercept in the

asynchronous ($M = 159.93$, $SE = 4.36$), $p = .014$. The intercept in synchronous condition ($M = 151.25$, $SE = 3.93$) was not significantly different from the asynchronous or no AG control conditions ($ps > .05$). The linear term also varied significantly as a function of AG type, $F(2, 39) = 3.95$, $p = .028$. Fisher's LSD comparisons indicated that the linear term in the no AG, control condition ($M = 0.26$, $SE = 0.19$) was different from the linear term in the synchronous ($M = -1.78$, $SE = 0.62$), $p = .019$, and asynchronous ($M = -1.84$, $SE = 0.83$), $p = .020$, conditions, but the linear term in the synchronous and asynchronous AGs were not significantly different ($p > .05$). The quadratic term did not vary as a function of AG type, $F(2, 39) = 1.50$, $p = .24$. An average intercept, linear term, and quadratic term were calculated for each AG type and plotted in Figure 5. Across the AG session, HR for the infants presented with a synchronous or asynchronous AG declined (i.e. negative slope), while HR did not change for infants in the no AG, control condition. This finding suggests that exposure to an attention-getting stimulus for 10-seconds produced a decline in HR, which reflects the attainment of an attentional state.
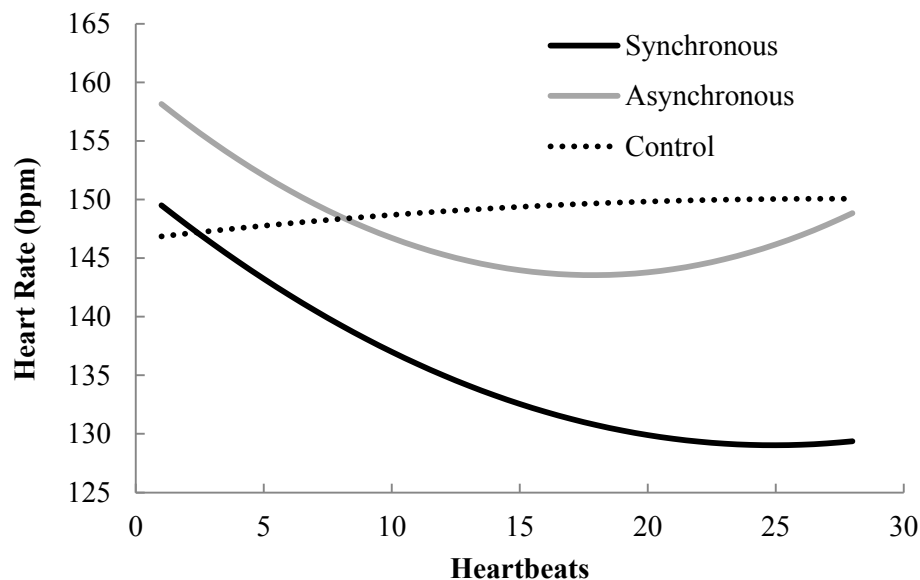

Figure 5. Heart rate as a function of heartbeats during the attention-getter session for the synchronous, asynchronous, and no attention-getter, control conditions.

Heart rate-defined phases of attention. The influence of AG type on physiological measures of the capture of attention and induction of attentional state was investigated for total time spent looking and heart rate in each HR-defined phase of attention. First, we conducted an AG type (synchronous, asynchronous, vs. control) x HR phase (OR, SA, AT) mixed-model ANOVA on total looking time to determine whether:

1) infants oriented more quickly (i.e. less time spent in an OR phase of attention), indicating attentional capture, to the synchronous AG, compared to the asynchronous AG and no AG control; and

2) the temporally synchronous AG was more effective in eliciting an attentional state (i.e. more time spent in a SA phase of attention) compared to the asynchronous and AG control conditions.

There were significant main effects of HR phase, $F(2, 82) = 44.27$, $p < .001$ and AG type, $F(1, 41) = 11.53$, $p < .001$. These were qualified by a significant interaction between HR phase and AG type, $F(4, 82) = 5.62$, $p = .004$), plotted in Figure 6. Fisher's LSD comparisons revealed no effect of AG type on time spent in OR or AT ($p > .05$); infants spent similar amounts of time in an OR phase of attention and in an AT phase of attention regardless of AG type. As anticipated, the amount of time spent in SA during the AG differed significantly as a function of AG type; however, Fisher's LSD comparisons revealed an effect of AG regardless of temporal synchrony. Infants in the no AG condition spent significantly less time in a SA ($M = 1.76$, $SE = 0.80$), compared to the synchronous ($M = 6.12$, $SE = 0.80$), $p < .001$ and asynchronous ($M = 5.40$, $SE = 0.82$), $p = .003$ AGs, but time spent in SA was not significantly different for the synchronous and asynchronous AGs were not significantly different ($p > .05$). Although there were no significant effects of temporal synchrony, note that the pattern is similar to the pilot data

in Figure 2. The synchronous condition yielded less time spent in OR and more time spent in SA compared to the asynchronous condition.

To explore the immediate effectiveness of the synchronous AG in capturing or getting attention, an independent samples t-test was used to compare percentage of time in an OR phase of attention during the first look to the synchronous ($M = 0.19$, $SD = 0.34$) and asynchronous ($M = 0.35$, $SD = 0.44$) stimuli. Although the difference was not significant, $t(27) = -1.08$, $p = .288$, it does reflect the expected pattern of results.
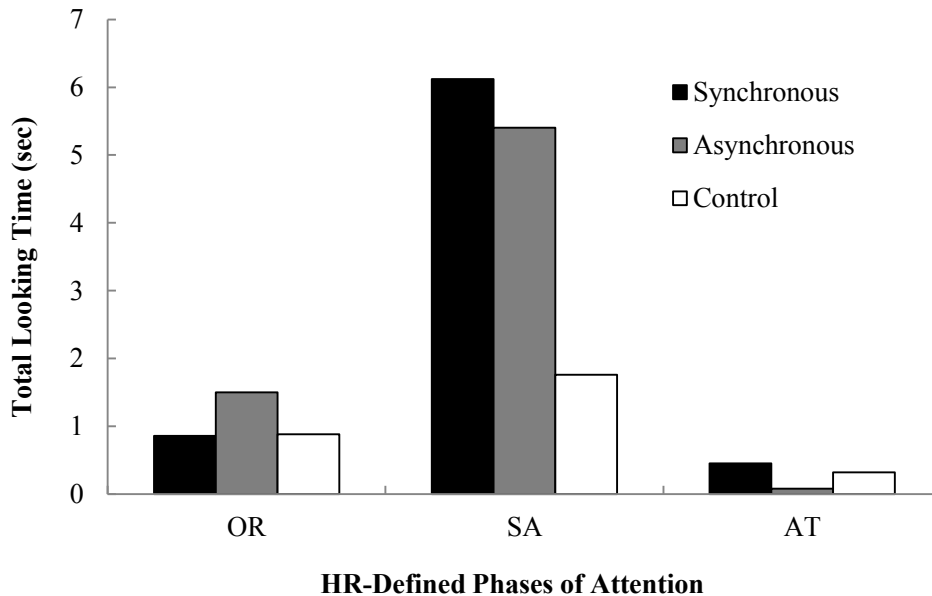
Figure 6. Total looking time as a function of each HR-defined phase of attention during the attention-getter session for the synchronous and asynchronous attention-getters and the no attention-getter control.

During the AG session, it was not possible to parse all infant looks into all three HR-defined phases of attention. For example, some infants spent all of their looking time in SA, while others failed to move beyond OR. This resulted in only nine infants with complete

datasets, including HR for OR, SA, and AT. Therefore, a mixed model ANOVA was not feasible. Instead, we conducted separate AG type (synchronous, asynchronous, vs. control) ANOVAs on HR during OR, SA, and AT. Heart rate did not differ significantly during SA, $F(2, 32) = 1.39$, $p = .265$, and AT, $F(2, 9) = 0.39$, $p = .686$. However, during OR, heart rate varied significantly as a function of AG type, $F(2, 22) = 3.89$, $p = .036$. Fisher's LSD comparisons revealed that HR was significantly lower during OR for the synchronous AG ($M = 143.28$, $SE = 3.83$) compared to the asynchronous AG ($M = 159.39$, $SE = 4.81$), $p = .011$. Heart rate during OR in the no AG, control condition ($M = 153.049$, $SE = 3.44$) did not differ significantly from the synchronous or asynchronous AG conditions ($ps > .05$).

Discrimination Task

The results of the discrimination task were used to examine the carry-over effects of the AG session. Behavioral and physiological data from the familiarization and test trials were analyzed separately for the familiarization trials. The test trials focused on behavioral measures of discrimination performance.

Familiarization.

Behavior. We conducted an AG type (synchronous, asynchronous, vs. control) ANOVA on total familiarization look duration to determine whether the AG session influenced capture and maintenance of attention during familiarization. The analysis revealed no significant effect of AG type, $F(2, 39) = 2.16$, $p = .129$ on look duration during familiarization. The amount of time infants spent looking during familiarization was not significantly different for the no AG ($M = 15.70$, $SD = 8.41$), synchronous ($M = 20.04$, $SD = 7.30$) or asynchronous ($M = 21.13$, $SD = 5.66$) conditions.

Although total look duration during familiarization did not differ as a function of AG type, we explored changes in look duration across time by separating the 30-second familiarization block into six 5-second epochs (see Figure 4 for design and Figure 7 for look durations). Overall, look duration, per 5-second epoch, did not decline rapidly across trials as predicted. The decline in looking or habituation that occurs over time and reflects learning of the stimulus is an essential part of familiarization. When looking does not decrease it may indicate that the stimulus was not fully encoded and as a result it may not be possible for the infant to show the recovery (increase in looking) necessary for discrimination during the test trials. To determine the percentage of infants who habituated during familiarization, we classified each infant as a habituator or nonhabituator. Habituation was achieved when an infant's last look was 50% less than his or her baseline looking (i.e. the average of the first two looks). In this study only 56% of the infants habituated during familiarization. When changes in look duration across the 30-second familiarization block (separated into six, 5-second epochs) were plotted for infants categorized as habituators, the decline in looking is closer to the initially expected pattern (see Figure 7).

A *chi* square test for independence, performed to investigate the relationship between habituation and AG type, was not significant. The analysis revealed that of the 25 infants who habituated, there were equal numbers of infants in the synchronous ($n = 9$), asynchronous ($n = 6$), and control ($n = 10$) conditions, χ^2 (2, N=44) = 1.77, $p = .413$. Because approximately half of the infants did not habituate, it was possible we would not see the anticipated discrimination performance results. Therefore, performance on the discrimination test was analyzed separately using two datasets: 1) all infants; and 2) only infants who met the habituation criteria during familiarization.
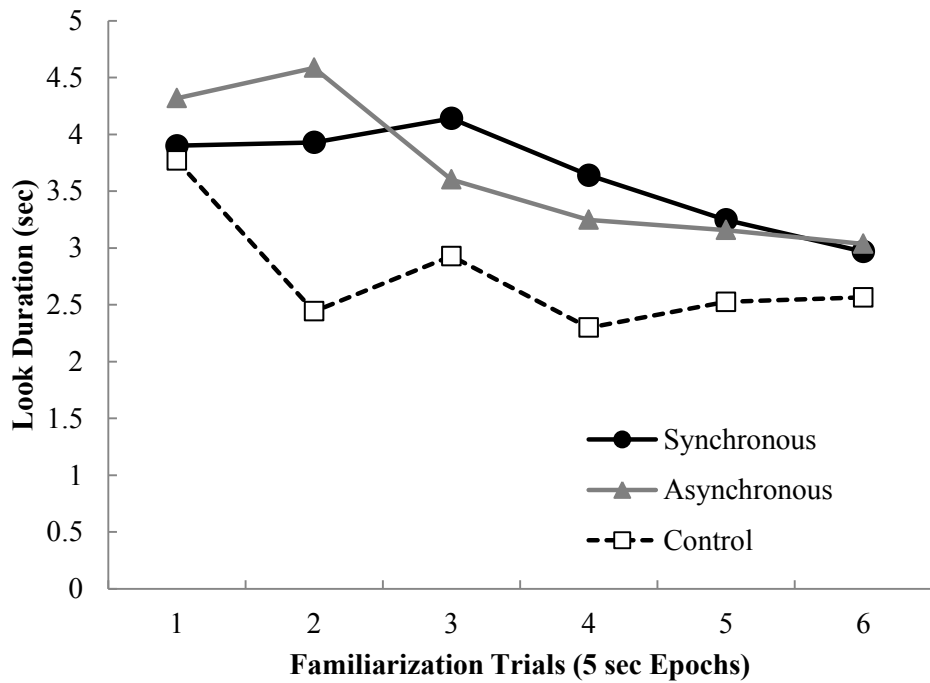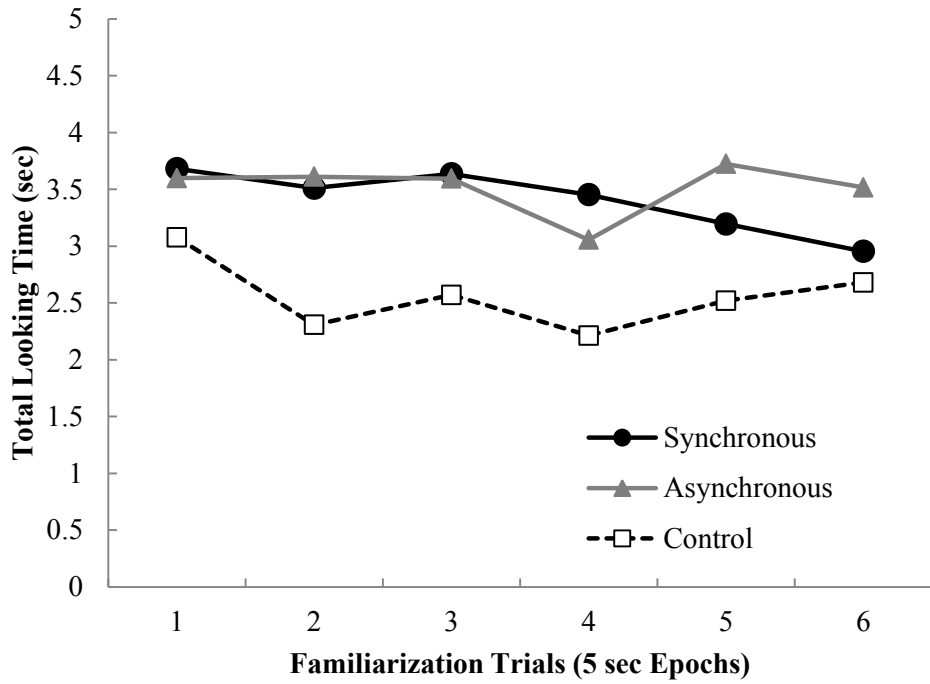
Figure 7. Total looking time across familiarization trials for the different attention-getters for all infants (top) and infant who habituated (bottom).

Heart rate. We predicted that the type of stimulus presented during the AG session to produce changes in HR and attentional state that continued in the discrimination task. Specifically, we expected HR to remain lower for infants who were in the synchronous AG condition compared to the asynchronous and control AG conditions. The effect of AG type on average HR during familiarization was investigated using a simple AG type (synchronous, asynchronous, vs. control) ANOVA. There was a significant effect of AG type on average HR during familiarization, $F(2, 39) = 3.60$, $p = .037$. Fisher's LSD comparisons indicated that HR was significantly higher in the asynchronous AG condition ($M = 158.29$, $SE = 3.44$) compared to the synchronous ($M = 146.84$, $SE = 3.20$), $p = .019$, and no AG, control ($M = 147.6$, $SE = 3.31$), $p = .031$, conditions, but HR in the synchronous and control conditions did not vary from one another ($p > .05$). Although we did not see the anticipated difference in HR between the synchronous and control AG conditions, temporal synchrony effects persisted, with significantly higher HR for infants presented with the asynchronous AG compared to those in the synchronous condition.

We explored the potential changes in HR across the 30-second familiarization block by plotting HR as a function of beats separately for each infant. The HR curve of each infant was then fit with a quadratic function ($y = ax^2 + bx + c$). This yielded an intercept, linear term, and quadratic term for every infant. These variables were entered into separate AG type (synchronous, asynchronous, vs. control) ANOVAs to examine the differences in the shape of the HR curves.

The intercept varied significantly as a function of AG type, $F(2, 39) = 4.21$, $p = .022$. Fisher's LSD comparisons indicated that the familiarization intercept for infants who experienced synchrony during the AG session ($M = 137.96$, $SE = 3.39$) was significantly lower than the

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intercept in the asynchronous (M = 151.06, SE = 3.34), p = .006. The intercept for infants in the no AG, control condition (M = 145.10, SE = 2.81) was not significantly different from the synchronous or asynchronous conditions (ps > .05). The linear term also varied significantly as a function of AG type, $F(2, 39)$ = 4.16, p = .023. Fisher's LSD comparisons indicated that the linear term in the asynchronous condition (M = -0.01, SE = 0.33) was different from the linear term in the synchronous (M = 0.36, SE = 0.35), p = .010, and no AG, control (M = 0.30, SE = 0.38), p = .031, conditions, but the linear term in the synchronous and control AGs were not significantly different (p > .05). The quadratic term varied significantly as a function of AG type, $F(2, 39)$ = 5.46, p = .008. Fisher's LSD comparisons indicated that the quadratic term in the asynchronous condition (M = 0.0014, SE = 0.0013) was different from the quadratic term in the synchronous (M = -0.0035, SE = 0.0011), p = .007, and no AG, control (M = -0.0014, SE = 0.0012), p = .005, conditions, but the quadratic term in the synchronous and control AGs were not significantly different (p > .05).

An average intercept, linear term, and quadratic term during familiarization were calculated for each AG type and plotted in Figure 8. Recall that during the AG session, the presence of an attention-getting stimulus, regardless of temporal synchrony, yielded decelerations in HR while HR in the no AG, control condition remained the same (see Figure 5). Across the familiarization block, HR for the infants presented with a synchronous AG or no AG increased slightly then declined, while HR increased for infants who experienced an asynchronous AG. This finding suggests that exposure to a brief, attention-getting stimulus prior to familiarization produces lasting changes in in HR, which may reflect changes in attentional state. In particular, the presentation of an asynchronous stimulus results in a pattern of increasing HR, which may reflect difficulty achieving an attentional state.
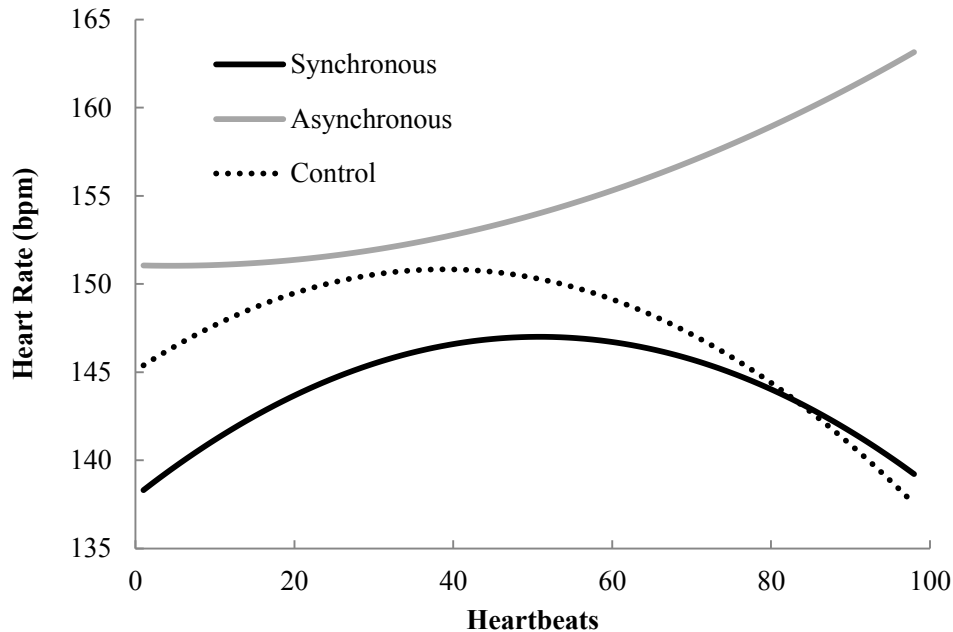
Figure 8. Heart rate as a function of beats during familiarization for the synchronous, asynchronous, and no attention-getter, control conditions.

Heart rate-defined phases of attention. The influence of AG type on physiological measures of attentional state during familiarization was investigated for total time spent looking and heart rate in each HR-defined phase of attention. First, an AG type (synchronous, asynchronous, vs. control) x HR phase (OR, SA, AT) mixed-model ANOVA was run on total looking time spent in each phase during familiarization (see Figure 9). There was a significant main effect of HR phase, $F(2, 78) = 9.52$, $p < .001$. Fisher's LSD comparisons revealed that infants spent significantly more time in a SA phase of attention ($M = 9.86$, $SE = 1.11$) than in OR ($M = 4.80$, $SE = 0.81$), $p = .004$, or AT ($M = 4.27$, $SE = 0.72$), $p < .001$). Infants spent roughly the same amount of time in OR and AT phases of attention ($p > .05$).This pattern is typical in studies of infant attention. The main effect of AG type and the interaction between HR phase and AG type were not significant (p > .05). Despite the differences in HR patterns described above,

the amount of time spent in each phase of attention did not differ significantly as a function of AG type.
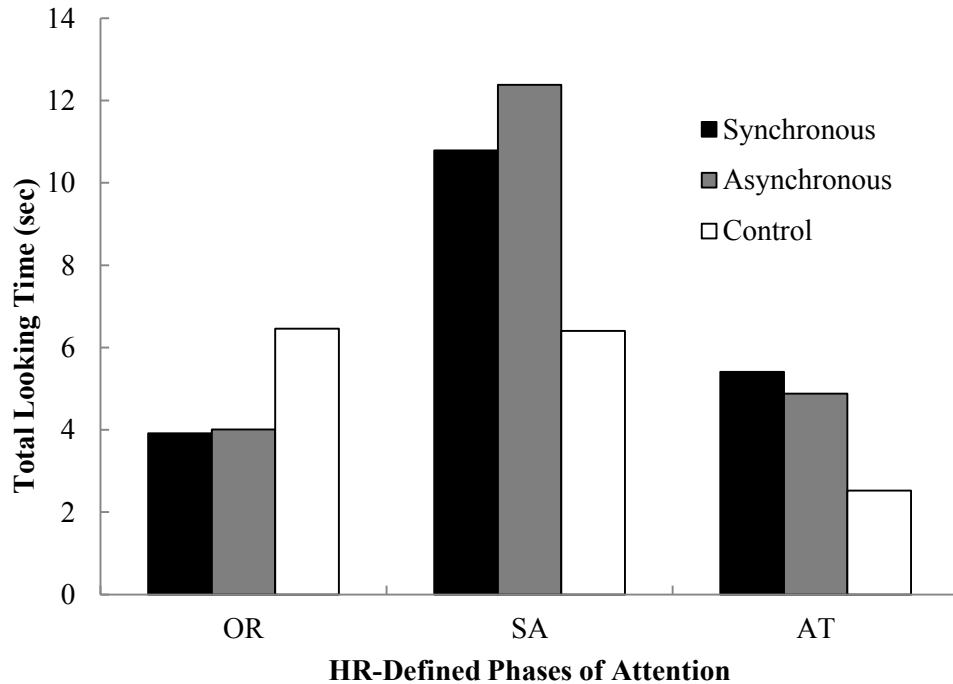
Figure 9. Total looking time as a function of each HR-defined phase of attention during familiarization for the synchronous and asynchronous attention-getters and the no attention-getter control conditions.

To further examine the influence of AG type on attentional state during familiarization, an AG type (synchronous, asynchronous, vs. control) x HR phase (OR, SA, AT) mixed-model ANOVA was performed on HR in each phase of attention. Heart rate during SA was expected to be significantly lower in the synchronous AG condition compared to the asynchronous and no AG, control condition. There was a significant main effect of HR phase, $F(2, 52) = 69.02$, $p <$ .001. Fisher's LSD comparisons revealed HR was significantly lower in a SA phase of attention ($M = 145.48$, $SE = 2.30$) than in OR ($M = 154.25$, $SE = 2.14$), $p = .01$, or AT ($M = 152.48$, $SE = 2.28$), $p < .001$). Based on the method of calculating the HR-defined phases of attention, this

result was not surprising. Heart rate was also significantly different during OR compared to AT, $p < .001$. The main effect of AG type and the interaction between HR phases and AG type were not significant ($p > .05$). Heart rate in each phases of attention did not differ as a function of AG type. Although the interaction between HR phases and AG type was not significant, mean HR during SA did follow the pattern we expected. Heart rate during SA was slightly higher for the asynchronous AG ($M = 150.48$, $SD = 13.48$) compared to the synchronous ($M = 141.88$, $SD = 13.93$) and no AG conditions ($M = 143.55$, $SD = 7.7$).

Test. Analysis of discrimination performance during test trials examined the potential carry-over effects of the AG session. Familiarization produced no significant behavioral effects of AG type, but the differences in physiological measures suggest that AG type differential influenced attentional state. It was predicted that infants who experienced a temporally synchronous AG (or the no AG, control) would perform significantly better in the discrimination task (i.e. increased looking to the novel event during test trials) compared to infants in the asynchronous AG condition. The analyses were carried out in two steps: 1) test for spontaneous recovery to ensure that the increase in looking to the novel stimulus was linked to the novel stimulus and not just a regression to the mean or spontaneous recover, and 2) comparison of the final familiarization trial to the first novel trial to evaluate discrimination performance.

Test for spontaneous recovery. Paired-sample *t*-tests were conducted on the sixth familiarization trial versus the first test trial for both the immediate and lagged change groups to assess spontaneous recovery. As expected, infants in the immediate condition showed significant recovery of looking time from the sixth familiarization trial ($M = 3.24$, $SD = 1.29$) to the first test trial ($M = 4.05$, $SD = 0.91$), $t(20) = 3.44$, $p = .003$, whereas infants in the lagged condition did not (sixth familiarization trial: $M = 2.80$, $SD = 1.54$; first test trial: $M = 3.35$, $SD = 1.11$), $t(20) =$

1.76, $p = .09$). These results ruled out spontaneous recovery, which allowed for the collapse of look duration across test conditions.

Discrimination performance. To explore discrimination of the familiar and novel stimuli, we entered looking times during the first familiar and first novel test trials into a set (familiar vs. novel) x AG type (synchronous, asynchronous, vs. control) mixed-model ANOVA. There were no significant effects set ($F(1, 39) = 1.18$, $p = .19$) or AG type ($F(2, 39) = 0.79$, $p = .46$), and no interaction ($F(2, 39) = 1.33$, $p = .28$). Infants did not show the expected response recovery in any of the AG type conditions. This null effect may be the result of incomplete habituation during familiarization.

Look durations to the novel and familiar stimuli for AG type were further investigated by classifying infants in terms of their preference for the first presentation of the novel stimulus during testing. A novelty response score was computed by dividing the duration of looking to the first novel stimulus by the amount of time the infant spent looking during the first familiar stimulus plus the duration of looking to the first novel stimulus or N1/(F1+N1). Then, the minimum value for a score to be considered greater than chance (i.e., .50) at the one-tailed .05 level (0.523), that is $t(41) = 1.17$, $SE = .019$, was calculated. Infants were classified as having a novelty preference (infants with a novelty response ≥ 0.523, $n = 22$) or not having novelty preference (infants with no novelty response < 0.523, $n = 20$). A *chi* square test for independence revealed a significant difference in the number of infants who did and did not show a novelty preferences in the synchronous, asynchronous, and control AG conditions, $\chi^2 (2, N=42) = 6.86$, $p = .032$. The counts are plotted in Figure 10. Fewer of the infants who showed a novelty preference were in the asynchronous AG condition compared to the synchronous AG and no AG conditions. Further, the asynchronous AG condition yielded more infants with no novelty

preference than the synchronous AG and no AG conditions. Data for all infants, habituators and

nonhabituators, were included in these analyses, so the results should be considered carefully.

Analyses of familiarization trials revealed that 44% of infants in this study did not display the

response decrement necessary for response recovery to the novel stimulus. To address this

concern, the next set of analyses only included data for infants classified as habituators.
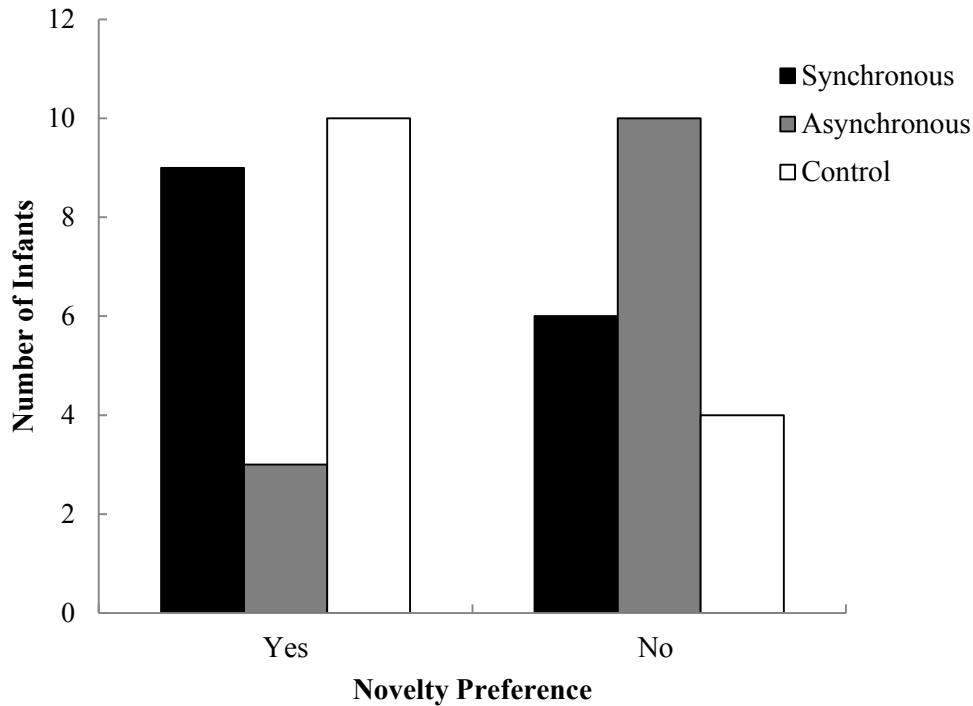
Figure 10. The number of infants with and without a novelty preference for the different AG
conditions.

Test for spontaneous recovery: Habituators. Paired-sample *t*-tests were conducted on

the sixth familiarization trial versus the first test trial for both the immediate and lagged change

groups to assess spontaneous recovery. As expected, infants in the immediate condition showed

significant recovery of looking time from the sixth familiarization trial ($M = 3.15$, $SD = 0.97$) to

the first test trial ($M = 3.88$, $SD = 1.13$), $t(10) = 2.86$, $p = .017$. Infants in the lagged condition

showed the same increase in looking (sixth familiarization trial: $M = 2.59$, $SD = 1.46$; first test trial: $M = 3.51$, $SD = 1.46$), $t(13) = -0.94$, $p = .023$). Look duration increased on the trial immediately following the 30-second familiarization block regardless of stimulus novelty.

Spontaneous recovery is a common concern when assessing infants' ability to discriminate stimuli. Bertenthal and colleagues (1980, 1983) investigated likelihood of spontaneous recovery, developed a partial-lag design that accounts for this chance recovery, and established a method to correct for it. We were able to correct for spontaneous recovery by using the following formula and procedure (modeled after Bertenthal et al., 1983):

$$EST\ LAG = b(FAM6) + c$$

EST LAG is the estimated lag score computed for each infant in the immediate (non-lag) condition, *b* is the regression coefficient (slope), *FAM6* is the look duration of the last (sixth) familiarization trial, and *c* is the intercept (constant). The first step in the procedure was generating a regression equation from the data of infants in the lag condition and using that equation to estimate the lag score (i.e. corrected value for the sixth familiarization trial including the contribution of spontaneous recovery or regression) for the immediate (non-lag) infants who received the novel stimulus on the first test trial. The relationship between the sixth familiarization trial and the first test trial was assessed using linear regression to compute a regression coefficient (slope) and an intercept. These values were then used in the equation above to generate a lag score for each infant in the immediate condition. The obtained lag scores replaced the sixth familiarization trial values.

Discrimination performance: Habituators. The next analysis examined whether infants showed response recovery following the introduction of a novel stimulus, which would indicate discrimination of the familiar and novel stimuli. We entered looking times during the first

familiar and first novel test trials into a set (familiar vs. novel) x AG type (synchronous, asynchronous, vs. control) mixed-model ANOVA. There were no significant effects set ($F(1, 22)$ = .17, p = .68) or AG type ($F(2, 22)$ = 1.89, p = .18), and no interaction ($F(2, 22)$ = 0.05, p = .95). Infants classified as habituators did not show the expected response recovery in any of the AG type conditions. If these infants did habituate and encode the familiar stimulus, they should have showed significant recovery to the novel stimulus.

This surprising null effect was further investigated by classifying infants in terms of their preference for the first presentation of the novel stimulus during testing. A novelty response score was computed by dividing the duration of looking to the first novel stimulus by the amount of time the infant spent looking during the first familiar stimulus plus the duration of looking to the first novel stimulus or N1/(F1+N1). Then, the minimum value for a score to be considered greater than chance (i.e., .50) at the one-tailed .05 level (0.517), that is $t(24)$ = 0.89, SE = .019, was calculated. Infants were classified as having a novelty preference (infants with a novelty response $\geq$ 0.517, n = 12) or not having novelty preference (infants with no novelty response < 0.517, n = 12). One infant showed no preference for the novel or the familiar stimulus (novelty response = 0.5). A *chi* square test for independence revealed no significant difference in the number of infants who showed a novelty compared to a familiarity preference in the synchronous, asynchronous, and control AG conditions, χ^2 (2, N=24) = 0.22, p = .90. Based on novelty scores, half of the infants showed a preference for the novel stimulus, indicating complete encoding of the familiar stimulus and half of the infants showed a preference for the familiar stimulus, which may reflect incomplete encoding during familiarization (Colombo, 1993; Sophian, 1980).

Discussion

Recently Domsch and colleagues (2010) highlighted the need for a better understanding of the attention-getting stimuli infant researchers often implement to redirect attention and reduce data loss due to fussiness. Their research suggests that AGs not only attract attention, but also produce decelerations in heart rate during habituation and faster dishabituation in a subsequent task, indicating changes in the state of sustained attention and enhanced stimulus processing. The current study sought to extend this work by examining the effects of AG temporally synchrony on behavioral and physiological measures of attention. First, we investigated whether a brief exposure to a multimodal, attention-getting stimulus, especially one presented in temporal synchrony, was effective in capturing attention and bringing an infant to an attentive state. Secondly, we examined potential carry-over effects of the AG on performance in a discrimination task.

Attention-Getter

It was expected that the presentation of a multimodal AG, particularly one that is temporally synchronous, would attract infant attention and induce an attentional state more effectively than a no AG, control condition. Although there were no significant effects of temporal synchrony on behavioral measures, the presentation of an AG, regardless of AG type, captured attention more effectively than the no AG, control condition. This finding was not surprising. The process of attention begins with the infant orienting toward and selecting for further exploration and learning stimuli that are salient and/or novel (Ruff & Rothbart, 1996). The control condition was not effective in capturing attention, because there was no interesting or important information on the screen to which infants could attend. The lack of a temporal synchrony effect on look duration is consistent with previous investigations of synchrony which

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reported physiological changes, but no differences in looking (Curtindale et al., 2011; Pizur-Barnekow, et al., 2008) to synchronous versus asynchronous stimuli.

Physiological measures revealed similar pattern of results. Infants in the AG conditions exhibited the expected decrease in median HR following the AG session, indicating a change in attentional state. Domsch and colleagues (2010) also reported similar HR decelerations in response to an AG. When considering overall HR during the AG session, we did find an effect of temporal synchrony. Heart rate was not significantly different prior to the presentation of the AG; however, HR was significantly lower during the synchronous AG compared to the asynchronous and control AG conditions, indicating infants in the synchronous condition may have reached a deeper sustained attentional state. Changes in HR across the AG session offer further support for the effectiveness of AGs in eliciting an attentional state. Analysis of intercepts, linear terms, and quadratic terms for the best-fitting HR curve of each infant revealed a significant effect of AG. Heart rate for the infants presented with an AG declined (i.e. negative slope), while HR of infants in the no AG condition did not change.

We predicted that HR-defined phases of attention would vary as a function temporal synchrony. During each look of the AG session, infants progressed through the HR-defined phases of attention – OR, SA, AT. Initially, infants orient (OR) toward potentially important sources of information. If a salient or novel event is selected for further exploration, OR is followed by SA. The sustained attention (SA) phase, marked by infant looking coupled with HR decelerations, can indicated an attentional state and often reflects cognitive activity (Graham & Clifton, 1966; Richards, 1985). When the infant is no longer engaged in a state of sustained attention HR returns to prestimulus levels and he or she is in an attention termination (AT). Infants were expected to orient more quickly (spend less time in an OR phase of attention) in the

synchronous compared to the asynchronous and control conditions. Although we did not find significant differences in OR, the pattern was similar to recent findings of the KU Infant Cognition Lab (Curtindale, et al., 2011) – infants spent less time orienting to the synchronous compared to the asynchronous events, particularly during the first look. We also predicted that infants in the synchronous AG condition would spend more time in a SA phase of attention than infants in the asynchronous AG condition. Instead, we found that attention-getters (both synchronous and asynchronous) yielded significantly more time spent in a SA phase of attention compared to the no AG condition.

Overall, these results provide further evidence that the effects of dynamic, multimodal AGs go beyond basic capture of attention. These attention-getting events resulted in significant decelerations in HR, which are often associated with the achievement of attentional state and readiness for stimulation. This set of results is an important contribution to the literature on infant attention because these findings suggest that attention-getters have the potential to induce an attentional state, which may in turn affect subsequent task performance by enhance perception and learning. In other words, when using attention-getters to encourage infants to attend to stimuli, researchers may be unintentionally influencing infants' attentional state and influencing their responses to experimental stimuli.

Discrimination Task

In addition to attentional capture and attentional state during the AG session, the current study examined the carry-over effects of AG type (i.e., synchronous AG, asynchronous AG, or no AG) on performance in a subsequent discrimination task. Previous research revealed that infants who have decelerated HR and are in a SA phase of attention (similar to the infants in the AG conditions of the current study) at the start of a task process stimuli more efficiently and

completely than infants with higher HR, who are in other phases of attention (Domsch et al., 2010; Frick & Richards, 2001; Richards, 1997). Based on performance during the AG session, we expected that the effects of the AG would extend to familiarization and test trials, with infants in the AG condition performing significantly better than infants in the no AG condition. In other words, it was presumed that infants in the AG condition would be in an attentional state following the AG session, which would lead to complete familiarization followed by response recovery to the novel stimulus.

Familiarization

Although both AGs captured attention and elicited an attentional state more effectively than the no AG control condition, this effect did not necessarily extend to familiarization. Infants spent similar amounts of time looking at the stimulus and in a SA phase of attention for all AG types. Additionally, plots of look duration across familiarization revealed that looking did not decline rapidly over time, as we would predict if the infant had habituated or encoded the familiar stimulus. To categorize each infant as a habituator or nonhabituator, habituation was operationalized as a 50% decrease in looking from baseline (i.e. the average of the first two looks) to the final look during familiarization. Using this method, we confirmed the observation that not all infants reached habituation during familiarization. Fifty-six percent of the infants in this study habituated to the familiar stimulus, with all AG conditions yielding similar numbers of habituating infants. In other words, almost half of infants in this study did not habituate to the stimulus during familiarization, regardless of AG condition. We will discuss this concern in more detail with regard to test and study limitations.

Recall that during the AG session infants in the synchronous condition had lower HR than infants in the asynchronous and control conditions. In addition, both AGs produced similar

patterns of HR deceleration (i.e., quadratic equation and SA), while HR remained near baseline levels in the control condition. It was hypothesized that this pattern would continue during the familiarization; however, average HR for infants presented with the asynchronous AG was significantly higher during familiarization than average HR of infants in the synchronous and control AG conditions. Further, analysis of intercepts, linear terms, and quadratic terms for the best-fitting HR curve of each infant revealed a significant effect of temporal synchrony. Infants in the synchronous and control AG conditions showed a slight increase in HR followed by a decline in HR across familiarization, while HR for infants in the asynchronous AG condition continued to increase. The lower average HR and pattern of decelerating HR found in the synchronous AG and control conditions is consistent with an attentional state, whereas, the increase in HR among infants in the asynchronous AG condition suggests that these infants may not be fully encoding or learning the stimulus during familiarization.

We pose two potential explanations for the relationship between familiarization HR and temporal synchrony. First, the synchronous condition provided infants with highly redundant, amodal information. According to the *intersensory redundancy hypothesis* (*IRH*), highly redundant (amodal) information, at the expense of non-redundant information, guides selectivity of attention and as a result, may facilitate perception, learning, and discrimination (Bahrick, Lickliter, & Flom, 2004; Lewkowicz & Kraebel, 2004). Differences in HR were the same for the synchronous and control AG conditions. This does not, account for the HR pattern for the control condition. Another possible explanation for the effect of temporal synchrony on HR is that the dynamic nature of the synchronous and asynchronous AG conditions allowed infants to develop expectancies during the AG session that may have been violated during the discrimination task. In the synchronous condition, each time the looming circle reached its largest point, the direction

changed was marked with an auditory stimulus. Infants likely perceived the synchronous stimulus as one unified event based on the temporally coordinated presentation of the visual and auditory input. These infants may have started the familiarization block with the expectation of experiencing one unified event. The presentation of a static image may not have violated that assumption. In the asynchronous condition, an auditory stimulus occurred before the looming circle reached its largest point and changed direction. Infants may have perceived this asynchronous stimulus as two separate events – a looming circle and a beep. These infants may have started the familiarization block with the expectation of experiencing two separate auditory and visual stimuli. The presentation of a single, static image may have violated that assumption. Infants in the asynchronous condition may have been waiting for a second stimulus to occur during the familiarization, which could have affected HR and attentional state.

Test

During familiarization there were no significant effects of AG type on behavior; however, differences in physiological measures indicated a relationship between AG type and attentional state. Based on the familiarization results, we hypothesized significantly better discrimination performance (i.e. increased looking to the novel event during test trials) from infants who experienced a temporally synchronous AG (or the no AG, control) compared to infants in the asynchronous AG condition. Infants did not show the anticipated increase in looking to the novel stimulus in any of the AG type conditions.

We considered the potential contribution of incomplete habituation in this null finding. Novelty preference scores were obtained for each infant and clear effects of AG type on novelty preference were found. Only 30% of infants who were presented with an asynchronous AG preferred the novel stimulus during testing, while 60% and 71% of infants in the synchronous

AG and no AG control conditions showed a novelty preference. Recall that infants in the asynchronous condition had a higher average HR and their HR increased rather than decreased across the familiarization block. If this accelerated HR reflects incomplete processing, the outcome would be a familiarity or null preference. Infants in both AG conditions showed increased SA during the AG session, but the induced attentional state seems only to benefit those infants who saw a synchronous AG. Indeed, the asynchronous AG seems to be somewhat detrimental to infants' subsequent learning, as infants in this condition were less likely show a novelty preference than infants who had seen no AG. That is, infants who were exposed either to a synchronous AG or to no AG were more likely to prefer the novel stimulus, but infants who viewed an asynchronous AG were more likely to show a familiarity preference or no preference.

These results should be interpreted carefully, because 44% of the infants in this sample did not meet the criteria to qualify as habituators. Specifically, it is important to consider the validity of response recovery in the absence of habituation. This lack of habituation likely influenced infant discrimination performance. When data for nonhabituators was excluded from the analysis, we found that habituators did not show the expected response recovery in any of the AG type conditions. Recovery scores were likely attenuated by novelty preference scores; half of the infants showed a novelty preference and half preferred the familiar stimulus. All of the infants, except one, showed a significant preference (novelty or familiarity) indicating that they discriminated the novel and familiar stimulus to some extent. This discrimination did not differ as a function of AG type.

Limitations and Future Directions

Despite the potential contributions of the current study, particularly for our understanding of AGs may affect infants' attention, there are some limitations of the study design and

unanswered questions that should be addressed in future research. For example, in the current study, the length of time that infants spent in an OR phase of attention was used to assess attentional capture in response to the different AG conditions; however, time spent in OR may not be the best measure of attentional capture. Historically, the attention-getting properties of a stimulus were measured using the latency to turn toward the stimulus (Cohen, 1972). To determine the natural speed at which an infant orients to a stimulus, the experimenter first controls where the infant is looking and then presents another stimulus in a different location (Cohen, 1972; DeLoache, Rissman, & Cohen, 1978). In the current study, it was not possible to assess latency in this way, because the task did not begin until the infant was looking at the screen to ensure that there was at least one look during the AG. As a way to address this in the future, a study could measure both latency and OR time for synchronous and asynchronous events with a procedure similar to the one used by Cohen and his colleagues (1972, 1978). This procedure would provide more information about the effects of synchrony on infants' responses to AGs by allowing researchers to compare both latency (i.e., attentional capture) and OR phases between these two AG conditions.

Another caveat to consider within the present study is that during familiarization look duration (per 5-second epoch) did not show the expected decline across trials in any of the AG conditions. Indeed, only 56% of infants in the current study were classified as habituators. This made interpretation of the results difficult. A means of addressing this issue in subsequent research would be to employ infant-controlled habituation (ICP) instead of a fixed familiarization procedure. An ICP would ensure that infants had habituated to the stimulus because it would continue to be presented to them until they reached criteria for habitation.

Another limitation is the variation in responses to the first presentation of the novel stimulus or response recovery. Roughly half of the infants labeled habituators demonstrated a preference for novelty, while the other half had a familiarity preference. A potential cause of these mixed results is the fatigue associated the 30-second familiarization period. Indeed, fatigue is a concern in infant research, because infants who are fatigued by the end of familiarization may be unable to demonstrate a novelty response (Bahrick, 1992; Bahrick & Lickliter, 2000; Bahrick & Newell, 2008; Spence & Moore, 2002). To control for fatigue, researchers present the same control stimulus prior to the start of the task (to measure baseline interest) and after the test trials. Look duration to final control trial is compared to look duration to the initial control stimulus presentation. If an infant's final level of looking is less than a criterion (e.g. 20% or 30% of the initial level), his or her data is excluded from the analyses due to fatigue. In the current study, it is possible that some infants became overly fatigued by the end of the 30-second familiarization block. A means of addressing the issue of time in future research would be to assess infant fatigue and exclude infants who do not meet an established criterion (Bahrick, 1992; Bahrick & Lickliter, 2000; Bahrick & Newell, 2008). One additional way to reduce fatigue effects is to avoid differences in time on task altogether in a subsequent study would be to use paired-comparison testing rather than a fixed-trial procedure.

Summary and Conclusions

Recently, there has been an increase in the use of AGs to redirect attention and reduce fussiness in infant studies. However, we know very little about the effect of these stimuli on attentional state and task performance. This study supports a recent report by Domsch and colleagues (2010) that when AGs are used in an infant habituation task, they not only capture attention, but also produce decelerations in HR. In addition to demonstrating that AGs can

change attentional state, the current study found differential effects of the temporal synchrony of AGs on HR during familiarization. The synchronous and asynchronous AG conditions produced similar patterns of attention during the AG session, but HR for infants in the asynchronous condition increased across familiarization, while HR for infants in the synchronous and control conditions declined. With regard to test trials, infants did not show the anticipated recovery of looking to the novel stimulus in any of the AG type conditions, which may be due to incomplete habituation during familiarization. This research provides insight into the types of environmental conditions and interactions that effectively capture attention and have the potential to facilitate processing and learning.

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