Published in final edited form as:
Infancy. 2012 ; 17(4): . doi:10.1111/j.1532-7078.2011.00094.x.

Your Eyes Say "No," But Your Heart Says "Yes": Behavioral and Psychophysiological Indices in Infant Quantitative Processing

Caitlin C. Brez and **John Colombo**
The University of Kansas

Abstract

Behavioral indices (e.g., infant looking) are predominantly used in studies of infant cognition, but psychophysiological measures have been increasingly integrated into common infant paradigms. The current study reports a result in which behavioral measures and physiological measures were both incorporated in a task designed to study infant number discrimination. Seven-month-old infants were habituated to several sets of stimuli varying in object type, but of a constant numerical value (either 2 or 3 items). Although looking time to each of the test trials revealed no differences, differences in heart-rate defined measures of attention revealed infants' ability to discriminate number. These findings imply that the inclusion of indices other than behavioral measures should become commonplace in studies of infant cognition.

Measures of looking have been the most widely used indices of infant perception and cognition (Cohen, 1979; Fantz, 1958), particularly within methods such as visual habituation (Colombo & Mitchell, 2009). Although psychophysiological measures such as heart rate (HR) are commonly available and easily accessed (Casey & Richards, 1991; Richards & Casey, 1991, 1992; Shaddy & Colombo, 2004), their inclusion in such methods is less common. Indeed, the use of these measures allows for a wider array for inference; for example, Richards and his colleagues have shown that infant looking can be divided into different phases of attention based on different HR responses (Casey & Richards, 1991), and the different phases are thought to reflect different levels of information processing. Orienting (OR), which occurs at the beginning of the look, represents the infant's initial engagement with the stimulus. Sustained attention (SA) is the middle portion of the infant's look and is defined by a deceleration in infants' heart rate. SA is thought to reflect infants' active processing of the stimulus. The final phase, attention termination (AT), is defined by a return of infants' heart rate to baseline and represents the process of disengaging from the stimulus as processing ends. While few studies directly compare behavioral and physiological measures of infant cognition, most studies have found convergence between these two types of measures (Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001; Elsner, Pauen, & Jeschonek, 2006; Frick & Richards, 2001; Lansick, Mintz, & Richards, 2000; Lansink, Mintz, & Richards, 2000; Shaddy & Colombo, 2004). One explanation for the relationship between these measures is that the same underlying processes (attention and arousal) account for responses in both of the measures (Colombo, et al., 2001; Maikranz, Colombo, Richman, & Frick, 2000; Richards & Casey, 1991).

While the vast majority of the existing evidence supports the convergence between behavioral and physiological measures of infant attention and cognition, the possibility remains that with multilevel measurement within the assessment of infant cognition, different measures may yield different outcomes. The current study presents a case study of

Please address all correspondence to: Caitlin C. Brez, Schiefelbusch Institute for Life Span Studies, 1000 Sunnyside Avenue, 1052 Dole Human Development Center, University of Kansas, Lawrence, KS 66045-7556 USA, cbrez@ku.edu.

such an instance, and raises the issue of how we might strive to better understand how measurement informs our research questions (Aslin, 2007). The study itself was designed to study infant number discrimination, a topic where behavioral measures are used almost exclusively. Here, we incorporated HR measures and report a finding in which the two measures did not converge. We offer these findings as a venue for cautioning researchers about the use of different measures, and as context for interpretations about null hypotheses.

In the field of infant number discrimination, researchers have discovered a distinction in how infants process small numbers (less than four) and large numbers. The approximate number system, which represents larger quantities is an imprecise system used by infants, adults, and primates (Halberda, Mazzocco, & Feigenson, 2008; Libertus & Brannon, 2009). Discrimination using this system follows Weber’s Law, such that infants are able to discriminate quantities as long as the ratio between them is large (7-month-old infants require a 1:2 ratio to discriminate these quantities; Xu & Spelke, 2000). In contrast, the exact number system represents smaller quantities and appears to be much more precise. Unlike the approximate number system, infants can discriminate exact quantities; the ratio between the quantities is not relevant. Many studies demonstrate that even young infants (6–7 months) can discriminate two versus three (Mack, 2006; Wynn, 1996). The exact number system aligns well with findings from studies of adults’ subitizing (Peterson & Simon, 2000; Trick & Pylyshyn, 1994). Subitizing is the process in which enumeration for small numbers (less than four) is rapid and occurs in parallel. However, with quantities greater than four, enumeration may occur by counting which is a serial process that requires more time. While many studies have investigated the limits and numerical representation of the approximate number system (Xu, Spelke, & Goddard, 2005), many issues and questions have yet to be addressed for the exact number system such as whether infants are more sensitive to numerical or other non-numerical featural information, such as color, texture or shape when discriminating small numbers.

Method

Participants

Participants were 24 7-month-old infants (M = months, range: 6.43 – 7.93 months; 12 males and 12 females). All were full-term and had no hearing or vision problems. An additional 22 infants participated, but were excluded from the analyses for the following reasons: failure to habituate (n = 12), prematurity (<38 weeks and <5lbs; n = 3), fussiness (n = 2), unusable HR data (n = 3) or other reasons (n = 2). Twenty infants were Caucasian (n = 20), one was American Indian, and the remaining two were biracial. Most of the mothers and fathers had at least a four-year college degree (73.9%). Infants and parents were recruited from metropolitan and suburban Kansas City, KS.

Stimuli and Apparatus

During the testing period, infants were in a car seat in a dark room seated directly in front of a 30-inch (76 cm) monitor approximately 112 cm away. The stimuli consisted of two-dimensional photographs of colorful, everyday objects (e.g., watch, car, and shoe; see Figure 1). A photograph of an abstract clay figure was presented during the pretest. A closed circuit television camera was mounted below the monitor, which allowed the experimenter seated in the control room to view the infants on a television monitor. All sessions were recorded on DVD. The parent(s) was in the testing room with the infant at all times but was instructed not to interact with their infant during the experiment. Stimuli were presented using the habituation software, HabitX (L.B. Cohen, Atkinson, & Chaput, 2000), which also tracks infants’ looking duration.

Heart-rate measures

Heart rate was measured with three electrodes placed on the infant's chest and abdomen. Two shielded Ag-AgCl electrodes were placed on either side of the infant's chest and one unshielded electrode on the infant's abdomen. The electrocardiogram (EKG) was collected and digitized through a commercially available data-acquisition software package (BioPac, Inc, Santa Barbara, CA).

Procedure

Each infant was habituated to either two or three objects, depending on their assigned condition (see Figure 1). During habituation, infants saw four different object types in blocks of four. The infants were shown a maximum of 20 habituation trials, or enough trials for their looking time to reach the 50% criterion (determined by a sliding window of four trials). Similar to other studies, a single trial lasted for 30 seconds or until the infant looked away for one second. The infant was required to look for at least one second in order for a look to be counted as a trial; otherwise the same stimulus was repeated in the next trial.

After the habituation phase, each infant viewed four test trials (see Figure 1). Just as in habituation, a single trial lasted for 30 seconds or until the infant looked away for one second. The first trial was a familiar object of the familiar number (either two or three depending on the habituation condition). The order of the last three test trials was counterbalanced using a Latin square, and included (a) a novel number with familiar objects, (b) a familiar number with novel objects, and (c) a novel number of novel objects. The first test trial always presented a familiar number of familiar objects to serve as a clean test of habituation independent of the habituation phase. With regard to the area of the objects in the test trials, half of the infants viewed test trials in which *all* of the objects were of the smaller area (5 square inches) regardless of the number of objects, and the other half of the infants saw objects of the larger area (10 square inches). This design assured that the area was familiar for all infants in all conditions because they were habituated to examples of both small and large areas.

This design varies significantly from most infant number discrimination studies in two major ways. First, the current design varies non-numerical featural information in such a manner that hypotheses regarding infants' use of non-numerical featural information to aid in number discrimination can be tested explicitly. However, there are three other studies that have systematically varied featural information (see Feigenson, 2005; Izard, Dehaene-Lambertz, & Dehaene, 2008; Strauss & Curtis, 1981). The second major difference in the methodological design of the current study is our use of a categorization task to test infants' number discrimination. In a categorization task, infants are shown multiple examples of a category (*e.g.*, dog, horse, pig) during habituation and are then tested on a novel member of that category (*e.g.,* cat) as well as an out-of-category test item (*e.g.,* apple). The novel member of the category (cat) is perceptually quite different from any of the habituation items, so if an infant is simply responding to perceptual novelty, then the infant should dishabituate to this item. However, if an infant is forming an abstract representation of the category "animals" (*i.e.* responding to the conceptual aspect of the stimuli, not the perceptual features of the stimuli), then the cat is no longer a novel item and the infant should not dishabituate to it. However, when presented with an exemplar from a new category (apple), infants should dishabituate to this out-of-category item as it is always both perceptually and conceptually novel. Standard categorization tasks demonstrate that infants can generalize beyond the specific stimuli presented in habituation to form an abstract categorical representation. They are responding to the category being presented during habituation, not just the perceptual features of the exemplars. Because categorization tasks require multiple habituation stimuli that vary along many dimensions, categorization tasks

NIH-PA Author Manuscript
NIH-PA Author Manuscript

are more complex than simple discrimination tasks. Most number discrimination studies are simple discrimination tasks, which show infants a single exemplar of a quantity during habituation and test infants on the same versus a different quantity. In a categorization task like ours, in order to demonstrate discrimination of number, infants must be able to understand that two refers to the cardinal number independent of which objects are presented, thus exhibiting generalization of infants' number concept.

The experiment began with the attention-getter playing on the monitor. Once the infants' attention was on the monitor, the attention-getter was turned off, and a single pretest trial was shown. After the pretest, the habituation trials began. The attention-getter reappeared between each trial to redirect the infant's attention to the monitor.

Results

Reduction of the HR Data

Prior to parsing infants' looking into the three distinct phases of attention, artifacts, such as missing heart beats or extra beats, were corrected. Most artifacts consist of missed beats and these are interpolated by using the surrounding interbeat intervals (IBI) to calculate where the missing beats should be placed. A smaller number of artifacts can occur in the form of an extra beat when the electrodes temporarily lose contact or the infant moves. These extra beats are removed by again analyzing the surrounding IBIs. Typically, in our studies, artifacts account for less than 1% of the total number of beats.

Infants' looking was divided into distinct phases of attention (OR, SA, and AT; (Richards & Casey, 1991) based on infants' HR responses while looking. All phases were defined based upon the parsing of SA, which was defined as the period during which HR fell below a prestimulus baseline (the median during the prior interstimulus period) for at least five consecutive beats. It is possible for infants to have multiple periods of SA within a single look, however it was not observed in the current study and is typically not observed in infants of this age (6–7 months). OR was defined as looking that occurred prior to the onset of SA and AT was defined as that period occurring after SA when HR returned to baseline levels or above while the infant was still looking. The intertrial period prior to each trial served as the baseline HR measure because HR varies throughout the session. For a more detailed account of HR coding and parsing, see Colombo et al. (2001).

Analysis of Infants' Look Durations

We first analyzed infants' look durations for each of the four test trials. Infants spent 5.72 seconds (SD = 3.47) looking at the familiar number/familiar object trial and 6.40 seconds (SD = 5.30) looking at the familiar number/novel object trial. Infants look duration totaled 5.73 seconds (SD = 5.18) for the novel number/familiar object trial and 4.65 seconds (SD = 4.86) for the novel number/novel object trial. A 2 × 2 ANOVA was conducted with number (familiar or novel) and object (familiar or novel) as within-subject factors. No significant main effects or interactions involving number or object emerged, as infants' look durations did not vary across test trials, $F(3, 69) = .82$, $p = .49$ (see Figure 2). Despite extant evidence suggesting that young infants (6–7 months) can discriminate number (Mack, 2006; Wynn, 1996), the behavioral indices did not yield any evidence of number discrimination.

Analysis of Infants' HR

In contrast to infants' behavioral data, however, infants' HR yielded an interesting and coherent story. As a measure of information processing, we analyzed the proportion of time that infants' spent in SA while looking (i.e., the period infants spent actively processing information). A 2 × 2 ANOVA was conducted with number (familiar or novel) and object (familiar or novel) as within-subject factors just as in the previous analysis of infants' looking behavior. For the percentage of time spent in SA, there was a significant main effect of number, $F(1, 22) = 7.00$, $p = .02$, suggesting that infants were attending to the change in number (see Figure 2). Infants spent 62% of the familiar number/familiar object trial in SA ($SD = .40$), 45% of the familiar number/novel object trial ($SD = .40$), 69% of the novel number/familiar object trial ($SD = .33$), and 74% of the novel number/novel object trial in SA ($SD = .31$). There was no significant main effect of object, $F(1, 22) = .51$, $p =. 48$. Additionally, there was no interaction between the number of objects and object identity, $F(1, 22) = 2.18$, $p = .15$. This finding replicates previous studies demonstrating that infants are capable of discriminating small quantities at this age (Mack, 2006; Wynn, 1996). More importantly, however, this result suggests that such discriminations may not always be evident in behavioral measures.

Discussion

Although behavioral and psychophysiological measures are often used concomitantly in studies of developmental and individual differences (Colombo et al., 2001, 2004; Shaddy & Colombo, 2004), they typically have not been used together in experimental studies of fundamental cognitive processes. The results of the current study, in which evidence for numerical discrimination was evident in HR indices of looking but not in the duration of looking suggest that researchers should perhaps reconsider this practice. This study provides the first evidence to date in which a specific inference about infants' cognitive ability was evident in physiological measures of infant cognition but not in behavioral measures.

Traditional measures of looking behavior have been applied successfully to test infants' number discrimination (Mack, 2006; Wynn, 1996). However, differences between the methods used to assess number discrimination in these studies and the current study could account for the varying results with each type of measure. One type of measure is not necessarily better than the other, but might rather be viewed as different levels of analysis to be used within the same methodologies and tasks.

These findings support the need for multidimensionally assessing constructs in infant cognition and perception. Furthermore, they reiterate the caution necessary in the interpretation of null findings in infancy, particularly when only one index is used.

In addition to the methodological implications of these results, this study did provide further evidence of 7-month-old infants' ability to discriminate small (i.e., fewer than 4) quantities (Mack, 2006; Wynn, 1996). These data align well with the existing literature demonstrating that infants can make precise discrimination of small numbers using the exact number system. Additionally, the current study suggests that infants may not rely on non-numerical featural information such as color and shape to make small number discriminations at least at this age and within the context of this experimental design. It is interesting to note that the current task is a categorization task, which is more complex than simpler discrimination protocols. However, infants were still able to generalize numerical properties across varying objects and differentiate the objects sets based upon numerical identity. Thus, along with the methodological contributions, the current data show number discrimination to be a fairly robust ability at this age.

We do not advocate jettisoning looking measures as tools for investigating infants' cognitive processes based on the findings of this study. Rather, we believe these data point to the importance of assessing infant performance with multiple indices. The measurement of such indices, at one time may have been difficult and costly, is now fairly easy and commonplace in the behavioral sciences, and perhaps should become commonplace within infant cognitive paradigms.

References

Aslin RN. What's in a look? Developmental Science. 2007; 10:48–53. [PubMed: 17181699]

Casey BJ, Richards JE. A refractory period for the heart-rate response in infant visual-attention. Developmental Psychobiology. 1991; 24:327–340. [PubMed: 1752353]

Cohen LB. Our developing knowledge of infant perception and cognition. American Psychologist. 1979; 34:894–899. [PubMed: 517842]

Cohen, LB.; Atkinson, DJ.; Chaput, HH. Habit 2000: A new program for testing infant perception and cognition (Version 1.0). Austin: The University of Texas at Austin; 2000.

Colombo J, Mitchell DW. Infant visual habituation. Neurobiology of Learning and Memory. 2009; 92:225–234. [PubMed: 18620070]

Colombo J, Richman WA, Shaddy DJ, Greenhoot AF, Maikranz JM. Heart rate-defined phases of attention, look duration, and infant performance in the paired-comparison paradigm. Child Development. 2001; 72:1605–1616. [PubMed: 11768135]

Elsner B, Pauen S, Jeschonek S. Physiological and behavioral parameters of infants' categorization: Changes in heart rate and duration of examining across trials. Developmental Science. 2006; 9:551–556. [PubMed: 17059451]

Fantz RL. Pattern vision in young infants. The Psychological Record. 1958; 8:43–47.

Feigenson L. A double-dissociation in infants' representations of object arrays. Cognition. 2005; 95:B37–48. [PubMed: 15788156]

Frick JE, Richards JE. Individual differences in infants' recognition of briefly presented visual stimuli. Infancy. 2001; 2:331–352.

Halberda J, Mazzocco MM, Feigenson L. Individual differences in non-verbal number acuity correlate with maths achievement. Nature. 2008; 455:665–668. [PubMed: 18776888]

Izard V, Dehaene-Lambertz G, Dehaene S. Distinct cerebral pathways for object identity and number in human infants. Plos Biology. 2008; 6:275–285.

Lansick JM, Mintz S, Richards J. The distribution of infant attention during object examination. Developmental Science. 2000; 3:163–170.

Lansink JM, Mintz S, Richards JE. The distribution of infant attention during object examination. Developmental Science. 2000; 3:163–170.

Libertus ME, Brannon EM. Behavioral and neural basis of number sense in infancy. Current Directions in Psychological Science. 2009; 18:346–351. [PubMed: 20419075]

Mack W. Numerosity discrimination: Infants discriminate small from large numerosities. European Journal of Developmental Psychology. 2006; 3:31–47.

Maikranz JM, Colombo J, Richman WA, Frick JE. Autonomic correlates of individual differences in sensitization and look duration during infancy. Infant Behavior & Development. 2000; 23:137–151.

Peterson SA, Simon TJ. Computational evidence for the subitizing phenomenon as an emergent property of the human cognitive architecture. Cognitive Science. 2000; 24:93–122.

Richards JE, Casey BJ. Heart-rate-variability during attention phases in young infants. Psychophysiology. 1991; 28:43–53. [PubMed: 1886963]

Richards, JE.; Casey, BJ. Development of sustained visual attention in the human infant. In: Campbell, BA.; Hayne, H.; Richardson, R., editors. Attention and information processing in infants and adults. Hillsdale, N.J: Erlbaum; 1992.

Shaddy DJ, Colombo J. Developmental changes in infant attention to dynamic and static stimuli. Infancy. 2004; 5:355–365.

Strauss MS, Curtis LE. Infant perception of numerosity. Child Development. 1981; 52:1146–1152. [PubMed: 7318517]

Trick LM, Pylyshyn ZW. Why are small and large numbers enumerated differently - A limited-capacity preattentive stage in vision. Psychological Review. 1994; 101:80–102. [PubMed: 8121961]

Wynn K. Infants' individuation and enumeration of actions. Psychological Science. 1996; 7:164–169.

Xu F, Spelke ES. Large number discrimination in 6-month-old infants. Cognition. 2000; 74:B1–B11. [PubMed: 10594312]

Xu F, Spelke ES, Goddard S. Number sense in human infants. Developmental Science. 2005; 8:88–101. [PubMed: 15647069]

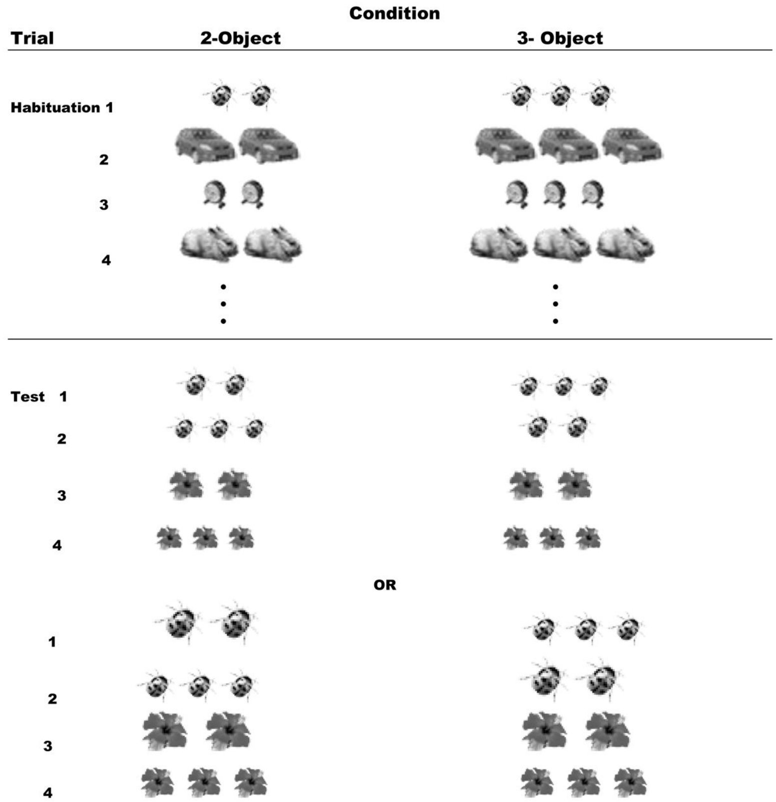

Figure 1.
Design of the study.

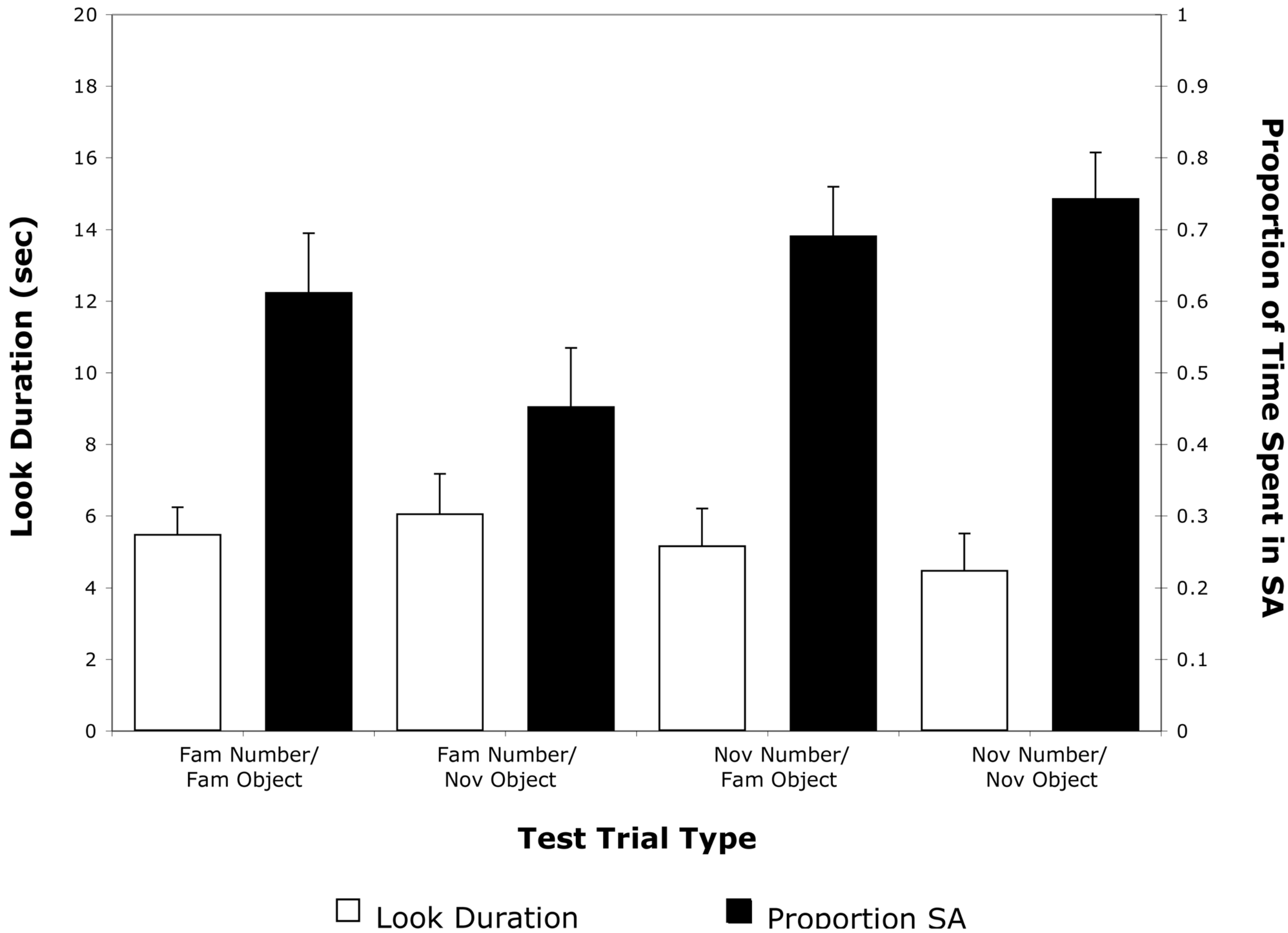

Figure 2.

Mean look duration (sec) and percentage of time spent in sustained attention (SA) for each test trial. Mean look duration is plotted on the left axis and percentage of time spent in SA is plotted on the right axis. Error bars correspond to one standard error.