The social origins of sustained attention in one-year-old human infants

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Summary

The ability to sustain attention is a major achievement in human development and is generally believed to be the developmental product of increasing self-regulatory and endogenous (i.e., internal, top-down, voluntary) control over one's attention and cognitive systems [1–5]. Because sustained attention in late infancy is predictive of future development and because early deficits in sustained attention are markers for later diagnoses of attentional disorders [6], sustained attention is often viewed as a constitutional and individual property of the infant [6–9]. However, humans are social animals; developmental pathways for seemingly non-social competencies evolved within the social group and therefore may be dependent on social experience [10–13]. Here, we show that social context matters for the duration of sustained attention episodes in one-year-old infants during toy play. Using head-mounted eye-tracking to record moment-by-moment gaze data from both parents and infants, we found that when the social partner (parent) visually attended to the object to which infant attention was directed, infants, after the parent's look, extended their duration of visual attention to the object. Looks to the same object by two social partners is a well-studied phenomenon known as joint attention which has been shown to be critical to early word learning and to the development of social skills [14, 15]. The present findings implicate joint attention in the development of the child's own sustained attention, and thus challenge the current understanding of the origins of individual differences in sustained attention, providing a new and potentially malleable developmental pathway to the self-regulation of attention.

Results

Voluntary control of attention becomes evident as early as an infant's first birthday, but even for 10- and 12-month old infants, attention is often controlled by novelty, habituation, and distraction with interest in one moment giving away in the next to some new object or event [2, 5, 16]. The duration of sustained attention grows incrementally and steadily from infancy through early childhood, becoming more extended in time and better able to withstand distraction [16–20]. While previous studies showed internal factors to this incremental growth [21], the present study examined whether social interactions that extend the duration of attention to objects could also be a critical factor. If the infant's own attention is influenced by the attention of a social partner [14, 15, 22], then the attentional behavior of a mature partner could incrementally extend the duration of the infant's attention and in so

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doing support the development of the attentional pathways that underlie enduring concentration on an attention target. To test this hypothesis, we used the task of infant toy play with multiple objects, a context that has been widely used to assess sustained attention in late infancy and which yields measures of sustained attention predictive of later cognitive developments [16–18, 23].

The final sample consisted of 36 (19 male infants) parent-infant dyads with the infants ranging in age from 11 to 13 months (mean = 12.52, SD= 1.15). In the task, infants and parents were given three highly engaging and novel toys (as determined by pre-testing) with which to play. In this free-flowing interaction, the infants' task was to engage and explore the toys. The parents' task was to actively encourage their infant to play with the toys. As shown in Figure 1, head-mounted eye tracking technology was used to collect high-density real-time eye movement data from both infants and their parents during the task [24, 25]. The gaze data were analyzed with respect to four regions-of-interest (ROIs): each of the three toys and the partner's face. As shown in Figure 2(b), infants' and parents' gaze dynamics were fundamentally different [13], befitting their different goals. Parents' gaze shifts were faster, generating 58.58 switches (SD=10.21) per minute with a mean duration of 0.95 seconds (SD=0.23), consistent with the parent's task of visually monitoring all the objects potentially in play and as well as their infant's face (and attention). Infants, in contrast, produced 30.57 switches (SD=6.43) among ROIs (objects or the partner's face) per minute with a mean duration of 2.16 seconds (SD=0.62) for each look. Overall, infants looked most frequently to the objects (proportion of time, M=62.54%, SD=8.23%) and not to their parent's face (M=12.82%, SD=3.71%). The infant pattern thus also fit their task: active engagement and play with the individual toys.

To test the hypothesis that parent attention (and thus joint attention) extended infants' visual attention to an object, we first independently measured joint attention (JA) and infant sustained attention (SA). Joint attention was objectively defined [26] as periods during which parents and infants were jointly fixated on the same object at the same time. Because meaningful shared attention should last some amount of time longer than a single video frame (33ms) but also be inclusive of as many meaningful parent looks as possible (given their monitoring of the whole scene with frequent brief glances), a joint attention bout was defined as a continuous alignment of parent and infant fixation that lasted longer than 500ms but that could include looks briefer than 300 ms elsewhere. Given that humans generate three saccades per minute, this threshold of 300ms allowed one brief look away before switching back to the target. Examples of joint attention bouts are shown in Figure 2(b). Parents and infants, on average, jointly attended to the same object 34.24% (SD=6.04%) of the total toy-play time, which was composed of 9.37(SD=1.65) distinct JA bouts with the average duration of each bout 2.39 (SD = 0.61) seconds. Figure 3(a) shows a histogram of the duration of JA bouts across all infants.

Figure 3(b) shows a histogram of the duration of infant looks to an object, the majority of which were very brief, with an average duration of 2.16 sec. Early work on sustained attention [17], defined the phenomenon in terms of a suite of behaviors, such as manual activities and facial expressions (viewed as indicative of focused concentration), and measured the duration of sustained looking when the infant's overall demeanor fit that

definition. To more objectively define sustained attention, we turned the approach around and defined sustained attention as looks longer than 3 sec, the average duration of concentrated attention for 1-year-olds reported in the earlier work [17]. This threshold ensures that the defined sustained attention bouts are on the tail of the distribution (exceeding the mean of the overall distribution), and thus at the upper end of what children this age can do when visually focusing attention on a single object [17, 27]. More specifically, we operationally defined 3 seconds of consistent looking within the ROI for a single object *without any looks elsewhere* as the threshold for sustained attention by the infant. Given this definition, infants generated 4.72 sustained attention bouts per minute with the mean duration of 5.05 sec which is much longer than the observed average duration of looks to a single object when one considers all such looks (t(35)=12.54, p<0.001, d=4.24). Analyses conducted on different thresholds for the duration defining SA (+/− 1 second changes of the 3-sec threshold) did not change the overall pattern of results reported below. In the following, we used linear mixed effects models [28] with both subjects and items as random effects to examine the links between joint attention and sustained attention.

We first divided the infant SA bouts into two categories: SA that overlapped with JA and SA alone. On average, 65.38% of SA instances occurred with an accompanying parent look and thus with JA while the rest were without JA. The average duration of SA-with-JA was much longer than the duration of SA-without-JA ($M_{\text{SA-with-JA}}$=5.33 sec, $M_{\text{SA-without-JA}}$=4.38 sec, β=1.27, SE=0.11,p<0.001). Results based on survival probabilities [21] can be found in supplementary materials. Overall, the results are consistent with the hypothesis of the social extension of sustained attention. The results are not definitive as longer bouts of sustained attention by the infant provide more time for parents to look to the same object and thus joint attention could be a byproduct of longer attention bouts by the infant rather than due to the hypothesized path that the parent's attention to the same object *extends* the infant's attention.

To test the extension hypothesis that parent attention to an object extends the duration of infant attention, three key predictions were considered. First, see Figure 4(a), the time it takes the parent to join the child in attending to the object should not be systematically related to the duration of the SA bout; that is, the SA bout with JA should not be long because children were already attending to the object for a long time before parents joined them. Second, see Figure 4(b), if parents entrain child attention and extend the duration while they – the parent – also visually attends to the object, then SA bouts with longer JA bouts should be longer than SA bouts with shorter JA bouts. Third, see Figure 4(c), if parent interest extends the child's interest beyond the period of joint attention, then the period of SA *after JA ends* should also be extended. That is, the sustained period should be dose-dependent -- longer when the accompanying JA portion is long than when it is short, and this dose-dependent influence should extend beyond the time of parent's shared attention.

The first test focuses on the timing with which parents joined their infants' attention. If SA-with-JA bouts are longer because parents have more time to join, then long delays between the child onset of attention to an object and the onset of JA should be associated with longer SA bouts. This was not the case. As shown in Figure 4(a), we divided all of SA-with-JA instances into two groups based on median split of the lag duration between the onset of the

infant's attention and parent's attention: long lag SA ($M_{long-lag}$=2308ms) and short lag SA ($M_{short-lag}$=548ms). There was no difference in the total durations of the SA-with-JA bouts for long and short lags ($M_{long-lag}$=5231ms; $M_{short-lag}$=4876ms; β=0.07, SE=0.17, n.s.). The speed with which parents joined the infant was not the determining factor of the duration of infant sustained attention.

The second hypothesis concerns the length of the JA portion of the infant's sustained attention: by our hypothesis, longer JA should be associated with longer overall sustained attention. Accordingly, we categorized the SA-with-JA bouts into two groups according to the duration of the JA portion, above or below the median, yielding two groups of SA with JA bouts, with long JA ($M_{long-JA}$=3243ms) versus short JA ($M_{short-JA}$=1835ms) portions of those bouts. As predicted, SA instances with long JA were overall longer than were SA instances with short JA ($M_{long-JA}$=6540ms; $M_{short-JA}$=4293ms; β=0.87, SE=0.17, p<0.001), as shown in Figure 4(b). A JA episode can be terminated either by the child or the parent. In cases when it was terminated by the infant (thereby also terminating SA), JA and SA durations were guaranteed to be correlated, without regard to parents' looks. To eliminate this possibility, we further selected a subset of SA with JA bouts that were terminated by the parent, divided those instances based on JA duration, and again found the predicted pattern ($M_{long-JA}$=5825ms; $M_{short-JA}$=4762ms; β=0.76, SE=0.21, p<0.005): the length of the JA period determined the overall length of infant sustained attention.

The third hypothesis is that parent attention extends infant attention, increasing the duration even after JA ends. This dose-dependent extension predicts that the period during which the infant attended to the object *after JA ends* should be longer, given longer, just prior, shared attention with the parent. This was the pattern obtained as shown in Figure 4(c). Infant attention to the target after JA ended was longer for longer JA periods than for shorter ones ($M_{long-JA}$=2146; $M_{short-JA}$=959ms; β=0.82, SE=0.09, p<0.001). Thus, even after joint attention, infants tended to look at the target longer after a period of long joint looking with the parent than after a period of short joint looking. Parent looks to the target of the infant's interest not only sustained that interest during parent attention but extended it after parents had shifted attention elsewhere. At a surface level, the phenomenon bears some similarity to what is known as "attentional inertia" observed in the context of older children watching television [21], the longer the child looks, the more likely they are to keep learning. The present results suggest that the parent interest extends infant looking and may similarly (through inertial processes) extend infant attention in time.

Discussion

An infant's first year marks the beginning of a period of steady incremental growth in the ability to sustain attention on a single target of interest. Sustained attention, in turn, is linked to object exploration, language development, and problem solving [1]. Emerging individual differences in sustained attention during this period predict later developmental outcomes in many domains [18, 19]. While the infant's own internal system (what is sometimes called temperament, [7, 29]) surely determines the nature and rate of individual growth in attentional skills, the infant's internal system is itself changing during this period of time and thus potentially malleable through its own intrinsic and evoked activity [30]. The results

provide evidence for a pathway through which social interactions may influence the development of sustained attention, a pathway through which individual differences in the development of sustained attention may emerge and through which atypical patterns of attention development may be addressed. The results here show that the duration of infant attention to an object is extended by a mature social partner's visual attention to and interest in that object, and that this socially shared attention extends the infant's own attention both during and after the joint attention portion, so that the infant continues to focus on the object after the adult has shifted attention elsewhere. The present evidence consists of in-the-moment effects on the duration of attention, not the long-term training of sustained attention. However, day-in and day-out interactions with mature social partners that stretch the duration of the child's concentration on an object may, over time, strengthen the internal networks responsible for the self-regulation of attention. By analogy, just as a parent may hold onto and balance a two-wheeler bike for their young rider, letting go, so that the young rider experiences and extends (at first, a product of the body's inertia) balancing a bike on their own, so may sustained joint attention help infants' attentional systems experience and then discover the means to concentrate on their own. One key open question is the parent behaviors that support this sustained attention and its extension in time. Here we measured parent looking to the attended object, but previous works [26, 31] shows that looking is associated with multiple other behaviors including handing of the object and talk about the object and these behaviors could play an important contributory role.

The role of the mature partner in these interactions is to be responsive to the infant's visual attention. Parental responsiveness is a construct that emerged in the study of infant temperament [32, 33] and refers to the degree to which parents respond contingently and appropriately to their child's emotional, social, and cognitive needs. Usually measured at a global level and conceptualized as a stable characteristic of a dyad's interaction, parental responsiveness measured when the child is either an infant or toddler, has been shown to be predictive of long-term developmental outcomes [34]. Responsiveness may also be conceptualized as real-time behavioral adjustments by the parent that are made in seconds and fractions of seconds [34, 35]. The present findings may help unify these two senses of responsiveness and provide a mechanistic pathway through which long-term predictions from the quality of early interactions play out. In brief, parents who are more "tuned" to their children's momentary interests, who are "responsive", may coordinate their visual attention with that of the infant and thereby entrain and train the child's self-regulation of attention, setting up a cascade of "down the road" effects. The present results discovered from free-flowing interactions are at their core correlational and thus require experimental tests for confirmation, for example, studies in which parents are instructed to either follow infants' attention all the time (and thus be responsive) or are cued to only sometimes attend to the object of infants' attention.

Sustained attention and joint attention are two well-studied phenomena with important development consequences [1, 36]. To our knowledge, they have never been jointly studied, primarily because sustained attention is conceptualized as a characteristic of individuals and joint attention as a social phenomenon among partners. The present findings thus also suggest that the pathway through which joint attention is positively associated with language learning and other outcomes may need to be reconsidered. Currently, shared social attention

is considered a marker of the infant's ability to build mental models and make inferences about the mental states of social partners [15]. However, socially shared attention with a partner may not be solely a marker of more mature social understanding but may more directly affect learning by entraining and stabilizing the infant's attention on the object of interest.

In conclusion, the self-regulation of attention may have social origins, because human development occurs in a social environment in which invested parents are part of evolutionary expected experiences. Infants' socially shared attention with a mature partner has real-time consequences on infant sustained visual attention to an object and may have a very long reach into developmental outcomes beyond social interactions, in non-social and core cognitive skills such as the self-control of attention.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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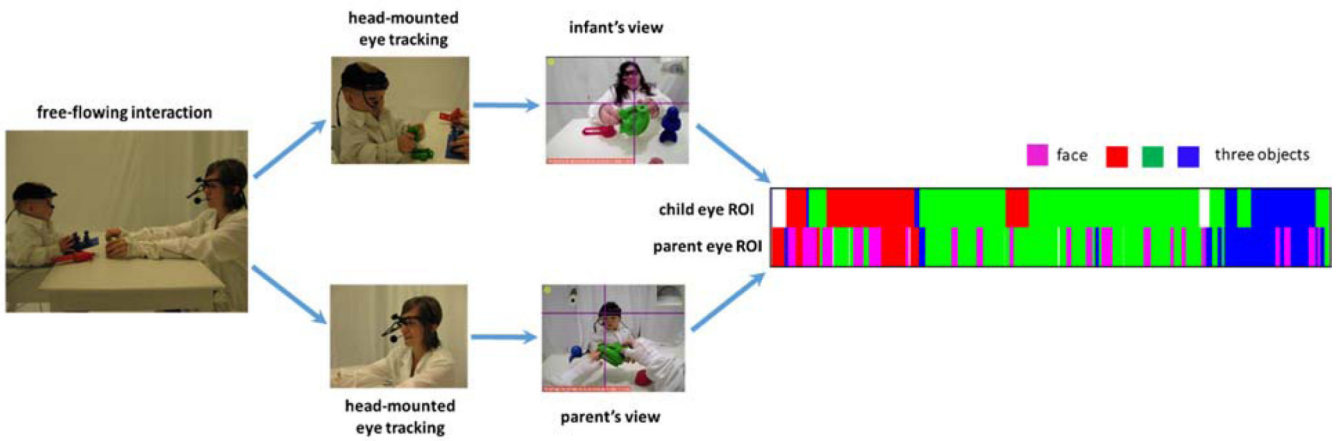
Figure 1.
Overview of the experiment. An infant and her parent played with a set of toys in a free-flowing interaction. Both participants wore a head-mounted eye tracker which recorded gaze data from the first-person view with a cross-hair indicating gaze direction moment by moment. Two gaze streams collected from the parent and infant respectively are used in data analysis.
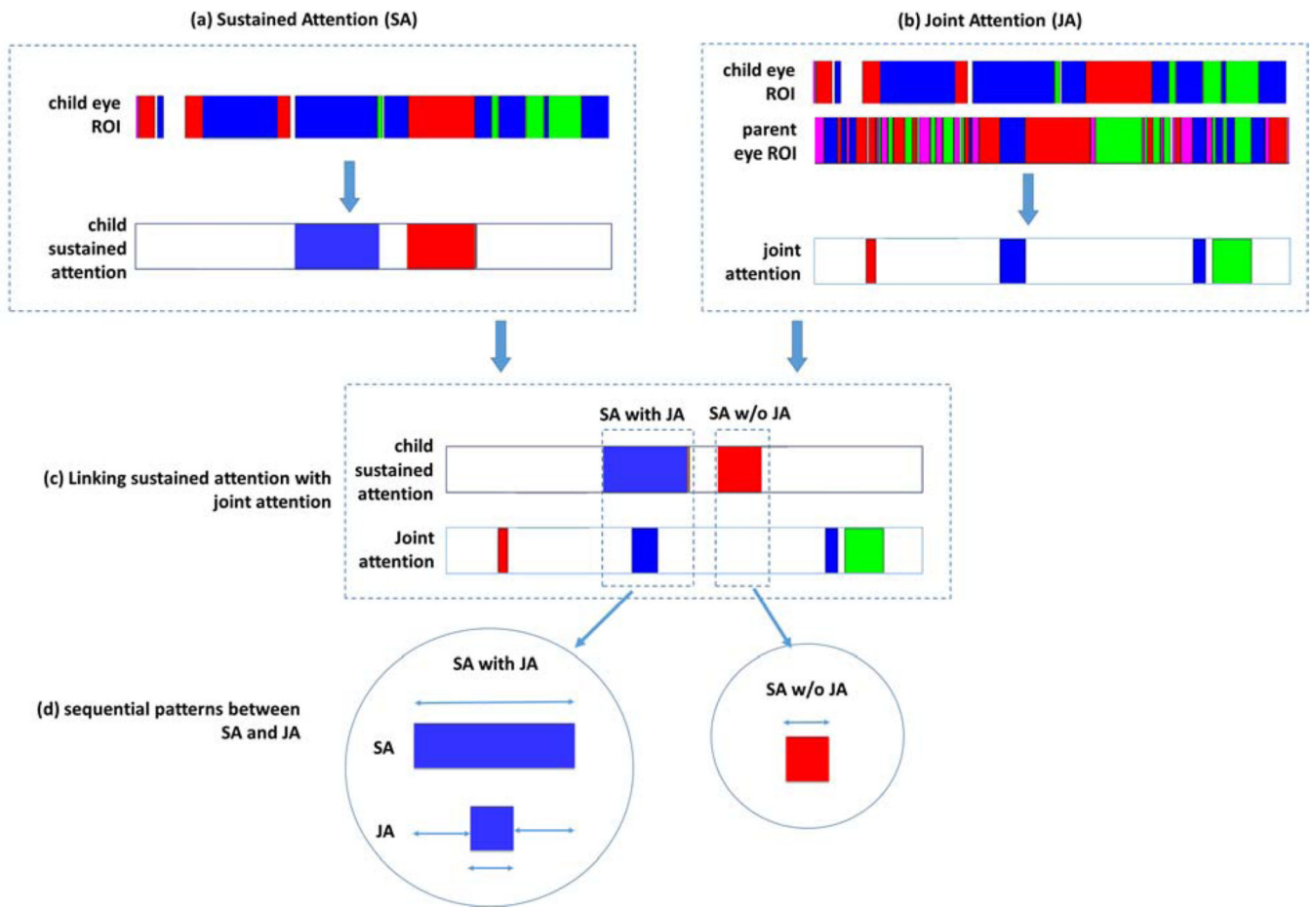
Figure 2.
Overview of data analysis. (a) Sustained Attention (SA) was defined based on infant eye ROI. (b) Joint Attention (JA) was measured independently based on infant and parent eye ROI streams. (c) SA instances were categorized into two cases: SA with an accompanying JA and SA without any accompanying JA. (d) Sequential patterns between SA and JA were examined for the instances of SA with JA, with a comparison of the instances of SA without JA.
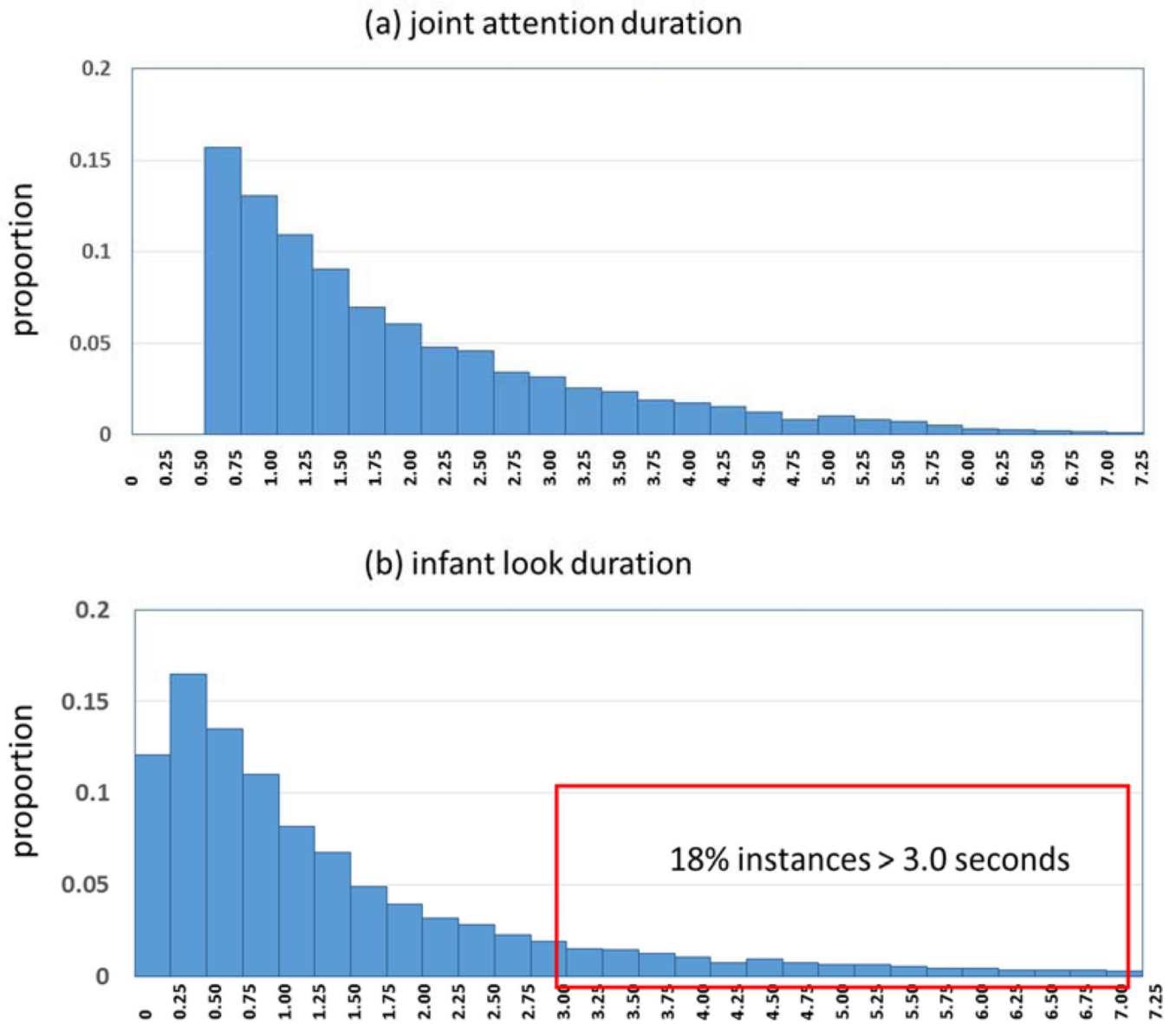
(a) joint attention duration

(b) infant look duration

Figure 3.
Histograms of durations of joint attention and infant looks. (a) Histogram of joint attention duration. Note that joint attention bouts are defined to be longer than 500ms. (b) Histogram of infant gaze duration. Infants generated lots of briefly looks. Only few than 20% looks are longer than 3 seconds – the threshold used to define sustained attention.
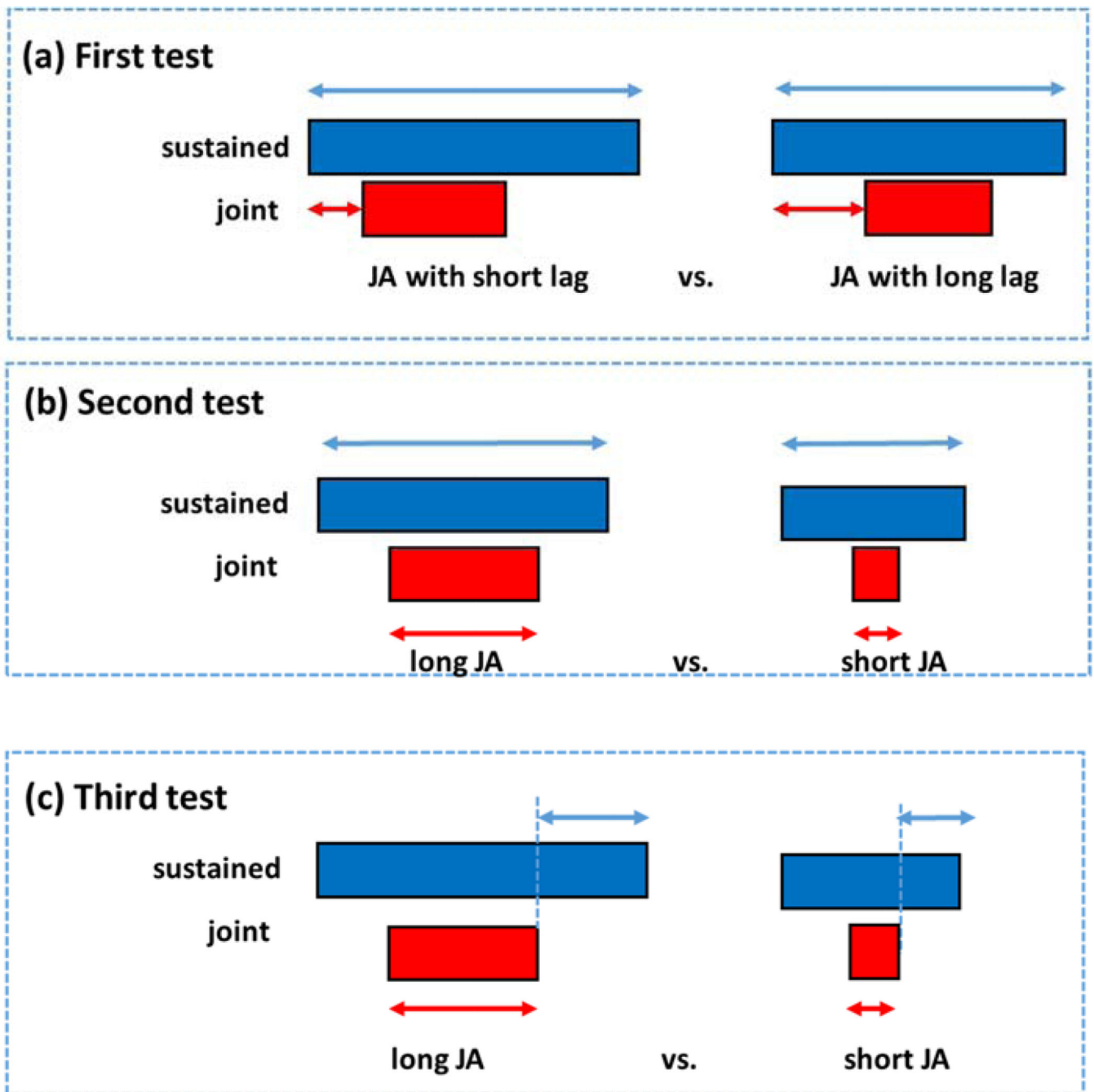
Figure 4.
Overview of data analysis to test three hypotheses. In all of the three cases, SA instances are divided into two groups based on the accompany JA instances (red arrows) and SA durations (blue arrows) in the two groups are compared. (a) SA instances are divided into SA instances with short-lag JA and those with long-lag JA. SA durations in the two groups show no significant difference. (b) SA instances are divided based on JA duration, and the results show that longer JA is associated with longer overall sustained attention. (c) SA instances

are divided again into long-JA and short-JA cases as in (b). Infant sustained attention to the target after JA ended is longer for longer JA periods than for shorter ones.