8-month-olds Know Which Face is Reliable

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Abstract

By 8 months of age, infants use statistical regularities and perceptual cues to orient attention (e.g. Kirkham et al., 2007; Wu & Kirkham, 2010). However, it is unclear whether infants are sensitive to the reliability of individual attentional cues. In this eye-tracking study, 8-month-olds were familiarized with a reliable face, which always looked to a box where an animation appeared, and an unreliable face, which looked only 25% of the time to the box containing the animation. At test, when the animations did not appear, infants searched longer in the corner cued by the reliable face, but did not search longer in the corner cued by the unreliable face. These results suggest that even young infants can track the the reliability of potential informants and use this information to distribute attention in support of early learning.

Keywords: Psychology; attention; spatial cognition; infancy; eye-tracking

Introduction

For young infants, the natural world is a constant stream of dynamic, multi-modal sensory experiences. In a short time, they are able to parse this sensory overload into discrete and recognizable objects, faces, and events. Selective attention plays a critical role in this early learning, as infants must focus on items that contain useful information while ignoring random variation and meaningless noise. A number of studies have demonstrated that infants can allocate attention selectively in support of task-relevant learning (Mareschal & Johnson, 2003; Richardson & Kirkham, 2004; Tummeltshammer & Kirkham, in press; Wu & Kirkham, 2010). However, the selection process by which they are able to filter relevant information from noise is less well understood.

Given that the natural world contains a high degree of statistical redundancy, showing considerable consistency across space and time (Field, 1994), and there is evidence that the developing response properties of some visual neurons exploit the statistical nature of the input (Olshausen & Field, 1996), it would be advantageous for the system to selectively attend to statistically reliable and coherent events. Research with young infants robustly shows that they are sophisticated statistical learners, tracking probabilistic events across multiple instances and updating their representations of the world based on incoming data (Fiser & Aslin, 2002; Kirkham et al., 2002; Kirkham et al., 2007; Saffran, Aslin & Newport, 1996; Smith & Yu, 2008; Wu, Gopnik, Richardson, & Kirkham, 2011).

Recent studies have demonstrated that infants distribute attention selectively based on statistical information (Kidd, Piantadosi, & Aslin, 2012; Tummeltshammer & Kirkham, in press), which may guide early learning of events and features that are reliably linked. For example, new evidence from Kirkham and colleagues (2012) shows that young infants prefer to look at objects with correlated rather than uncorrelated parts and are surprised when statistically coherent parts split apart (Wu, et al., 2011). Infants also deploy attention with the influence of external cues, including bottom-up perceptual salience and even abstract cue-target associations (Cohen, 1972; Colombo, 2001; Johnson, Posner, & Rothbart, 1991; 1994; McMurray & Aslin, 2004). If these cues contain reliable information, then they may guide the infant toward learnable content; however, a mismatch between external cues and statistical coherence may drive infants to distraction and prevent them from encoding the critical stimulus events. A few studies have shown that young infants will use central cues to orient attention to peripheral locations when individual cues and targets are perfectly correlated (Johnson, Posner & Rothbart, 1991; McMurray & Aslin, 2004). At present, however, there is little evidence to address whether infants use statistical information to evaluate the reliability of salient attentional cues.

Faces offer a good opportunity to test whether attention to salient cues is mediated by statistical reliability. From birth, infants are drawn to faces, particularly those expressing eye contact (Senju & Johnson, 2009), and very young infants will orient faster to visible targets in the direction of an adult's gaze (Farroni, Massaccesi, Pividori, & Johnson, 2004; Hood, Willen, & Driver, 1998). Infants follow faces from 4 months of age, and are sensitive to the relationship between an adult's gaze and the locations of objects (D'Entremont, 2003; Senju, Csibra, & Johnson, 2008). Indeed, there is recent evidence that infants learn better from faces than other attention-directing cues (e.g., flashing lights; Wu & Kirkham, 2010). It is unclear whether infants follow faces as a category of salient attentional cues or perhaps have a general expectation that faces will provide information. It remains an empirical question whether infants track the statistical coherence of associations between cues and their targets, and further, whether they can update their expectations of individual face cues to guide attention optimally.

Research on 'selective trust'/'source monitoring' with young children has demonstrated that they take an informant's knowledge into account when soliciting or accepting new information. Preschoolers prefer to engage with informants who are knowledgeable rather than ignorant (Koenig & Harris, 2005), and will extend labels to novel objects when they were provided by a reliable rather than an unreliable adult (Clement, Koenig, & Harris, 2004; Koenig, Clement, & Harris, 2004). This work has recently been extended down to older infants: In a recent study, Begus and Southgate (2012) found that 16-month-olds point more to solicit information from adults who had previously labeled objects correctly than from those who had mislabeled objects. In addition, across two studies, Poulin-Dubois and colleagues found that 14-month-olds were sensitive to an adult's reliability in a search task, and were more likely to follow a reliable adult's gaze behind an occluder (Chow, Poulin-Dubois, & Lewis, 2008) and to imitate a reliable adult's actions (Poulin-Dubois, Brooker, & Polonia, 2011). These studies suggest that infants as young as 14 months can make an association between an informant's actions and the true state of the world and use it to guide their own responses.

There are, however, some reasons to suspect that young infants may have difficulty tracking the reliability of face cues and allocating attention accordingly. First, while young children may be sensitive to the reliability of an informant, young infants may not attend to the relationship between a salient cue and its target outcome. This could be due to a general bias to follow faces, or the inability to simultaneously attend to the face cue *and* keep track of its reliability over trials. Second, young infants may have difficulty making within-category distinctions; even if they could successfully track the reliability of a category of attentional cues (e.g. 'Faces offer reliable information'), infants may fail to make separate inferences for individual instances of the same category (e.g. 'Face A is reliable, but Face B is not'). Third, young infants may form initial associations between cues and targets that are difficult to update in light of noisy data. In all of the studies described with young children, the unreliable or ignorant adults always provided false or incongruent information, so children may have simply represented those adults as 'wrong' or 'unsuccessful' without having to update their inferences.

The present eye-tracking study aimed to investigate whether 8-month-old infants are sensitive to the statistical reliability of attentional cues. Infants were familiarized with four audio-visual animations of animals that appeared within four boxes in each corner of the screen. On separate trials, the locations of the animals were cued by either a reliable or an unreliable face. The reliable face always looked in the box where an animal would then appear, while the unreliable face looked in the box containing an animal only 25% of the time (and rather, looked in an empty box 75% of the time). Following familiarization, infants viewed test trials in which the faces looked in the previously-cued boxes and the animal sounds played, but the animations did not appear. If infants had learned to expect an animation in the cued box, then we hypothesized that they should search longer in the cued box than in the uncued boxes. In addition, infants viewed generalization trials in which the faces looked to boxes that were never cued before and novel animal sounds played, but again no animations appeared. If 8-month-old infants were able to track the reliability of the individual faces across trials, then we hypothesized that they should follow the reliable face to a new box, but abstain from following the unreliable face.

Methods

Participants

Twenty-four 8-month-old infants (11 females, M = 8 months 13.4 days, range: 7m12d – 9m7d) participated in the experiment, with an additional four infants tested but not included due to fussiness, inattention and/or failure to calibrate. Infants were recruited on a voluntary basis via local advertisements. Informed consent was received from all caregivers, and babies received a small gift.

Apparatus and Stimuli

Infants were eye-tracked using a Tobii TX300 eye-tracker (www.tobii.com) with a 23" built-in monitor. Stimuli were presented using Tobii Studio presentation software, and sounds were played through stereo external speakers. Throughout testing, infants were monitored via a built-in video camera and their eye movements through the Tobii Studio Live Viewer display. Two female actors were filmed in controlled settings and their footage was edited into face cue stimuli in Final Cut Express HD3 (Apple Inc., CA). The animated clips were created using Macromedia Director MX 2004 and combined with the face cues in Final Cut Express.

Infants saw a full-screen display (1920 X1080 pixels) comprised of four white boxes in the four corners of a black screen. Within each box, an animated animal appeared: a barking dog in Box 1, a croaking frog in Box 2, a gurgling fish in Box 3, and a chirping bird in Box 4. The animations were preceded by centrally presented face cues. On each trial, one of two female faces appeared in the center, smiled at the infant and said "Wow, look!". She then turned to one of the boxes and froze. An animal sound played and after a 500 ms delay, the corresponding animal appeared in its box. The animated animal moved within the box for 3.5 seconds, while the face remained frozen, as shown in Figure 1.

Figure 1. *Examples of four familiarization trials with a reliable face cue (left) and four familiarization trials with an unreliable face cue (right). While the reliable face always looked to the correct box, where an animal would appear, the unreliable face only looked to the correct box on one out of four trials.*

Design and Procedure

All infants were tested individually in a quiet room, seated on their caregiver's lap approximately 60 cm away from the monitor. A 5-point calibration sequence (the four corners and center of the screen; for details, please refer to von Hofsten, Dahlström, & Fredricksson, 2005) was used to obtain a reliable signal. Infant needed to fixate each point before the experimenter manually advanced the calibration sequence; if fewer than four points were accurately calibrated, the sequence was repeated.

Following successful calibration, infants were familiarized with a reliable face and an unreliable face on separate blocks (order counter-balanced across infants). The reliable face always looked at the box in which an animal animation would appear, reliably cueing two different boxes on separate trials. The unreliable face also cued two different boxes on separate trials, but only looked 25% of the time at the box containing an animation; that is, for the unreliable face, the animals often appeared in boxes that did not correspond to where the face had looked. For example, if the reliable face looked in Boxes 1 and 2 on four separate trials, either the dog (Box 1) or the frog (Box 2) would appear to match where the face had cued (see Figure 1A). However, if unreliable face looked in Boxes 1 and 3 on four separate trials, either the frog (Box 2) or the fish (Box 3) would appear, so that the cue and animation only matched on one of the four trials (see Figure 1B). Critically, one box was only cued by the reliable face, a second box was cued by both faces on separate trials, a third box was only cued by the unreliable face, and the last box was never cued.

Following familiarization, infants viewed test trials and generalization trials. On a test trial, the face looked to the box it had previously cued (whether reliably or unreliably) and the animal sound played; however, the animation did not appear. Instead, all four white boxes flashed briefly (200 ms) to encourage infants to make a saccade. On a generalization trial, the face looked to the box it had never looked at before and a new animal sound played. Again, no animation appeared, but all four white boxes flashed briefly to encourage saccades.

Infants viewed four blocks of four familiarization trials, with the reliable and unreliable faces on alternating blocks, followed by the two test blocks. This sequence was then repeated, for a total of 40 familiarization (20 reliable, 20 unreliable), 4 test, and 4 generalization trials[1].

Data Analysis

Eye movements were recorded and filtered into discrete fixations using a spatial filter of 30 pixels and a temporal filter of 100 ms. On test and generalization trials, when all four boxes flashed but no animations appeared, accumulated looking times (i.e. the summed durations of all fixations) to each of the four boxes were measured as a proportion of total looking time.

Results

Familiarization Trials

There were no differences in infants' attention to the faces (i.e. proportion of total accumulated looking time spent on the face) across familiarization trials, suggesting that infants looked equally to the reliable face (M=0.609, SE=0.017) and the unreliable face (M=0.621, SE=0.016), paired $t(23)$=1.02, p=*ns*.

[1] Infants also viewed preferential looking pre- and post-tests of the two faces side by side; however, as no differences in looking to the faces emerged, perhaps due to their novel 'out of context' presentation, this data is not reported.

Test Trials

Proportions of looking time to the four boxes during test trials, displayed in Figure 2, were analyzed with a 2 (Reliability) x 4 (Box) repeated measures ANOVA[2]. Results show a significant main effect of Box, $F(3,66)=3.64$, $p=0.017$, $\eta_p^2=0.142$, as well as a significant Reliability x Box interaction, $F(3,66)=3.55$, $p=0.019$, $\eta_p^2=0.139$. This interaction was unpacked using separate univariate ANOVAs for test trials with reliable and unreliable face cues. On reliably cued trials, a significant main effect of Box was apparent, $F(3,66)=8.32$, $p<0.001$, $\eta_p^2=0.274$, and post-hoc comparisons indicated that infants looked longer at the cued box than at any other box, $p<0.040$ (Bonferroni-corrected). However, on unreliably cued trials, no effect of Box emerged, $F(3,66)=0.21$, $p=0.888$, indicating that infants did not look longer at the cued box, nor at any other single box. Finally, a planned comparison across reliably and unreliably cued test trials confirmed that infants looked more to the cued box when it was cued by a reliable face than by an unreliable face, $t(22)=2.66$, $p=0.014$.

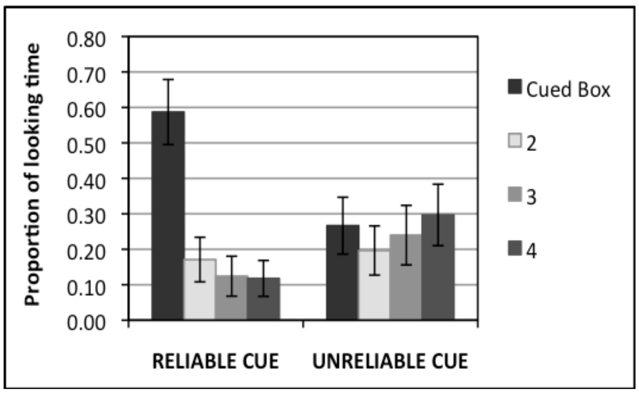

Figure 2. *Mean proportions of looking time to the four boxes on test trials with the reliable and unreliable face cues.*

Generalization Trials

Similarly, proportions of looking time to the four boxes during generalization trials, shown in Figure 3, were analyzed with a 2(Reliability) x 4(Box) repeated measures ANOVA[3]. Results show a slight main effect of Box, $F(3,63)=2.70$, $p=0.053$, $\eta_p^2=0.114$, as well as a significant Reliability x Box interaction, $F(3,63)=9.83$, $p<0.001$, $\eta_p^2=0.319$. This interaction was explored using separate univariate ANOVAs for generalization trials with reliable and unreliable face cues. On reliably cued trials, a significant main effect of Box emerged, $F(3,63)=12.39$, $p<0.001$, $\eta_p^2=0.379$, and post-hoc comparisons indicated that infants followed the cue to the new box, looking longer at the new box than at any other box, $p<0.024$ (Bonferroni-corrected). However, on unreliably cued trials, no effect of Box was apparent, $F(3,63)=0.40$, $p=0.754$, indicating that infants did not follow the cue to the new box, nor did they look longer at any other single box. Finally, a planned comparison across reliably and unreliably cued generalization trials confirmed that infants followed the cue to the new box more when it was a reliable face cue than an unreliable face cue, $t(21)=4.20$, $p<0.001$.

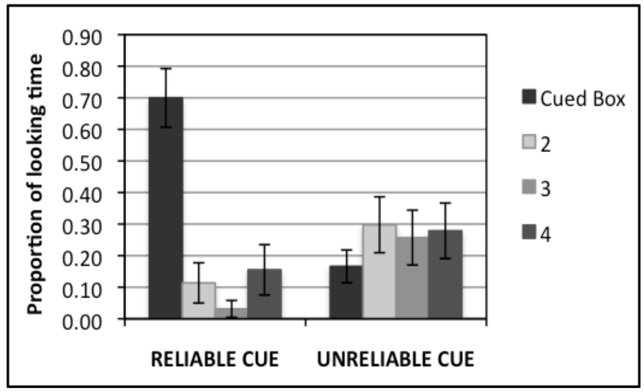

Figure 3. *Mean proportions of looking time to the four boxes on generalization trials with the reliable and unreliable face cues.*

Discussion

Previous research has demonstrated that young infants are sensitive to statistical and perceptual cues and can use them to allocate attention in their busy, multisensory world. The present study suggests that infants can also integrate these sources of information to infer the reliability of individual cues and modify their responses. In the current study, infants searched consistently in the box cued by the reliable face, and even followed it to search in a box where no animation had appeared before. At the same time, infants did not follow the unreliable face, and rather searched at chance among all four boxes. These differences in looking behavior could not be accounted for by mere differences in global attention, as infants looked equally long at both reliable and unreliable face cues during familiarization trials.

Cue reliability also appeared to have important consequences for infants' audio-visual learning. Infants correctly predicted where a reliably cued animal would appear, but did not learn to localize the animal that had been unreliably cued. This study adds to a growing body of research suggesting that appropriate cues can enhance infants' processing and learning of cued events (Reid, Striano, Kaufman, & Johnson, 2004; Senju, Csibra, & Johnson, 2008; Yoon, Johnson, & Csibra, 2008; Wu & Kirkham, 2010). For example, Wu and Kirkham (2010) found that 8-month-olds were better able to remember the spatial locations of audio-visual targets preceded by social cues compared to uncued targets. It is possible that infants' sensitivity to reliable cues may act as a driving force for

[2] One out of 24 infants did not search in any boxes during test trials, and thus was omitted from this analysis.

[3] Two out of 24 infants did not search in any boxes during generalization trials, and thus were omitted from this analysis.

early learning, with cued attention helping the learner gather information and integrate it over time (Smith, Colunga, & Yoshida, 2010). Indeed, enhanced detection and processing of cued stimulus events are well-documented in studies of selective attention with adults and children (Goldberg, Mauer, & Lewis, 2001; Mackintosh, 1975; Posner, 1980).

While the present results suggest that infants are sensitive to the reliability of attentional cues, it remains unknown whether this sensitivity is face-specific or would extend to other types of cues. A few studies have shown that infants struggle to direct attention with a non-social central cue (Varga et al, 2009), though they seem to succeed in learning the cue-target relationship when the cue is perceived as social (Corkum & Moore, 1998; Deligianni, Senju, Gergely, & Csibra 2011; Johnson, Slaughter, & Carey, 1998; Wu & Kirkham, 2010). However, in these studies, cues have been used to direct infants' attention to one of multiple objects, with the result that infants look equally to both cued and uncued objects. Perhaps, then, infants need to learn the function of an abstract, non-social cue with a singular target (as in McMurray & Aslin, 2004) before it can be used to disambiguate multiple targets. Future experiments will aim to evaluate whether infants consider the statistical reliability of attentional cues more broadly.

The mechanisms driving statistically cued attention are also unclear and worth investigating in future research. A modelling approach, using infants' own trial-by-trial data as input (cf. Piantadosi, Kidd, & Aslin, in press; Yurovsky, Hidaka, & Wu, 2012), may help to characterize the multiple processes involved in statistical learning of cued events, such as selective attending to cues and targets, tracking the correspondence between them, and deciding which cues to follow. Further, it would be interesting to distinguish whether infants' selective attention to cued events is motivated by the prospect of an exciting reward, or if there may be something intrinsically motivating about the predictive information itself. Bromberg-Martin and Hikosaka (2009) found that macaque monkeys prefer to have predictive cues rather than unpredictive cues, even when the ensuing rewards were identical. In the present study, infants received audio-visual animations on both reliably cued and unreliably cued trials, but did not develop a preference for the reliable (or unreliable) face. This may be due, in part, to the salience of the faces, or perhaps because infants were not trained to make a choice between cues as the monkeys were in Bromberg-Martin and Hikosaka (2009). Nevertheless, future research will aim to explore interactions in cued attention between the reliability of the cue and the salience of the reward.

Conclusions

The present study demonstrates that 8-month-olds can distinguish reliable and unreliable faces and use this inference to modify attention to cued targets. These results extend the existing literature on 'selective trust'/'source monitoring' to young infants, suggesting that a sensitivity to the reliability of potential informants may be present early in development. Selective trust, like selective attention, is influenced by statistical regularity, external cues, and the extent to which these factors are weighted in a particular context. This study has provided evidence that 8-month-old infants can track the reliability of individual cues to deploy attention optimally in support of early learning.

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