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Neural evidence for the impact of facial trustworthiness on object processing in a gaze-cueing task in 7-month-old infants

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ABSTRACT
Humans automatically judge a person's trustworthiness solely based on facial features and use these judgments to inform subsequent behavior. While recent studies demonstrate that already infants are sensitive to variance in facial trustworthiness, it remains unclear whether this variance also influences subsequent socio-cognitive processes. We investigated event-related brain responses (ERPs) to faces varying in trustworthiness in a gaze-cueing paradigm in 7-month-old infants. Our analysis focused on the ERP responses to cued or un-cued objects shown in isolation after the gaze-cue was presented. We observed an enhanced occipital positive slow wave (PSW) to un-cued compared to cued objects, suggesting a gaze-cueing effect irrespective of facial trustworthiness. Furthermore, objects in the un-cued condition elicited a larger fronto-central Nc when the gaze cue was provided by trustworthy compared to untrustworthy faces. This pattern suggests that while gaze cueing occurs irrespective of facial trustworthiness, allocation of attention, as indexed by modulation of the Nc amplitude, varies as a function of trustworthiness. Taken together, our results show that facial trustworthiness impacts object processing in the context of a gaze cueing paradigm, adding to the notion that it serves as an important social cue from early in ontogeny.

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Infancy; ERP; trustworthiness; face; gaze

Determining whether someone is to be trusted or not is a fundamental aspect of any social interaction, especially when encountering someone for the first time. Recent research shows that people do not wait to accumulate actual behavioral evidence about someone's trustworthiness, but they quickly, consistently, and automatically judge a person as more or less trustworthy based solely on their facial appearance (Todorov, Olivola, Dotsch, & Mende-Siedlecki, 2015; Todorov, Pakrashi, & Oosterhof, 2009; Todorov, Said, Engell, & Oosterhof, 2008).

Not only do humans judge others to be more or less trustworthy based on facial appearance, but this judgment also informs their behavioral choices. For instance, in economic decision making games, participants tend to invest more in a trustworthy as opposed to an untrustworthy looking partner (Chang, Doll, van 't Wout, Frank, & Sanfey, 2010; De Neys, Hopfensitz, & Bonnefon, 2017; Stirrat & Perrett, 2010; van 't Wout & Sanfey, 2008). Furthermore, not only can this bias based on facial appearance be observed in an experimental setting, but it can also be seen in real world situations. In criminal trials, for instance, less trustworthy-looking suspects receive more severe sentences (Wilson & Rule, 2015). Additionally, in shared economy situations such as Airbnb, more trustworthy-looking persons achieve higher ratings and can demand higher prices (Ert, Fleischer, & Magen, 2016). At the brain level, these judgements of facial trustworthiness are assumed to rely on an overextension of brain processes principally involved in emotion processing, including brain structures such as the amygdala (Said, Baron, & Todorov, 2008; Said, Dotsch, & Todorov, 2010), yet importantly, adults rated the face stimuli used as emotionally neutral.

One fundamental question in the investigation of facial trustworthiness and its perception is where this phenomenon originates (see Over & Cook, 2018). Recent developmental studies suggest that a basic sensitivity to variance in facial trustworthiness is already present from early in development. For instance, preschoolers judge faces as more or less trustworthy based on facial appearance cues, consistent with what is known from adults (Cogsdill, Todorov, Spelke, & Banaji, 2014). Furthermore, infants, who cannot provide verbal judgements like preschoolers and adults, show

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a preference for faces perceived by adults as more trustworthy as indicated by an increased looking time (Jessen & Grossmann, 2016, 2019). Moreover, at the brain level, infants show differential brain responses to faces varying in facial trustworthiness (Jessen & Grossmann, 2016, 2019). Taken together, these findings suggest that the basic mechanisms to differentiate features of facial trustworthiness are present from early in human development.

As in adults, we assume this discrimination of facial trustworthiness in infants to arise primarily from a processing of subtle facial features associated with positive compared to negative emotional facial expressions (see Todorov et al., 2008). More specifically, trustworthy-appearing faces have been argued to share subtle yet invariant features seen in happy facial expressions, which may lead the infant to perceive trustworthy faces as more positively valenced than untrustworthy faces. Relatedly, infants may view trustworthy faces as more familiar given that they are predominately exposed to positive facial expressions (Malatesta & Haviland, 1982). However, a purely emotion-based account of facial trustworthiness processing in infants appears unlikely, as the faces are rated as emotionally neutral by adults (Oosterhof & Todorov, 2008). The existing results from prior work using ERPs are somewhat mixed in this respect. Conscious processing of facial trustworthiness has been shown to result in an enhanced Nc response to neutral as opposed to either highly trustworthy or highly untrustworthy faces (Jessen & Grossmann, 2016), pointing to an increased familiarity with faces neutral in trustworthiness, a feature configuration that has also been suggested as the most prototypical and probably most familiar to adults (Said et al., 2010; Stewart et al., 2012). However, in a study on the unconscious processing of facial trustworthiness, results indicate greater familiarity with both, neutral and highly trustworthy faces, as compared to highly untrustworthy faces (Jessen & Grossmann, 2019).

Critically, to date, it is unclear to what extent the differentiation of facial trustworthiness seen among infants goes beyond a mere detection of variance and may actually impact other social and cognitive processes beyond face processing in infants. While studies with older children suggest that facial trustworthiness is used as a cue in economic decision making games (Ewing, Caulfield, Read, & Rhodes, 2015), it is currently unknown whether facial trustworthiness influences social cognitive processes that can already be observed during infancy such as eye gaze cueing of objects (Gredebäck, Fikke, & Melinder, 2010; Hoehl & Striano, 2008, 2010).

In the present study, we therefore sought to investigate the influence of facial trustworthiness on object processing in a gaze-cueing paradigm. In particular, we were interested in whether or not perceived trustworthiness influences joint attention and subsequent object processing in 7 month-old infants, as an example of a vital social cognitive process that can be probed during infancy.

Direction of gaze is a salient cue as to where an adult is directing his/her attention, and infants reliably follow a person's gaze by 6–8 months of age (Gredebäck et al., 2010). In a typical gaze-cueing paradigm, an infant is presented with a face looking directly at them and subsequently shifting its gaze to either the left or the right side. If as a result both, the person providing the gaze cue and the infant, focus their attention on the same location (usually an object), such an interaction is referred to as a triadic interaction based on joint attention (Frischen, Bayliss, & Tipper, 2007; Grossmann & Johnson, 2010).

How readily and reliably an infant engages in such joint attention is influenced by a number of factors. For instance, if the person providing the gaze cue does not make eye contact with the infant before shifting his/her gaze, the infant is much less likely to follow the cuer's gaze (Grossmann & Johnson, 2010; Parise, Reid, Stets, & Striano, 2008; Striano, Reid, & Hoehl, 2006). Furthermore, properties of the face of the person providing the gaze cue, including familiarity (Gredebäck et al., 2010; Pickron, Fava, & Scott, 2017) and emotional content (Niedźwiecka & Tomalski, 2015) have been shown to influence infants' gaze-following behavior. For example, infants ages 9 to 12 months show a gaze-cueing effect for happy faces but not for fearful or angry faces (Niedźwiecka & Tomalski, 2015), suggesting that a positive (friendly) attitude towards the infants may facilitate gaze following and establishing joint attention.

The method that has been used extensively to investigate infants' gaze behavior in such settings is eye-tracking (see Gredebäck et al., 2010; Niedźwiecka & Tomalski, 2015; Pickron et al., 2017). However, another approach is the use of electroencephalography (EEG), which, while offering a more indirect measure of overt visual attention, has the additional benefit of allowing insights into brain correlates of face, gaze, and object processing in these interactive gaze-following scenarios. Furthermore, the use of EEG rather than eyetracking allows us to find evidence for shifts in overt attention which we would not be able to assess using eyetracking. Therefore, in the present study we decided to use event-related brain potentials (ERPs) to examine a potential interaction between the processing of facial trustworthiness and gaze direction.

An established way to use EEG to investigate gaze-cueing effects is to present a toy simultaneously with the gaze-cueing face, either on the same side as the face is looking (match) or on the opposite side (mismatch) (see e.g. Hoehl & Pauen, 2011; Hoehl & Striano, 2010; Hoehl, Wahl, Michel, & Striano, 2012). Directly afterwards, the toy is presented in isolation, and the infant's ERPs to the toy are measured. ERP studies with infants using this kind of procedure have shown that mismatch trials when compared to match trials typically evoke greater novelty responses in infants' brains, indexing a different processing of objects that had been part of a joint-attention context. Furthermore, initial eye contact between the infant and the person providing the gaze cues appears to play an important role. Infants show a stronger attentional response to objects (toys), if the person providing the cue first establishes eye contact with the infant compared to a condition in which the person simply looks at the object without previously engaging in eye contact with the infants (Parise et al., 2008; Striano et al., 2006).

The most commonly investigated ERP component in this context is the Nc (Hoehl & Striano, 2010; Hoehl et al., 2012). This fronto-central ERP component occurring between 400 and 800 ms after stimulus onset has been linked to allocation of attention and has been shown to originate from the prefrontal and anterior cingulate cortex (Reynolds & Richards, 2005; Webb, Long, & Nelson, 2005). It has been shown that characteristics of the faces providing the gaze cue can influence the Nc response to objects presented in isolation following the initial presentation of the object in the gaze cueing scenario. For instance, 3- as well as 6-month-old infants show an enhanced Nc response to objects that had previously been gaze-cued by a fearful face (Hoehl & Striano, 2010; Hoehl, Wiese, & Striano, 2008), suggesting a stronger attention allocation elicited by threat signals. The same holds true for surprised faces in 3-month-old infants, but this effect has disappeared by 9 months of age (Hoehl & Pauen, 2011).

Furthermore, the Nc amplitude is also sensitive to whether prior to the cueing, the cue-giver had established eye-contact with the infant. If eye contact had been established, a larger Nc response is elicited compared to a scenario in which a face only gazes towards an object (i.e. no joint attention, Striano et al., 2006). This effect can also be observed when only the object is presented in isolation subsequent to gaze-cueing with or without prior eye-contact (Parise et al., 2008).

A second ERP component of interest in this context is a positive slow wave (PSW) typically recorded at occipital electrodes, which has been linked to familiarity processing and memory updating (Snyder, Webb, & Nelson, 2002). At 4 months of age, infants show a larger PSW response to objects that had previously *not* been gaze-cued (Reid, Striano, Kaufman, & Johnson, 2004), in particular if the person providing the gaze cue is a familiar person such as the caregiver (Hoehl et al., 2012). Hence, gaze-cueing seems to be sufficient not only to direct an infant's attention to a given object but also to elicit an enhanced processing of the attended object, leading to a subsequent facilitation in object processing (Reid et al., 2004).

In the current study, we examined the impact of facial trustworthiness on gaze-cueing in 7-month-old infants using ERPs. We focused our ERP analysis on the above-mentioned Nc and PSW components in response to an object (toy) that either had or had not been gaze-cued by either a highly trustworthy or a highly untrustworthy face. We chose to study this in 7-month-old infants because by this age infants have been shown to be sensitive to variance in facial trustworthiness (Jessen & Grossmann, 2016, 2019) and have also been shown to display a robust gaze-cueing effect (Gredebäck et al., 2010).

Hypotheses

Based on prior work, we expected a main effect of gaze direction (match vs. mismatch) on the PSW amplitude, resulting in an enhanced PSW amplitude for objects that had not been gaze-cued (Hoehl et al., 2012; Reid et al., 2004). Moreover, if infants indeed perceive trustworthy faces as more familiar and positive then this might result in a stronger gaze-cueing effect as previously seen for familiar and positive faces (Hoehl et al., 2012; Niedźwiecka & Tomalski, 2015). We did not have a specific directional hypothesis regarding the Nc response. Prior studies have reported an enhanced Nc response to objects previously cued by faces showing negative, in particular fearful, facial expressions, which has been linked to an increased attentional response to potential threats (Hoehl & Striano, 2010; Hoehl et al., 2008). If untrustworthy faces are perceived as generally more negative, this should lead to a larger Nc response to objects cued by untrustworthy faces. However, it is also possible that untrustworthy faces (unlike fearful faces with averted gaze that signal a source of threat in the environment) serve as an indicator as to whom to trust or mistrust when following gaze and learning about objects. In such a scenario, one would expect an enhanced Nc response to object previously paired with trustworthy over those paired with untrustworthy faces.

Methods

Participants

Thirty-three 7-month-old infants were invited to participate in the study. Eight infants were excluded from further analysis because they failed to contribute at least 10 artifact-free trials per condition. The final sample for the ERP analysis therefore consisted of 25 infants (13 male, mean age: 216 ± 7 days, range: 204–231 days). All infants were born full-term (38 to 42 weeks gestational age) with a birth-weight of at least 2500 g. Parents provided written informed consent, the study was conducted according to declaration of Helsinki, and approved by the local ethics committee.

Stimuli

As face stimuli, we used pictures from an existing database containing faces varying in perceived trustworthiness but perceived as emotionally neutral by adult observers (Oosterhof & Todorov, 2008). The faces were computer-generated using the software FaceGen Modeller 3.2 (Singular Inversions, 2007, Toronto, Canada), and varied in trustworthiness according to a model described by Oosterhof and Todorov (2008). All faces were male in order to increase comparability to prior work with infants (Jessen & Grossmann, 2016, 2019) and adults (Oosterhof & Todorov, 2008). We selected three faces perceived as low in trustworthiness (–3 SD from a neutral face; ID 11, 16, and 17) and three faces perceived as high in trustworthiness (+ 3 SD from a neutral face; ID 1, 14, and 20; see supplementary material, Figure 1, for all faces used a stimulus material). Using the Adobe Illustrator, we manipulated the eyes of these faces by moving the pupil to the left or right to created faces that appeared to gaze to the left or the right.

In addition, we used ten color images of toys found on the internet. None of the toys displayed contained any faces or were animals of any kind, but rather we used images of various types of rattles and balls.

Design

The experiment followed a 2 × 2 × 2 design with the factors Trustworthiness (high, low), Match (match, mismatch), and Side (left, right). For each condition, a maximum of 30 trials was presented (10 from each identity), leading to a total of 240 trials. Trials were arranged in 10 mini-blocks of 24 trials each (3 per condition) that were presented consecutively without interruption.

Each trial started with the presentation of a white fixation cross in the center of a black screen for 300 ms followed by a face high or low in trustworthiness gazing straight at the observer (see Figure 1). In contrast to prior studies on gaze-cueing (e.g. Hoehl et al., 2012), we decided against presenting the object (toy) already at this point in order to rule out that infants form an association between the face (trustworthiness) and the toy irrespective of gaze direction. After 750 ms, the same face was presented with gaze averted to either the left (Side: left) or the right (Side: right). At the same time, a toy was displayed either at the same side the gaze was directed (match) or at the opposite side (mismatch). This display was shown for another 750 ms and then replaced by a black screen for a random duration between 400 and 600 ms. After this, the same toy was shown in isolation in the center of the screen for 750 ms. The next trial started after an inter-trial interval varying randomly between 800 and 1200 ms.

Procedure

After arrival, parents and infant were given time to familiarize themselves with the new environment. Parents were explained the details of the study and signed a consent form. For EEG preparation, the infant was sitting on his/her parent's lap. An elastic cap (EasyCap, Eaton, OH) in which 27 AgAgCl-electrodes were mounted according to the 10–20-system was used for recording. An additional electrode was attached below the infant's right eye to record the electrooculogram (EOG). The EEG signal was recorded with a sampling rate of 500 Hz using

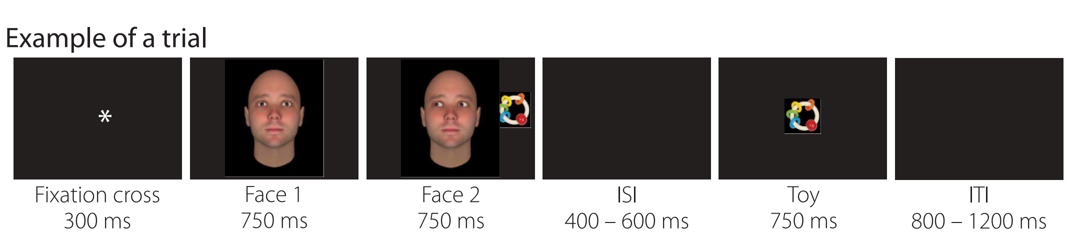

Figure 1. Example of trial. A face high or low in trustworthiness was followed by the same face, gazing either to the side where a toy was presented or to the opposite side. After a brief interstimulus interval, the same toy was shown in isolation. ISI = interstimulus interval, ITI = intertrial interval.

a REFA-8 amplifier (Twente Medical Systems, Oldenzaal, The Netherlands) and with Cz as online reference.

The experiment took place in an electrically- and sound-shielded chamber. The infant was sitting on his/her parent's lap and the stimuli were presented on a CRT monitor with a screen size of 1024 × 768 and a refresh rate of 60 Hz. The parent was instructed not to interact with the infant during the experiment and the infant's attention was monitored online using a small camera mounted above the screen. If necessary, short video clips containing ringtones and abstract moving shapes were played after the end of a trial to redirect the infant's attention to the screen. The experiment continued until the maximum number of trials was presented or the infant became too fussy to continue.

Analysis

Data were analyzed using Matlab (TheMathWorks,Inc., Natick, MA) and the Matlab toolbox FieldTrip (Oostenveld, Fries, Maris, & Schoffelen, 2011). In addition to the ERP analysis reported here, we also computed an exploratory time-frequency-analysis of the EEG data, which can be found in the supplementary material.

Data were re-referenced offline to the mean of TP9 and TP10 (linked mastoids) and filtered using a bandpass filter of 0.2–20 Hz. The video recording of the infant during the experiment was inspected visually and if the infant did not attend to the screen during any part of the trial, the entire trial was discarded (for two infants, visual inspection was not possible due to technical problems during the recording).

For the ERP analysis, data were segmented into epochs of 200 ms before until 800 ms after the onset of the toy. To detect trials contaminated by artifacts, we computed the standard deviation in a sliding window of 200 ms over the entire epoch. If the standard deviation exceeded 80 µV at any electrode, the entire trial was rejected. Since we did not expect any effect of Side (left, right), we pooled trials across these conditions. If less than 10 trials remained in any condition, the infant was excluded from further analysis. On average, infants contributed 17 ± 5 (mean ± SD) trials (trust-match: 18 ± 6; trust-mismatch: 16 ± 5; untrust-match: 17 ± 5; untrust-mismatch: 17 ± 5).

We analyzed the responses at occipital electrodes (O1, O2) in a time-window between 150 and 225 ms, 225 and 400 ms, and 400 and 800 ms as well as at frontocentral electrodes (F3, Fz, F4, C3, Cz, C4) between 350 and 450 ms. The electrodes were chosen based on prior comparable work with infants (Jessen & Grossmann, 2019) and the time-windows were based on visual inspection of the present data. We computed a repeated measures ANOVA with the factors Trustworthiness (high, low) and Match (match, mismatch) and report effect sizes as partial eta square (η_p^2) for ANOVAs and as *r* for t-tests.

Results

Object – ERP

At occipital electrodes, we observed a marginally significant effect of Match between 150 and 225 ms [$F(1,24) = 2.981$, $p = .097$, $\eta_p^2 = .11$], but no other significant effect (all $p > .24$).

We did not find any significant effect in the time-window between 225 and 400 ms (all $p > .15$).

Between 400 and 800 ms after stimulus onset, we observed a main effect of Match [$F(1,24) = 4.342$, $p = .048$, $\eta_p^2 = .15$, see Figure 2]. No other effect reached significance (all $p > .29$).

Furthermore, we observed an interaction between Match and Trust at frontocentral electrodes between 350 and 450 ms [$F(1,24) = 4.382$, $p = .047$, $\eta_p^2 = .15$, see Figure 3], revealing a larger Nc amplitude in response to toys previously paired with a trustworthy face gazing in the opposite direction of the toy (trustworthy – mismatch) compared to toys previously paired with untrustworthy faces gazing in the opposite direction [untrustworthy – mismatch; $t(24) = -2.307$, $p = .03$, $r = .43$].

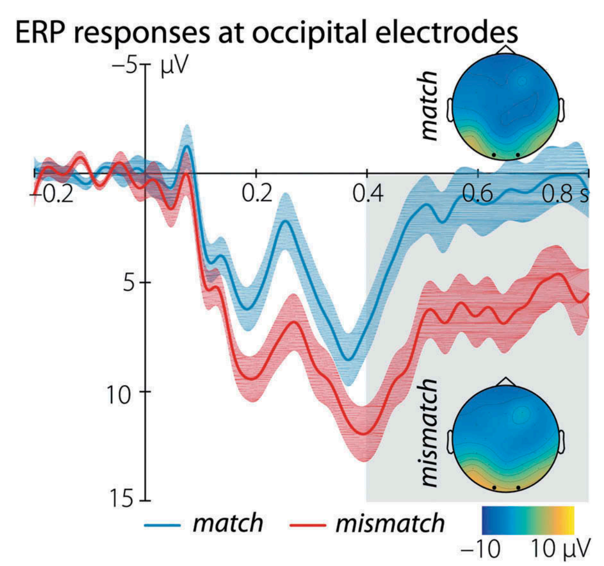

Figure 2. ERP responses at occipital electrodes. Between 400 and 800 ms after the onset of the toy, we observed a larger positivity in response to toys previously paired with a face gazing in the opposite direction (red) as opposed to toys previously paired with a gaze-matching face (blue). Shown are mean responses and within-subject errors.

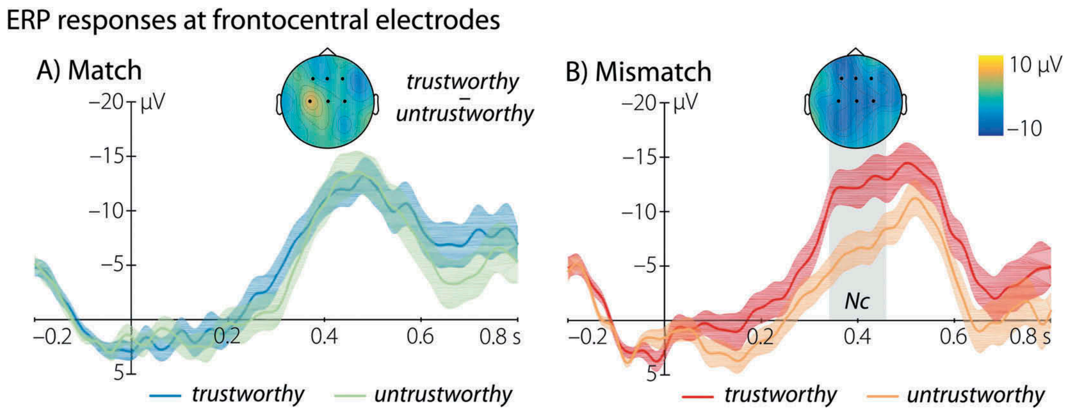

Figure 3. ERP responses at fronto-central electrodes (F3, Fz, F4, C3, Cz, C4). A) No differential response was observed to toys previously paired with a trustworthy face (in blue) or an untrustworthy face (in green) gazing at the toy. B) In contrast, if the face previously paired with the toy looked in the opposite direction, the toy elicited a larger Nc response between 350 and 450 ms when previously paired with a trustworthy (in red) as opposed to an untrustworthy face (in orange). Shown are mean responses and within-subject errors. Topographic representations show the difference in response between trustworthy and untrustworthy faces.

Discussion

We investigated the impact of facial trustworthiness on gaze-cueing and object processing in 7-month-old infants. In a gaze-cueing paradigm, infants were presented with faces high or low in trustworthiness that shifted their gaze either in the direction of a simultaneously presented toy or in the opposite direction. Our primary interest was the event-related brain response to the subsequent presentation of the object (toy) in isolation, focusing our analysis on ERP components previously shown to be modulated in gaze-cueing tasks with infants: (1) the PSW at occipital electrodes, and (2) the Nc at frontocentral electrodes. For the PSW, we observed a clear impact of whether or not the gaze cue had matched or mismatched with the object location. Specifically, we observed that the PSW was more positive in response to objects that had previously not been gazed at (mismatch condition) compared to objects that had been gazed at (match) condition. This is in line with previous ERP work (Hoehl et al., 2012; Reid et al., 2004) providing evidence for a gaze-cueing effect on visual object processing independent of facial trustworthiness. For the Nc, we observed an interaction between facial trustworthiness and gaze congruency (match versus mismatch). More specifically, our analysis showed that Nc responses to objects that were not gaze-cued (mismatch condition) were smaller for untrustworthy faces than for trustworthy faces. This suggests that attention allocation to the object, as indexed by the Nc, is modulated depending on the facial trustworthiness of the face providing invalid gaze-cues. In the following, we will discuss the obtained pattern of functionally and topographically distinct ERP component modulation on Nc and PSW.

Positive slow wave

Our data show that objects that had previously not been gazed at elicited a greater PSW compared to objects that had previously been gaze cued, a pattern that was unaffected by variance in facial trustworthiness. This finding demonstrates that infants in the present study used gaze-direction as a cue for attention allocation, and that this shift in attention resulted in differential processing of the presented object. Our results are in line with prior studies, reporting robust gaze-cueing effects in 7-month-old infants (Gredebäck et al., 2010), and with ERP findings showing greater PSW responses to objects that were not gaze-cued (Reid et al., 2004). The reduced PSW seen in infants in the current study when objects were gaze-cued (match condition) is thought to reflect familiarity detection (Reid et al., 2004). This suggests that gaze-cueing not only leads to a shift of infants' visual attention to the object but also influences the encoding of the attended object in memory and recognition as familiar when presented in isolation from the face (Reid et al., 2004). Moreover, we could not find evidence for an influence of facial trustworthiness on the gaze-cueing effect observed at the PSW. This lack of an effect of facial trustworthiness on the PSW is unlikely due to the infants' inability to discriminate faces varying in trustworthiness, because previous research using ERP and behavioral measures attests that infants at this age are capable of discriminate between faces based on facial trustworthiness (Jessen & Grossmann, 2016, 2019). In summary, our data indicate that gaze-cueing appears to occur for both trustworthy and untrustworthy faces, adding to a growing body of literature emphasizing the importance of gaze as a social cue (see Michel, Wronski, Pauen, Daum, & Hoehl, 2019).

Nc

We observed an interaction between facial trustworthiness and gaze congruency for the Nc, providing first evidence that facial trustworthiness affects object processing in a gaze-cueing context. Our ERP data show that while facial trustworthiness did not impact the Nc response to objects that had been gaze-cued, invalid gaze cues provided by faces low in trustworthiness resulted in a significantly reduced Nc amplitude to objects, suggesting reduced allocation of attention to these objects. The pattern of findings regarding the Nc suggests that if gaze-cues are valid, and a triadic interaction occurs, then objects receive greater attention allocation when subsequently presented in isolation (regardless of facial trustworthiness). This is in line with previous research using triadic interaction manipulation to study the neural correlates of joint attention and how it influences object processing (Parise et al., 2008; Striano et al., 2006). Interestingly, the current ERP data further revealed that infants show a similar Nc response to objects that were simply paired with trustworthy faces even though the faces did not provide a valid gaze cue. Our ERP data show that only when the gaze cue is invalid *and* the face is low in facial trustworthiness, the Nc response is actually reduced in its amplitude, as expected for a context in which no triadic interaction with the object and therefore no joint attention has occurred (Parise et al., 2008; Striano et al., 2006).

To explain exactly how trustworthy faces in spite of providing invalid gaze cues would still impact object processing such that the object simply paired with a trustworthy face later receives greater attention allocation when presented in isolation is difficult. One possibility is that even in the invalid gaze context, an association between face and object occurred in the presence of the trustworthy but not the untrustworthy faces. Such an interpretation is plausible considering that infants at this age discriminate gaze and trustworthiness cues automatically, that is, when presented subliminally (without conscious perception, see Jessen & Grossmann, 2014, 2019), pointing to a highly robust processing of both signals. This potential explanation also fits well with research showing that adults may rely on facial trustworthiness in spite of knowing better as shown by putting more trust in a trustworthy-looking person although they know from prior interactions with this particular person ought not to be trusted (Rezlescu, Duchaine, Olivola, & Chater, 2012). Considering the present results, we speculate that a somewhat similar mechanism may be at play in infants. Namely, infants allocate heightened attentional resources to an object previously paired with a trustworthy face, although the face did not provide a valid behavioral cue indicating trustworthiness.

Interestingly, the current ERP findings show that gaze cueing and facial trustworthiness impact two distinct ERP components during object processing, namely the PSW and the Nc, which can be separated both temporally and spatially. While the former has primarily been linked to familiarity processing (Snyder et al., 2002), the latter has been linked to attention allocation (Webb et al., 2005). It therefore seems to be the case that, irrespective of facial trustworthiness, infants shift their attention to an object that has been referenced by the gaze of an adult, leading to an increased familiarity with such objects as reflected in the main effect of Match on the PSW. However, while they appear equally familiar (or unfamiliar) with the respective objects irrespective of facial trustworthiness, infants appear to allocate more attention to objects that have been presented in a positive social context, either in a joint-attention-interaction or linked to a trustworthy face, as suggested by the interaction between facial trustworthiness and gaze congruency on the Nc. Clearly, future research is needed to further examine the impact of facial trustworthiness on the processing of gaze cues in infants. In particular, eyetracking will be invaluable to directly assess infants' looking patterns and investigate whether infants are more likely to follow the gaze of a trustworthy looking face. Ideally, EEG and eyetracking should be recorded simultaneously to explicitly probe how infants' gaze behavior is influenced by facial trustworthiness and subsequent object processing, and how this links to neural processes, including the ones identified here. This approach would be particularly useful to differentiate between a potential covert shift of attention, which may be reflected in the ERP response but not in the looking behavior, and an overt attentional shift reflected in looking behavior (and potentially also in the ERP response).

Another issue to consider in the investigation of facial trustworthiness processing in infants is the role that gender may play in the perception of character traits such as trustworthiness. In keeping with prior studies (Jessen & Grossmann, 2016, 2019), we only used pictures of male faces. However, considering that gender has been shown to influence trustworthiness perception in adults (Sutherland, Young, Mootz, & Oldmeadow, 2015), future studies with infants should manipulate gender, also because infants display a bias towards female faces (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002).

Conclusion

In summary, the current results replicate and extend previous research by demonstrating a robust gaze-cueing effect on object processing irrespective of facial trustworthiness. Importantly, our findings also show that facial trustworthiness can impact object processing even when gaze cueing is invalid. Specifically, infants showed enhanced allocation of attention to objects that were previously paired with a trustworthy face, but not an untrustworthy face, looking away from the object. The current results thus show that infants are not only sensitive to variance in facial trustworthiness as has already been shown in prior studies, but also that this information impacts other cognitive processes. This adds to the notion that facial trustworthiness serves as an important social cue from early in ontogeny.

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