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Neural evidence for the subliminal processing of facial trustworthiness in infancy

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ABSTRACT

Face evaluation is thought to play a vital role in human social interactions. One prominent aspect is the evaluation of facial signs of trustworthiness, which has been shown to occur reliably, rapidly, and without conscious awareness in adults. Recent developmental work indicates that the sensitivity to facial trustworthiness has early ontogenetic origins as it can already be observed in infancy. However, it is unclear whether infants' sensitivity to facial signs of trustworthiness relies upon conscious processing of a face or, similar to adults, occurs also in response to subliminal faces. To investigate this question, we conducted an event-related brain potential (ERP) study, in which we presented 7-month-old infants with faces varying in trustworthiness. Facial stimuli were presented subliminally (below infants' face visibility threshold) for only 50 ms and then masked by presenting a scrambled face image. Our data revealed that infants' ERP responses to subliminally presented faces differed as a function of trustworthiness. Specifically, untrustworthy faces elicited an enhanced negative slow wave (800–1000 ms) at frontal and central electrodes. The current findings critically extend prior work by showing that, similar to adults, infants' neural detection of facial signs of trustworthiness occurs also in response to subliminal face. This supports the view that detecting facial trustworthiness is an early developing and automatic process in humans.

1. Introduction

When human adults encounter another person's face for the first time, they are surprisingly quick and highly consistent in ascribing certain character traits to that person solely on the basis of their facial features. For example, there is work to show that these judgments occur with respect to character traits such as dominance, trustworthiness, and competence (Oosterhof and Todorov, 2008; Todorov et al., 2015).

Trustworthiness judgments are of special importance for humans as a highly cooperative species, as trustworthiness is essential in assessing who is friend and who is foe (Fiske et al., 2007). It is thus not surprising that judgments of another person's trustworthiness based on facial appearance have a strong impact on a person's decision-making in social situations. For instance, in economic games, participants are less likely to give money to an untrustworthy looking person (Chang et al., 2010; Tingley, 2014; van 't Wout, and Sanfey, 2008) and this tendency persists even if knowledge about a person's behavior indicates that he can be trusted (Rezlescu et al., 2012). The influence of facial signs of trustworthiness has also been shown to affect people's decisions outside the laboratory, in real-word settings. For example, people who were rated to possess higher levels of trustworthiness (and competence) based on facial appearance had a higher chance of being elected into political office (Chen et al., 2014), people who look less trustworthy are more likely to receive a more severe sentencing in court (Wilson and Rule, 2015), and trustworthy looking partners are chosen more often and can demand higher prices in shared economy situations such as Airbnb (Ert et al., 2016).

Regarding the underlying psychological processes, evaluating faces with respect to their trustworthiness is thought to rely on an over-generalization of emotion reading skills in humans to physiognomic features of the face (Todorov, 2008). Namely, extremely trustworthy faces are commonly perceived as positive (happy), whereas extremely untrustworthy faces are typically perceived as negative (angry) (Oosterhof and Todorov, 2008, 2009). However, there is also evidence to show that facial trustworthiness judgments occur for faces that are perceived as emotionally neutral (Oosterhof and Todorov, 2008). This has been taken to suggest that the judgment of trustworthiness from faces and the assessment of emotional expressions, in particular

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happiness and anger, rely on shared but not necessarily identical (neural) mechanisms (Engell et al., 2010).

Event-related brain potential (ERP) work with adults shows that facial trustworthiness processing occurs very rapidly during the early stages of visual processing and face encoding (Dzhelyova et al., 2012; Marzi et al., 2014; Ohmann et al., 2016). For example, facial trustworthiness has been shown to elicit differences in the face-sensitive N170 event-related potential (ERP) component (Dzhelyova et al., 2012) and for early visual ERP components such as the P100 (Marzi et al., 2014).

The developmental origins of trustworthiness processing from faces have been examined in recent studies. There is evidence to show that children from the age of three years differentiate trustworthy from untrustworthy, dominant from subdominant, and competent from incompetent looking faces (Caulfield et al., 2015; Cogsdill et al., 2014). In an economic decision making game, 5-year-olds have been shown to exhibit a response pattern similar to the one described above for adults (e.g. Chang et al., 2010); children were more likely to invest in a trustworthy looking partner compared to an untrustworthy looking partner (Ewing et al., 2015).

Furthermore, in a recent EEG study, we investigated the processing of facial trustworthiness in 7-months-old infants. We presented infants with computer-generated faces showing three different levels of trustworthiness (low, intermediate, and high). For an intermediate level of facial trustworthiness, infants showed an enhanced amplitude for the P400 elicited at occipital sites and for the Nc at frontal and central sites (Jessen and Grossmann, 2016b). Therefore, similar to what has previously been reported for adults (face-sensitive ERP component N170, see Dzhelyova et al., 2012), infants show a sensitivity to differences in facial trustworthiness reflected in a face-sensitive ERP component, the P400. In addition to the ERP results, this study employed a preferential looking paradigm administered after the EEG measurement and reported that infants' looking duration to faces increased with increasing trustworthiness such that trustworthy faces were looked at for the longest duration. Interestingly, at the age of 7 months, sensitive responding to facial character traits was limited to trustworthiness but not seen in response to faces varying in dominance. This supports the notion that trustworthiness detection represents a foundational process, which does not require extensive learning, guiding human social behavior from early in ontogeny.

In adults, overt trustworthiness judgments can be observed for faces presented as short as 33 ms (Todorov et al., 2009). While these explicit evaluation processes occur rapidly they are still assumed to rely on the conscious processing of the faces. Critical for the context of the current study, there is also evidence showing that adults process facial trustworthiness without conscious awareness. Trustworthy and untrustworthy looking faces presented below the face visibility threshold for only 20 ms have been shown to prime the processing of subsequently presented neutral faces. Specifically, adult participants judged neutral faces as less trustworthy when subliminally primed by untrustworthy faces than neutral faces subliminally primed by trustworthy faces (Todorov et al., 2009). Further evidence for adults' unconscious processing of facial trustworthiness comes from work using masking paradigms relying on continuous flash suppression (Getov et al., 2015; Stewart et al., 2012). In these studies, faces varying in trustworthiness were presented monocularly and rendered unconscious by simultaneously presenting a flashing pattern to the other eye (continuous flash suppression). Participants became aware of the faces more slowly when the faces looked either very trustworthy or very untrustworthy compared to an intermediate neutral face. This pattern is taken to index preconscious processing of facial trustworthiness, which in turn may delay emergence to visual awareness (Stewart et al., 2012). Furthermore, on a neural level, subliminally presented faces evoke systematic differences in amygdala activation in adults. Specifically, faces varying in trustworthiness have been shown to modulate amygdala activity even if the face is not consciously perceived (Freeman et al., 2014). Taken together, these findings suggest that the processing of facial trustworthiness does not require conscious awareness in adults. However, it is unclear whether this is the result of extensive experience resulting in automatic processing of facial trustworthiness or whether unconscious processing of facial trustworthiness can already be observed during the earliest stage of postnatal development, which is infancy.

Research on social processing outside conscious awareness in infancy is still relatively sparse and has only recently come into focus. Prior research shows that face visibility thresholds in infants are higher than those reported for adults, and have been identified between 100 and 150 ms for infants younger than 10 months of age (Gelskov and Kouider, 2010; Kouider et al., 2013). Building on this research establishing face visibility threshold for infants, using ERPs (Jessen and Grossmann, 2014, 2015) and pupil dilation measures (Jessen et al., 2016), it has been shown that, at the age of 7 months, infants distinguish between fear and happiness from subliminal facial information. Furthermore, subliminal processing of facial cues in infants of this age cannot only be seen in response to emotional stimuli but has also been found for other types of social information such as gaze direction (Jessen and Grossmann, 2014). This line of work shows that subliminal face processing exists in infancy and that this is a viable approach to experimentally examine unconscious face processing in early ontogeny.

We therefore extended this work by investigating the subliminal processing of faces varying in trustworthiness in 7-month-old infants. We chose to study this particular age group because: (a) discrimination of facial expressions of emotion can first be observed by around 7 months of age as shown with both supra- and subliminally presented faces (Jessen and Grossmann, 2016a; Peltola et al., 2009), and (b) the processing of facial trustworthiness and emotion have been suggested to rely on shared neural processes (see Todorov, 2008). In the current ERP study, infants were presented with faces for only 50 ms, which is well below the face visibility threshold for infants of this age (Gelskov and Kouider, 2010; Kouider et al., 2013) and in the following will be considered as subliminal. After the subliminal face presentation, we presented a scrambled face as a mask to further ascertain that the face stimuli were not seen by the infants (see Todorov et al., 2009). Our ERP analysis was focused on the following ERP components previously linked to various stages of face processing in infants: P400, Nc, and the Negative Slow Wave (NSW). The infant P400 is commonly considered a precursor of the adult N170 (de Haan et al., 2003), and it has been shown to vary as a function of facial trustworthiness when faces are presented supraliminally (Jessen and Grossmann, 2016b). We thus decided to include the P400 in our analysis, although prior work on the processing of unconscious emotional information suggests that it is not sensitive to facial information that is presented below the visibility threshold (Jessen and Grossmann, 2014, 2015). The Nc has been linked to the allocation of attention to visual stimuli (Reynolds and Richards, 2005; Webb et al., 2005) and has also been shown to differ as a function of facial trustworthiness in infants (Jessen and Grossmann, 2016b). Finally, the NSW is thought to reflect face memory processes, whereby an enhanced NSW is seen in response to unfamiliar (novel) faces (Nelson and Collins, 1991, 1992).

During the ERP experiment, face stimuli and scrambled masks were followed by Greebles (e.g., Gauthier et al., 2004; Gauthier and Tarr, 1997), which were used because they represent neutral objects that are unfamiliar to the infants. The rationale for using these unfamiliar stimuli was two-fold. First, they served to increase the infants' interest in the experiment, which had otherwise only consisted of stimuli not visible to the infants. Second, it allowed us to explore whether the trustworthiness of the subliminally presented face might impact infants' responses to the unfamiliar Greebles by pairing one Greeble identity with one of the facial trustworthiness conditions. To explore this possibility, we conducted a preferential looking paradigm after infants had completed the EEG experiment. More specifically, we reasoned that if the trustworthiness of the subliminally presented face influences the evaluation of the Greeble then we would find a looking preference for the Greeble paired with the trustworthy faces. Finally, we also carried out a preferential looking paradigm with faces varying in trustworthiness in order to find out whether we can replicate the behavioral results from Jessen and Grossmann (2016b).

To summarize, we hypothesized that if the processing of facial trustworthiness in infancy is similar in its automatic and unconscious nature to what has previously been reported in adults (Freeman et al., 2014; Getov et al., 2015; Stewart et al., 2012) then we would find evidence for the subliminal discrimination of facial trustworthiness in infants. Considering that trustworthiness detection has been argued to be of primary importance for humans as a highly cooperative species (Fiske et al., 2007) and what has already been shown regarding infants' unconscious detection of other social cues from faces (Jessen and Grossmann, 2014, 2015), we predicted that this hypothesis is likely to be confirmed. If, contrary to our prediction, the unconscious processing of facial trustworthiness in adults is the product of extensive experience with evaluating faces then rather than an early developing feature of human face processing, we would probably not see any evidence of subliminal processing of facial trustworthiness in infants. Investigating whether subliminal processing of facial trustworthiness is operational in infancy is therefore not only relevant to a better understanding of the early development of face evaluation but it can also more generally inform our understanding of how conscious and unconscious face processing relate to each other.

2. Methods

2.1. Participants

Thirty-one 7-month-old infants were invited to participate in the study (209 ± 7 days [mean ± SD], range: 199–228 days, 19 female). For the analysis of the EEG data, four infants (two female) were excluded from the final sample because of failure to contribute at least 10 artifact-free trials per condition, leading to a final sample size of $n = 27$. For the preferential looking experiment, infants who did not complete all three trials of one task were excluded from further analysis ($n = 6$ for the face task and $n = 4$ for the Greeble task). In addition, preferential looking data from one infant had to be excluded because of technical problems during the recording. All infants included in the analysis were born full-term (38–42 weeks of gestational age) with a birth weight of at least 2500 g. Parents provided written informed consent, the study was approved by the ethics committee at the University of Leipzig and conducted according to the Declaration of Helsinki.

2.2. Stimuli

We presented computer-generated faces from an existing database of faces varying in trustworthiness (see Oosterhof and Todorov, 2008, see Fig. 1). Faces had been created using the software FaceGen Modeller 3.2 (Singular Inversions, 2007). More specifically, we selected faces from Caucasian male identities (005, 010, and 016). We chose to include only male identities to increase comparability to prior adult studies using similar stimuli (Oosterhof and Todorov, 2009; Todorov et al., 2010, 2011) as well as to allow for the comparison to the one existing prior study on supraliminal trustworthiness processing in infants (Jessen and Grossmann, 2016b). From each identity, we selected faces classified as untrustworthy (−3 SD from an average neutral face), neutral, and trustworthy (+3 SD from an average neutral face).

In addition, we created a scrambled version of each picture to be used as a mask to ensure subliminal presentation. To do so, we partitioned the section of the picture in which the face was shown into 60 same-sized tiles, which were then randomly rearranged using Matlab (The MathWorks, Inc., Natick, MA).

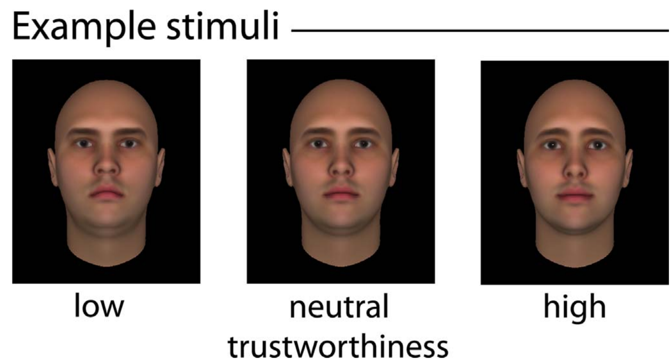

Fig. 1. Example of the stimulus material used. We presented computer-generated faces varying in trustworthiness from very low trustworthiness (left) over neutral with respect to trustworthiness (middle) to very high trustworthiness (right).

Furthermore, we presented the infants with pictures of Greebles (stimulus images courtesy of M. J. Tarr, Center for the Neural Basis of Cognition and Department of Psychology, Carnegie Mellon University, http://www.tarrlab.org/). Greebles are artificially created objects that were originally designed to investigate the role of learning on visual object (face) processing (see e.g. Gauthier et al., 2004; Gauthier and Tarr, 1997). For the present purpose, these objects served as visual object stimuli that are unfamiliar to the infants. We selected three different Greebles (one each from family 1, 2, and 4, all from the same gender and angle, Greebles 2.0).

For the preferential looking paradigm, pictures of the Greebles used during the EEG experiment as well as a face varying in trustworthiness (untrustworthy [−3 SD], neutral, and trustworthy [+3 SD]) from a fourth identity not used during the EEG experiment (017) were printed to a size of 13 × 18 cm and glued to a wooden canvas. Stripes of Velcro were attached to the back of the pictures to be able to fix them at an equal distance on a wooden board during the experiment.

2.3. Design

The EEG experiment consisted of three conditions: trustworthy, neutral, and untrustworthy. For each condition, a maximum of 90 trials (30 per facial identity) were presented, leading to a total maximum of 270 trials. Trials were split up into 10 mini-blocks of 27 trials each that were presented consecutively without any breaks. Each condition (trustworthy, neutral, and untrustworthy) was paired with one Greeble. The pairing between the subliminally presented facial stimulus and the supraliminally presented Greeble stimulus remained stable throughout the experiment for one infant, but was counterbalanced across infants to control for potential ERP differences evoked by Greeble identity alone. Each trial started with the presentation of a white fixation cross on a black background for 300 ms (see Fig. 2 for an example trial). The fixation cross was followed by the subliminal face stimulus presented for 50 ms, which was then followed by the scrambled face mask (created from the same face stimulus) for another 50 ms. After that, the Greeble was presented for 800 ms. The next trial started after an intertrial interval with duration randomly varying between 800 and 1200 ms.

The EEG experiment was followed by two preferential looking tests (visual paired preference test in which two visual stimuli are presented side-by-side). In the first preferential looking test, pictures of the supraliminally presented Greebles that had been paired with the subliminally presented faces during the EEG experiment were shown in pairs (side-by-side) for a duration of 30 s, leading to a total of three pairings (Greeble A vs. Greeble B; Greeble A vs. Greeble C; Greeble B vs. Greeble C). The order of the pairings shown and which Greeble was presented on what side was counterbalanced across infants. In the second part, pictures of faces varying in trustworthiness were presented pairwise for 30 s, leading to a total of three pairings (trustworthy vs.

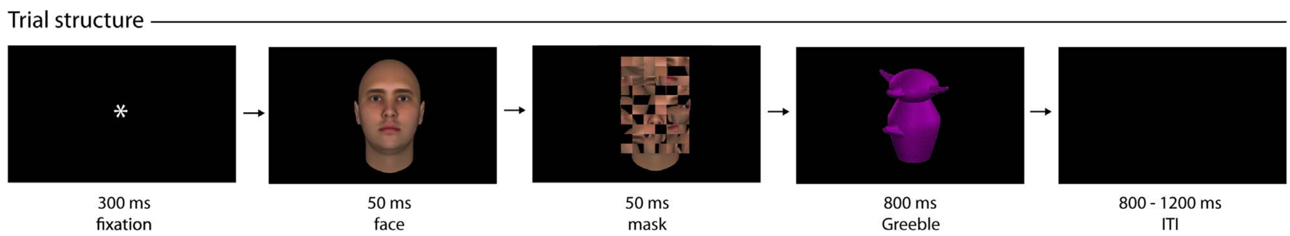

Fig. 2. Example of a trial. Face stimuli were presented for 50 ms, which is below the threshold for face visibility in 7-month-old infants. To further ensure faces were not perceived, face stimuli were followed by a scrambled face mask for another 50 ms. After the mask, a Greeble was presented for 800 ms, which was then followed by a blank screen. (ITI = intertrial interval).

untrustworthy; trustworthy vs. neutral; untrustworthy vs. neutral). Faces were taken from a fourth identity (017) and had not been presented during the EEG experiment. The order as well as side-assignment was counterbalanced across infants. The preferential looking test with the faces was always carried out after the preferential looking test with the Greebles because any potential Greeble preferences would have relied on learning during the EEG experiment, which we needed to probe as soon as possible after the EEG recording.

2.4. Procedure

After arriving in the lab, infant and parent were familiarized with the new environment. Parents were explained the experiment and signed a consent form. During EEG preparation and recording, the infant sat on her parent's lap. For recording, an elastic cap (EasyCap) was used in which 27 Ag-Ag-Cl electrodes were mounted according to the modified international 10–20 system. An additional electrode was positioned below the infant's right eye to compute the electrooculogram. The EEG signal was recorded with a sampling rate of 500 Hz using a REFA-8 amplifier (Twente Medical Systems, Oldenzaal, The Netherlands).

The EEG recording took place in a soundproof, electrically shielded chamber and stimuli were presented on a CRT monitor with a screen size of 1024 × 768 and a refresh rate of 60 Hz. The infant's attention during the experiment was monitored via a small camera mounted on top of the monitor. If necessary, short video clips containing abstract moving colorful shapes accompanied with ring tones were presented to redirect the infant's attention to the screen. The video clips were played before the beginning of a trial (before the onset of the fixation cross) upon a button-press controlled by the experimenter. The experiment continued until the maximum number of trials was presented or the infant became too fussy.

After completion of the EEG experiment and removal of the EEG equipment, the preferential looking tests followed. The infant was seated on a blanket on the floor on her parent's lap or in front of her parent. The experimenter sat opposite the infant. The pictures were attached to a wooden board 25 cm apart (measuring from the inner corner of the pictures), which was initially covered with a black cloth. A trial started with the removal of the cloth and lasted for 30 s. If the infant did not attend to the pictures, the experimenter tapped in the center of the wooden board to redirect the infant's attention to the pictures. After 30 s, the pictures were exchanged and again covered with a black cloth until the beginning of the next trial. The parent was instructed to close her eyes or look sideways during the experiment in order to avoid an influence on the infant's responses. The entire session was video-taped for offline coding of the infant's looking responses.

2.5. EEG analysis

EEG data were analyzed using Matlab (The MathWorks, Inc., Natick, MA) and the Matlab toolbox FieldTrip (Oostenveld et al., 2011). Data were re-referenced offline to the mean of TP9 and TP10 and filtered between .2 and 20 Hz. We segmented the data into 1.2-sec epochs from 200 ms before to 1000 ms after the onset of the subliminal face. In two participants, one electrode was noisy and therefore interpolated using spherical spline interpolation (Perrin et al., 1989). In order to detect trials contaminated by artifacts, we computed the standard deviation in a sliding window of 200 ms. If the standard deviation exceeded 80 μV at any electrode, the entire trial was rejected. The remaining trials were also inspected visually for artifacts and rejected according to the judgment of a trained coder. The video recording of the infant during the EEG experiment was used to ensure the infant attended to the screen during the presentation of the stimuli. Any trials during which the infant did not attend to the screen were excluded from our analysis. After these steps, per infant an average of 29 ± 11 (mean ± SD) trials per condition were included in our final analysis (trustworthy: 30 ± 12; neutral: 29 ± 10; untrustworthy: 29 ± 11).

Time-windows and electrode groups were selected based on prior work and visual inspection of the present data (P400: Hoehl and Striano, 2008; Jessen and Grossmann, 2016b; Nc: de Haan et al., 2004; Nelson and De Haan, 1996; NSW: Nelson and Collins, 1991, 1992). We focused our analysis on the Nc (400–600 ms) as well as a subsequent NSW (800–1000 ms). For both components, we computed the mean amplitude over a group of frontocentral electrodes (F3, Fz, F4, C3, Cz, C4), and entered these values into a repeated measures ANOVA with the factors Trustworthiness (trustworthy, neutral, untrustworthy) and Electrode (F3, Fz, F4, C3, Cz, C4). To ensure any potential differences were not affected by the (supraliminal) presentation of the Greeble following the face, we also regrouped the trials according to Greeble presented, and conducted the same analysis of Nc and NSW with the factor Greeble (Greeble A, Greeble B, Greeble C).

We did not expect any effects on the P400 response, as no influence of subliminal face stimuli on these components was found in previous work (Jessen and Grossmann, 2015). Nevertheless, since prior work reported differential responses to facial trustworthiness on the P400 (Jessen and Grossmann, 2016b), we computed the mean amplitude over occipital electrodes (O1 and O2) in a time-window between 300 and 500 ms and entered these values into a repeated measures ANOVA with the factors Trustworthiness (trustworthy, neutral, untrustworthy) and Electrode (O1, O2).

For all analyses, t-tests were computed as follow-up tests using the Bonferroni-Holm-method to control for multiple comparison. ANOVAs were Greenhouse-Geisser-corrected and effects sizes are reported as partial eta-squared for ANOVAs or r for t-tests.

2.6. Behavioral analysis

Looking duration to the left and right side during the behavioral tasks was coded offline by a coder blind to the hypotheses of the experiment. In addition, videos from a subset of our sample (six infants) were also coded by a second coder to check for reliability. Inter-rater reliability was assessed using Pearson's correlation coefficient ($r = .95$).

To analyze the preferential looking task, we followed the same procedure as previously described in Jessen and Grossmann (2016b). Summed looking duration across all three trials was computed separately for each picture. Since every picture was presented twice (once in

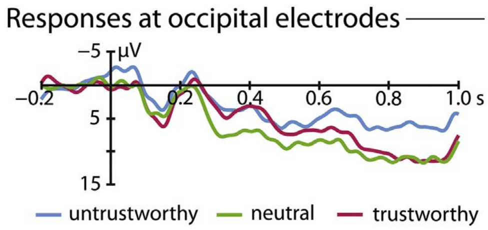

Fig. 3. ERP responses at occipital electrodes. Shown are mean responses following the subliminal presentation of faces varying in trustworthiness (blue = untrustworthy, green = neutral, red = trustworthy). No modulation by facial trustworthiness was observed. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

combination with each of the other two faces/Greebles), the summed looking duration was therefore computed from two values. The percentage looking duration was computed by dividing this summed looking duration by the mean summed looking duration across all three conditions (all three faces or all three Greebles).

Based on previous results (Jessen and Grossmann, 2016b), we expected a linear increase in looking time as a function of trustworthiness. Hence we computed one-tailed *t*-tests to examine potential linear trends.

3. Results

3.1. P400

We did not observe any significant effect of Trustworthiness at occipital electrodes between 300 and 500 ms after stimulus onset ($F[1.99,51.84] = 1.05$, $p = .36$, $\eta_p^2 = .04$, see Fig. 3 and Table 1). We did not observe a significant effect of Electrode ($F[1.72, 44.81] = 0.027$, $p = .960$, $\eta_p^2 = .001$).

3.2. Nc

We did not observe a significant effect of Trustworthiness at frontal and central electrodes between 400 and 600 ms (faces: $F[1.97,51.21] = .92$, $p = .40$, $\eta_p^2 = .03$; Greebles: $F[1.71,44.47] = .23$, $p = .76$, $\eta_p^2 = .01$, see Fig. 4 and Table 1). We did not observe a significant effect of Electrode ($F[5.90, 153.50] = 0.866$, $p = .520$, $\eta_p^2 = .0329$).

Table 1
Overview of ERP responses. Shown are mean ERP amplitudes and standard error in μV averaged over the respective time-window and electrodes. Significantly different values are marked in bold.

ERP component	Untrustworthy	Neutral	Trustworthy
P400 Electrodes: O1, O2 Timewindow: 300–500 ms	4.369 ± 2.924	7.634 ± 2.768	4.485 ± 2.912
Nc Electrodes: F3, Fz, F4, C3, Cz, C4 Timewindow: 400–600 ms	−15.225 ± 2.156	−12.592 ± 2.440	−15.572 ± 2.207
NSW Electrodes: F3, Fz, F4, C3, Cz, C4 Timewindow: 800–1000 ms	**−6.969 ± 1.978**	**−.309 ± 1.849**	−2.373 ± 2.393

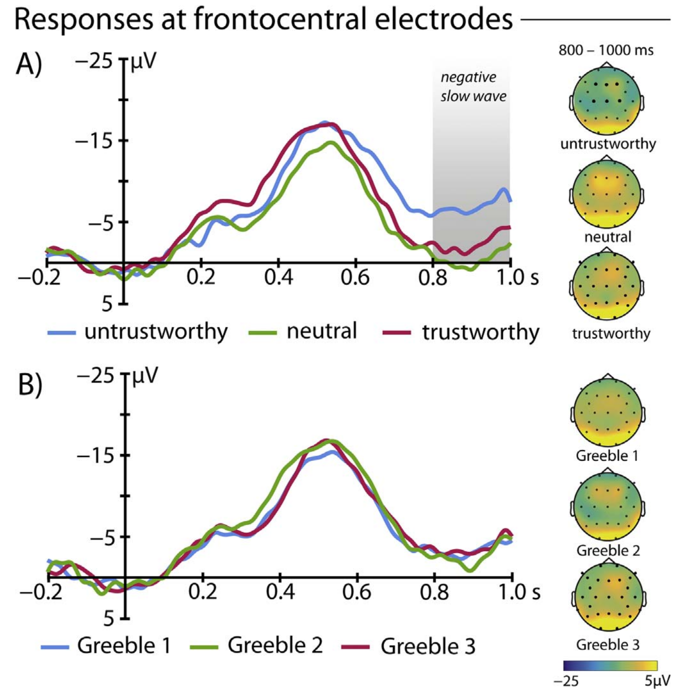

Fig. 4. ERP responses at frontal and central electrodes. Panel (A) shows ERP responses to subliminally presented faces varying in trustworthiness (blue = untrustworthy, green = neutral, red = trustworthy). Untrustworthy faces elicited a significantly greater Negative Slow Wave (NSW) between 800 and 1000 ms after stimulus onset. On the right sight, topographical distribution in a time window from 800 to 1000 ms after stimulus onset is shown. Panel (B) shows the ERP data analyzed in response to the supraliminally presented Greebles, which did not result in any significant differences. The right column shows again the topographical distribution between 800 and 1000 ms after stimulus onset. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).

3.3. NSW

We observed a significant effect of Trustworthiness at frontal and central electrodes between 800 and 1000 ms ($F[1.74,45.23] = 3.48$, $p = .045$, $\eta_p^2 = .12$, see Fig. 4 and Table 1). Post-hoc tests revealed subliminally presented untrustworthy faces elicited an enhanced NSW when compared to neutral faces ($t(26) = 2.54$, $p = .017$, $r = .45$). The comparisons between neutral and trustworthy faces ($t(26) = .99$, $p = .33$, $r = .19$) and between untrustworthy and trustworthy faces ($t(26) = -1.56$, $p = .13$, $r = .29$) did not yield any significant differences. We did not find a significant effect of Greeble ($F[1.77,45.92] = .06$, $p = .92$, $\eta_p^2 = .002$) or Electrode ($F[5.62, 146.07] = 1.087$, $p = .372$, $\eta_p^2 = .0401$).

3.4. Preferential looking

We observed a significant effect of Trustworthiness on looking duration ($t(23) = -1.84$, $p = .04$, $r = .36$, see Fig 5), revealing a linear increase in looking duration with increasing trustworthiness.

We did not observe any significant effect of Greeble on looking duration ($t(25) = -.98$, $p = .170$, $r = .19$, see Fig 5).

4. Discussion

The current study examined the subliminal processing of facial signs of trustworthiness in 7-month-old infants. We observed an enhanced NSW in response to subliminally presented untrustworthy faces compared to subliminally presented neutral faces. Our data therefore provide neural evidence for the subliminal processing of facial trustworthiness in infants of this age. These findings suggest that infants' processing of facial trustworthiness is similar to adults' processing in that it occurs automatically without conscious perception of the faces (Freeman et al., 2014; Getov et al., 2015; Stewart et al., 2012). This is in line with the notion that trustworthiness detection is of vital importance for humans as a highly cooperative species (Fiske et al., 2007). Moreover, it critically extends prior work with infants by showing that infants' subliminal processing of facial cues is not only seen in response to changeable features of faces such as emotion and gaze (Jessen and Grossmann, 2014, 2015) but also to invariant facial features of trustworthiness.

Our ERP data show a differential response to faces varying in trustworthiness although these faces were presented subliminally. This adds an important piece to our understanding of the developmental origins of assessing trustworthiness from faces. While previous work provided evidence for sensitive responding to facial signs of trustworthiness in infancy when faces are consciously perceived during supraliminal presentation (Jessen and Grossmann, 2016b), the current results demonstrate that neural discrimination occurs even if the faces are presented subliminally. Subliminal processing of facial signs of trustworthiness has previously been shown in adults using behavioral and brain measures (Freeman et al., 2014; Getov et al., 2015; Stewart et al., 2012; Todorov et al., 2009). The finding that subliminal processing can already be observed in infancy attests its early ontogenetic roots and provides further evidence for facial trustworthiness detection being a foundational aspect of human social interactions.

The current results revealed ERP differences as a function of facial trustworthiness for a late slow wave response. Specifically, we observed an enhanced NSW at frontal and central electrodes between 800 and 1000 ms in response to subliminally presented untrustworthy faces compared to neutral faces. Based on prior ERP work with 6-month-old infants, the NSW has been linked to face memory processes during supraliminal presentation of faces (Nelson and Collins, 1991). Specifically, in the study by Nelson and Collins (1991), infants were first familiarized with two faces before the ERP measurement. Then, during the ERP task, infants were presented with one of the two familiar faces at a high probability (60% of the time), the other familiar face at a low probability (20% of the time), and a third face that was completely unfamiliar (novel) to the infants also at a low probability (20% of the time). Nelson and Collins (1991) reported an enhanced NSW in response to unfamiliar (novel) faces presented at a low probability, which is thus thought to reflect novelty detection. With respect to the current findings with an enhanced NSW to untrustworthy faces, this may indicate that subliminally presented untrustworthy faces are detected as unfamiliar or novel. In turn this also suggests that infants subliminally detect trustworthy and neutral faces as (more) familiar. Assuming that trustworthy and neutral faces are more familiar to infants is in line with research in adults that suggests a higher typicality for neutral faces (compared to very trustworthy and very untrustworthy faces, see Said et al., 2010; Stewart et al., 2012) as well as research showing that infants are more familiar with positive than negative facial expressions (Malatesta and Haviland, 1982).

Our finding that neural discrimination between faces varying in trustworthiness occurs during later processing stages might be related to the fact that it likely relies on more complex discrimination processes involving the global integration of facial features. For example, ERP differences in the late slow wave range were observed in 6-month-old infants when processing global as opposed to local visual stimulus features (Guy et al., 2013). In this study, infants showed a more negative-going slow wave to novel global features in contrast to novel local features or familiar features in visual stimuli. Considering that the discrimination between varying levels of trustworthiness is thought to require the processing of complex feature-combinations (Oosterhof and Todorov, 2008), predominantly at the global level (Todorov et al., 2010), it is plausible that these processes would be reflected in the modulation of ERP components linked to global visual processing in infants. In this context it is important to mention that the distinction between global and local visual processing might also help explain differences between the ERP effects observed in the current study and previous infant ERP work on subliminal face processing. In previous work infants' subliminal detection of emotion and gaze reflected in the earlier modulation of the Nc has been shown to depend on a specific visual feature of the face, namely the eye alone (Jessen and Grossmann, 2014), whereas, as argued above, infants in the current study probably relied on global visual processes when detecting facial trustworthiness, which is reflected in the modulation of later slow wave activity.

Our data show that the ERP effect elicited by subliminally processing facial signs of trustworthiness occurred after the faces were masked and while infants' were consciously viewing a visual object that was unfamiliar to them (Greeble, see e.g. Gauthier et al., 2004; Gauthier and Tarr, 1997). Thus, the present ERP effect could be interpreted either as a very late differential effect elicited by the subliminal face or as a differential effect in processing the Greeble, which in turn would indicate a form of subliminal priming. However, since subliminal face (the potential prime) and Greeble (the potential target) were presented in very close succession in the present study it is not possible to differentiate between these two possibilities and future studies using a different timing of stimulus presentation are needed to resolve this question. Importantly, our results also show that the ERPs did not differ in response to the three Greeble identities, ruling out the possibility that physical differences in Greeble identity can account for any of the effects seen in our experiment.

In addition, we conducted behavioral preference tests (looking time) after the ERP experiment using the Greebles. Our analysis of

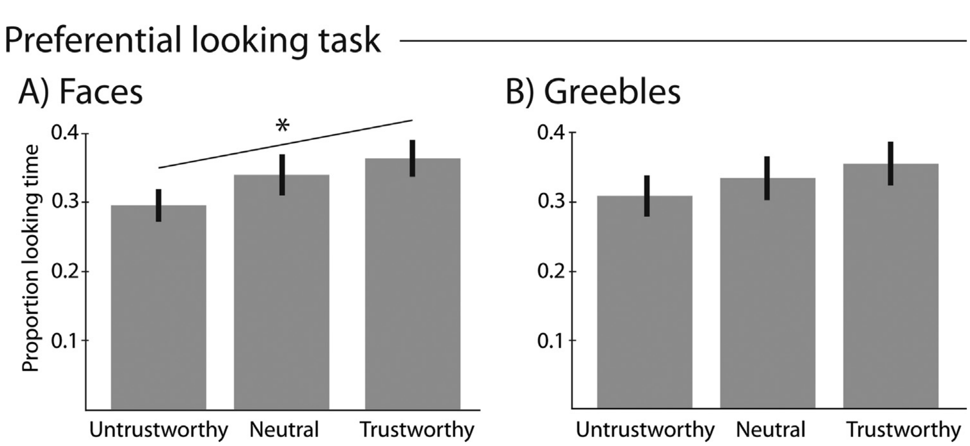

Fig. 5. Results of the preferential looking tasks, which followed the ERP experiment. Panel (A) shows proportion looking time to consciously presented faces of varying degrees of trustworthiness (mean ± SEM). Panel (B) shows proportion looking time to Greebles that had been paired with untrustworthy, neutral, or trustworthy faces during the preceding ERP experiment.* = $p < .05$.

the looking time data revealed that there were no differences between the Greebles depending on whether they were paired with trustworthy, neutral, or untrustworthy faces during the ERP experiment. Together with the ERP data, this pattern suggests that while facial trustworthiness may impact the immediate neural processing as seen in the NSW effect, it does not appear to influence behavioral preferences for objects longer term. It is possible that supraliminally presented facial trustworthiness stimuli, which would provide conscious primes, may be required to induce longer-term learning effects that result in differences in behavioral preference.

Following the behavioral preference tests using Greebles, we also carried out a behavioral preference test using trustworthy, neutral, and untrustworthy faces presented supraliminally. Our analysis revealed a significant effect of trustworthiness on looking time; infants looked shortest at the most untrustworthy looking face, while they looked longest at the most trustworthy looking face. The present results therefore replicate findings previously reported for the same paradigm with the same age group but in a different sample (Jessen and Grossmann, 2016b). They corroborate the assumption that infants show a behavioral preference for trustworthy looking faces, as indicated by an increase in looking time as facial trustworthiness increases.

One potential limitation of the present study may be the exclusive use of male rather than female faces, which are most commonly used in studies on emotion perception in infants (e.g. Jessen and Grossmann, 2015; Peltola et al., 2009). We chose to include only male faces to increase comparability to prior work on trustworthiness processing, which has predominately used male faces in both adults (Oosterhof and Todorov, 2009; Todorov et al., 2010, 2011) and infants (Jessen and Grossmann, 2016b). However, we would expect comparable results when using female faces based on the finding that studies on infant emotional face processing that had included both male and female faces did not report an effect of gender (Hoehl and Striano, 2008, 2010a, 2010b; Nelson and Dolgin, 1985).

One valuable next step for future research might be to further explore unconscious social processing in infants using different methodologies. While short presentation durations below 100 ms have successfully been used in a number of prior studies investigating subliminal processing in infants (Gelskov and Kouider, 2010; Jessen et al., 2016; Jessen and Grossmann, 2014, 2015; Kouider et al., 2013), differentiating between conscious and unconscious processing is challenging in infants who cannot provide verbal report about their perceptual experience. The thresholds used in the present study- as well as prior work- therefore rely on an indirect measure, namely looking preference for faces, which can only be observed for presentation durations of at least 150 ms in this age group (Gelskov and Kouider, 2010). Thus, future studies further elucidating the threshold for conscious perception in infancy, ideally relying on multiple, corroborating methods such as short presentation duration and continuous flash suppression, are necessary to arrive at a more comprehensive understanding of unconscious processing in infancy.

In summary, the present study provides first evidence for the subliminal processing of facial trustworthiness in 7-month-old infants. Our finding of neural discrimination of facial signs of trustworthiness in the absence of conscious awareness in infants suggests that facial trustworthiness processing occurs automatically and does not depend on extensive experience in evaluating faces. This supports the general notion that sensitive responding to signs of trustworthiness is an early emerging and foundational feature of human social functioning.

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