Children show neural sensitivity to facial trustworthiness as measured by fast periodic visual stimulation

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Abstract

Adults exhibit neural responses over the visual occipito-temporal area in response to faces that vary in how trustworthy they appear. However, it is not yet known when a mature pattern of neural sensitivity can be seen in children. Using a fast periodic visual stimulation (FPVS) paradigm, face images were presented to 8-to-9-year-old children (an age group which shows development of trust impressions; N = 31) and adult (N = 33) participants at a rate of 6Hz (6 face images per second). Within this sequence, an ‘oddball’ face differing in the level of facial trustworthiness compared to the other faces, was presented at a rate of 1Hz (once per second). Children were sensitive to variations in facial trustworthiness, showing reliable and significant neural responses at 1Hz in the absence of instructions to respond to facial trustworthiness. Additionally, the magnitude of children’s and adults’ neural responses was similar, with strong Bayesian evidence that implicit neural responses to facial trustworthiness did not differ across the groups, and therefore, that visual sensitivity to differences in facial trustworthiness can show mature patterns by this age. Thus, nine or less years of social experience, perceptual and/or cognitive development may be sufficient for adult-like neural sensitivity to facial trustworthiness to emerge. We also validate the use of the FPVS methodology to examine children’s implicit face-based trust processing for the first time, which is especially valuable in developmental research because this paradigm requires no explicit instructions or responses from participants.

Keywords: facial first impressions, trustworthiness, EEG, fast periodic visual stimulation, development

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Within 33 ms of seeing someone’s face, adults form a judgement of how trustworthy that person might be (Todorov et al., 2009). These judgements are thought to be based on certain visual cues that make faces look either more or less trustworthy. For example, happy, feminine, and attractive faces are generally perceived as being trustworthy; while angry, masculine, and unattractive faces are perceived as being untrustworthy (Ma et al., 2015; Todorov et al., 2009). Impressions of trustworthiness are observable very early in life, with even preschool children choosing similar faces as adults do, when asked who looks “nice” (Cogsdill & Banaji, 2015). These impressions continue to develop over the course of childhood, becoming more nuanced and reliable with age, until they reach maturity between 10 and 13 years (Siddique, Sutherland, et al., 2022). Importantly, the middle childhood period (e.g., 8-to-9 years of age) has been identified as a critical period for the development of face-based trust impressions, although not much is known about which mechanisms underpin this development (Siddique, Sutherland, et al., 2022).

Understanding the development of trustworthiness impressions from faces is important because these impressions can have strong consequences. For example, across many social situations, both children and adults are more likely to approach and interact with people whose faces appear trustworthy, and avoid those that appear untrustworthy (Ewing et al., 2019; Hooper et al., 2018; Shen et al., 2020; Sutherland et al., 2019). Although the accuracy of face-based trust impressions is low (Foo et al., 2021), forming impressions about people based on their facial appearance seems to be observed around the world (Sutherland et al., 2018). Such ubiquity may be due to the functional advantage that forming impressions based on appearance can provide – allowing us to structure our expectations while minimising cognitive load, in the same way that other stereotypes do (Collova et al., 2019;

Foo et al., 2021). Examining the developmental trajectory of children’s impressions of trustworthiness from faces and how they compare to adults’, can provide insights into the origins of these apparently ubiquitous and highly impactful impressions.

There are likely several mechanisms that underlie the development of trustworthiness impressions during the middle-childhood period, including age-related increases in social experience, and general cognitive and emotional development (Over & Cook, 2018; Siddique, Sutherland, et al., 2022; Sutherland, Burton, et al., 2020; Sutherland & Young, 2022). For example, social learning accounts suggest that both children and adults must learn to associate certain traits and behaviours with particular facial appearances in order to demonstrate the commonly observed face-based trustworthiness impressions reported in research (Over & Cook, 2018; Sutherland & Young, 2022; Verosky & Todorov, 2013). Indeed, there is now evidence to suggest that individual social experience shapes the associations we form between certain facial appearances and traits (Feldmanhall et al., 2018; Sutherland, Burton, et al., 2020; Verosky & Todorov, 2013). There is also evidence to suggest that children’s early emotion understanding ability is associated with their readiness to judge trustworthiness from faces. Therefore, children’s tendency to infer trait trustworthiness might build upon the ability to consistently use transient facial cues to infer internal emotional states (Baccolo & Cassia, 2020). However, while some research suggests social and emotional development might be some of the mechanisms underlying the development of trustworthiness impressions across childhood (and into adulthood), less is known about the neural mechanisms that might underlie such development. In the current study, we examine the maturity of 8-to-9-year-old children’s neural activity underlying visual sensitivity to variations in facial trustworthiness. This particular focus can clarify whether changes in neural sensitivity might account for the development of face-based trust impressions observed during the middle childhood period.

One recent and effective means of examining neural sensitivity underpinning face processing utilises electroencephalography recording (EEG) together with the fast periodic visual stimulation (FPVS) technique (Rossion, 2014). FPVS has previously been utilised to examine aspects of face processing including identity (Liu-Shuang et al., 2014) and expression (Dzhelyova et al., 2017; Gwinn et al., 2018a), and only recently has been employed in first impressions research (Swe et al., 2020; Verosky et al., 2020). Swe et al. (2020) recently examined adults' neural sensitivity to facial trustworthiness by presenting participants with face stimuli at a predetermined frequency/rate while their neural activity was recorded with electroencephalography (EEG). Specifically, a sequence of faces was presented at a rate of six per second (6Hz) and the property of interest (facial trustworthiness) varied every sixth face in the stimulus presentation cycle. That is, every sixth face appeared trustworthy compared to the preceding five faces (and vice versa), with facial trustworthiness determined by prior judgements made by an unrelated sample. Thus, within the face sequence, trustworthiness varied at a rate of 1Hz (once every second). Although participants were never told that facial trustworthiness was the property of interest, significant neural responses at 1Hz to changes in facial trustworthiness were observed over right occipito-temporal areas (Swe et al., 2020). In parallel, Verosky et al. (2020) used a slightly different FPVS paradigm to Swe et al. (2020) but results similarly showed neural sensitivity in adults to facial trustworthiness over right occipito-temporal areas. This scalp region has been associated with face perception in previous research, for example, in the N170 potential evoked by face stimuli (Rossion, 2014).

FPVS has also recently been used to successfully examine aspects of face perception in children (Lochy, de Heering, et al., 2019; Lochy, Schiltz, et al., 2019; van der Donck et al., 2019; Vettori et al., 2020), though it has not yet been applied to development of first impressions of trustworthiness. Specifically, previous studies have shown that preschool children's neural sensitivity to face identity and emotional expression can be measured with FPVS, including to examine developmental trends from childhood to adulthood (Dzhelyova et al., 2017; Lochy, de Heering, et al., 2019; Lochy, Schiltz, et al., 2019; van der Donck et al., 2019). Critically, FPVS is an ideal technique to examine the rapid discrimination of trustworthiness from faces in a developmental sample because it measures neural sensitivity via largely passive viewing of faces, thus, explicit instructions are not needed (Regan, 1966; Rossion, 2014). Therefore, children's cognitive constraints in understanding task instructions or complex concepts (e.g., "trustworthiness") do not limit interpretation of results. The high signal-to-noise ratio in FPVS also allows for a shorter task with fewer trials as compared to typical EEG event-related potential (ERP) designs (Rossion, 2014). Further, FPVS methods provide results in the frequency domain, instead of the time-domain. While time course information (e.g., from ERP studies) is valuable, there is currently limited agreement in the field regarding the exact time course of face perception processes and the direction of modulation (Baccolo et al., 2021; Jessen & Grossmann, 2016; Rossion, 2014). In contrast, FPVS responses in the frequency domain provides a direct measure of automatic and rapid face categorisation at the exact frequency that is defined in advance with high validity and specificity (Rossion, 2014; Vettori et al., 2020). This approach addresses limitations around inconsistency in the direction of modulation of ERP components in trust processing (Baccolo et al., 2021; Gredebäck et al., 2015; Jessen & Grossmann, 2016) by measuring many overlapping responses. In this way, FPVS is a complementary approach to existing EEG methods including ERP research.

Additionally, FPVS results are not confounded by task demands, decisional processes, or social desirability (Hofmann et al., 2005; Rossion, 2014), unlike behavioural methodologies such as those that require explicit judgements (e.g., Likert rating scales; (Zebrowitz & Montepare, 2008), or more implicit tasks reflecting the use of trustworthiness impressions to guide behaviour (e.g., economic trust game paradigms; Chang et al., 2010; Hooper et al., 2018; Sutherland et al., 2019). Therefore, FPVS is an ideal paradigm with which to examine children’s neural sensitivity to facial trustworthiness, and can provide important insights into whether changes in neural sensitivity can explain the development of trustworthiness impressions observed during the critical middle childhood period (Siddique, Sutherland, et al., 2022).

There is currently limited research investigating neural activity underlying children’s impressions of trustworthiness from faces, and that which has been conducted has focused on infants and adolescents. One such study (Jessen & Grossmann, 2016) has shown that 7-month-old infants display ERP P400 and Nc responses to faces varying in trustworthiness, which are the same ERP responses that have previously been implicated in emotion processing from faces, and in response to behavioural cues to trustworthiness (Gredebäck et al., 2015; Jessen & Grossmann, 2016; Leppänen, Moulson, Vogel-Farley, & Nelson, 2007). Untrustworthy, as compared to neutral faces, also elicit an enhanced negative slow wave in infants. The negative slow wave is linked to face memory and it has been theorised that this response may indicate that untrustworthy faces are detected as unfamiliar or novel, whereas trustworthy faces are perceived by infants as more familiar, possibly because infants are predominantly exposed to people who present positive facial expressions to them (Jessen & Grossmann, 2019). These findings have been replicated and extended in other research using realistic female face images (Baccolo et al., 2021), although the direction of the modulation of the P400 and Nc components when realistic face images were used differed to results of studies using CGI face images (Jessen & Grossmann, 2016, 2019). This difference may be explained by a possible processing advantage enjoyed by realistic face images that trigger a friendlier approach than that evident in CGI images (Baccolo et al., 2021).

Another study has shown that adolescents show activation in subcortical emotion-linked regions when making decisions about trustworthy and untrustworthy faces (Kragel et al., 2015), paralleling patterns found in adult samples (Engell et al., 2007). However, neural activity has not yet been examined during the middle childhood period, despite the importance of this period to the development of trust impressions, given children in this age range are known to form trust impressions, but these trust impressions are not yet consistently adult-like (Siddique, Sutherland, et al., 2022). Therefore, in the current study, we measured 8-to-9-year-old children’s neural sensitivity to facial trustworthiness in an FPVS task, alongside a control group of adults. Given neural sensitivity to trustworthiness in faces has been observed in infants (Baccolo et al., 2021; Jessen & Grossmann, 2016), it was likely that some level of sensitivity would also be observed in middle childhood. However, it was unclear how this sensitivity would compare to that of adults, given that impressions themselves are still developing in this period of childhood (Siddique, Sutherland, et al., 2022). As our primary index of maturity of trust impressions, we examined the strength of children’s neural sensitivity to facial trustworthiness. However, in addition, we also examined any age-related differences in quality, harmonic distribution, and location of the response to characterise the maturity of children’s neural responses to trustworthiness at this age, as previous research has identified age-related differences in neural responses across all of these facets (Lochy et al., 2019; Rossion et al., 2020). If children and adults differed across any of these parameters, it might suggest that age-related changes in neural sensitivity could be one mechanism that contributes to the development of trustworthiness impressions during and beyond middle childhood. Equally interesting would be to see a highly similar pattern of neural responses to facial trustworthiness in both child and adult groups. Great similarity in neural responses would suggest that neural sensitivity to trustworthiness appearance is unlikely to explain the development of trustworthiness impressions during this period, because it may already be mature by 8-to-9 years of age.

Our experimental methodology was almost identical to a previous study with adults (Swe et al., 2020), except that our participants completed the 20 min FPVS task only once, due to children's shorter attention spans, whereas Swe et al.'s (adult) participants completed the same task twice. In the FPVS task, participants were shown sequences of faces where the base faces (e.g., trustworthy faces) were presented at 6Hz base frequency (*f*), while the oddball faces (e.g., untrustworthy faces) were introduced at the rate of every 6th face, resulting in an oddball frequency of 1Hz (=*f*/6 = 6Hz/6). This design allowed us to frequency-tag the trustworthiness discrimination response at the exact frequency where the facial trustworthiness changed (here, at 1Hz). Like previous work using similar paradigms, we expected to observe significant neural responses in adults at 1Hz (and its harmonics) over the right occipito-temporal region in response to a change in stimulus trustworthiness (Swe et al., 2020; Verosky et al., 2020). Examination of children's neural responses and how they may compare to adults' responses, both quantitatively in terms of strength, as well as qualitatively, formed the primary focus of this study.

2. Method

The preregistration of the methods and analysis plan for this study can be found at [link blinded for review]. We did not deviate from the preregistered methods.

2.1 Participants

Thirty-one children (aged 8-to-9 years; *M* = 8.94, *SD* = 0.49; 1 left-handed; 16 females, 15 males), and 33 adults (aged 18-to-32 years; *M* = 20.10, *SD* = 3.28; 2 left-handed; 22 females, 11 males) participated in this study. The sample size was based on the power analysis in Swe et al. (2020) who reported that 28 participants were required to find an effect size of 1.16 (Cohen's d; based on a conceptually related face perception oddball FPVS study;

Beck et al.,2017) with a power of .99 at the standard .05 alpha error probability. Therefore, we aimed to include 30 participants per age group. We tested more than 30 participants in each age group (37 children and 37 adults), however, to allow for any exclusions (e.g., incomplete data, significant problems with concentration) per our preregistered exclusion criteria. Six children and 4 adults were excluded either due to significant concentration difficulties or excessively noisy EEG recordings during testing. Child participants were recruited through online mailing lists and social media advertisement, and were remunerated $20 for participation. Adults were recruited from the university undergraduate psychology student population and were awarded partial credit for participating. This study was approved by the [blinded for review] Human Research Ethics Committee.

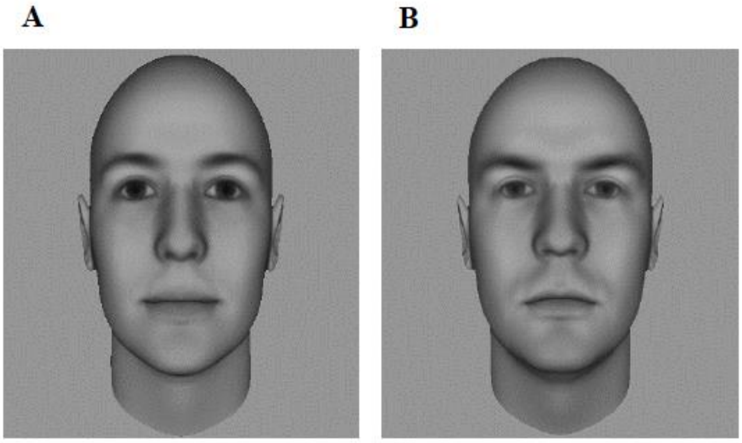
2.2 Stimuli

Stimuli were identical to those used by Swe et al., (2020), selected from an existing database (Todorov et al., 2013). They were twenty pairs of faces (40 faces in total), each consisting of a trustworthy and an untrustworthy version of the same face identity. Faces were computer-generated FaceGen images, were forward facing with direct gaze, and did not display overt emotional expressions (Todorov et al., 2013). Trustworthy faces in the current study were at the +1SD level on the trustworthiness dimension, while untrustworthy faces were at the -3SD level. This asymmetry was used as a precaution due to concern that increasing trustworthiness further would make male faces look androgynous or female. Stimuli were selected to appear male to avoid potential gender effects on trustworthiness impressions (Buchan et al., 2008; Sutherland et al., 2018). Faces were grey-scale and luminance and contrast adjusted to the average of all images to reduce the extent to which low-level features affected neural responses (*Figure 1*). Stimulus size was randomly jittered between 80-120% in 2% increments across presentations within trials, to further avoid the influence of low-level features on neural responses. Stimuli were presented on a NEC

MultiSync V730 Flat Square Technology CRT monitor with 1680 x 1050 display resolution and a 60Hz screen refresh rate, at approximately 55 cm viewing distance in a dark room. The average visual angle of the stimuli was 11° in height and 3.71° in width.

Figure 1

Examples of face stimuli employed in this study (Todorov et al., 2013). Twenty face identities were used, each with a trustworthy and untrustworthy version. Image **A** is the trustworthy-looking version and image **B** the untrustworthy-looking version of the same face (one of 20 face identities used in the current study).



2.3 Procedure

In the FPVS task, faces were presented at a base frequency of 6Hz, which corresponds to six faces per second (i.e., approximately 167 ms per face). The oddball discrimination frequency was calculated as 6Hz/6 = 1Hz. Therefore, five trustworthy faces were presented in a row, followed by an untrustworthy oddball face (and vice versa for untrustworthy to trustworthy trials). Trials lasted 40 s each, and included 240 faces (10 repetitions of the 20 base faces, and 10 repetitions of the four oddball faces, with a different set of faces presented in each of the 20 trials). All 20 face identities were presented equally as base and oddball faces across the task to avoid confounding identity with trustworthiness.

Half of the trials had untrustworthy faces as the oddball face (with base trustworthy faces), and the other half had trustworthy faces as the oddball face (with base untrustworthy faces). Faces were presented through square wave modulation – presented at full contrast for the entire duration of each cycle of the square wave (167 ms, i.e., 1000 ms/6 faces), followed by the next face, which appeared immediately. To maintain participants' attention throughout the task, they were asked to press a key whenever the central fixation cross changed to a square, which happened eight times during each trial at random time points. Participants were never instructed to make judgements relating to trustworthiness.

We also included an inverted condition, which was identical to the upright condition, except that the face stimuli were rotated 180°. Inverting face stimuli allowed low-level visual features to remain intact, while disrupting normal face processing (Rhodes et al., 1993; Rossion & Gauthier, 2002; Todorov et al., 2010; Yovel & Kanwisher, 2005). Comparing the upright and inverted conditions allowed us to control for possible low-level visual confounds such as angle, contrast, curvature, luminance, and spatial frequency, and thus determine whether the recorded upright neural responses were face-selective.

Following the FPVS task, participants were asked to rate how trustworthy stimulus faces appeared on a Likert scale ranging from one to nine (one = not at all trustworthy, nine = extremely trustworthy). Explicit trustworthiness ratings served as a manipulation check to assess whether participants rated the faces selected to look trustworthy as indeed more trustworthy, and vice versa for untrustworthy-looking faces. First, participants were asked to define the word "trustworthy" and were given feedback based on two practice trials asking them to rate the trustworthiness of "someone who breaks a promise", and "someone who keeps their best friend's secret" (following logic of previous developmental studies in this field; Siddique, Jeffery et al., 2022). They then rated all 40 faces on how trustworthy they appeared. The experimental procedure, including fitting and removing the EEG cap and electrodes, required approximately 60 to 90 min to complete.

To motivate and reward child participants, the experiment was presented as a 'space mission', where they could progress through the 'solar system' by completing different parts of the experiment. They were given a printed solar system chart and rewarded a sticker on it after the completion of every step (e.g., measuring their head, affixing the EEG cap, plugging in the electrodes, and approximately every 5 minutes during the FPVS task). Given that participants were only required to look at the screen during the FPVS task, there was no difficulties with ensuring task instructions were understood by the children. To maintain participants' attention on the screen, we asked them to press the space bar every time the central fixation cross changed to a square. Children were told that pressing the space bar quickly and accurately would allow them to progress through the space mission. During breaks, these instructions were reiterated when required, and children were verbally reinforced for effort.

2.4 EEG Analyses

2.4.1 EEG acquisition and pre-processing

The EEG data were recorded using the 64-channel Biosemi ActiveTwo system (Biosemi, Amsterdam, Netherlands) with the extended 10-20 layout. Electrode offsets were kept below 30 mV, and the EEG recording was digitised at 2048Hz, then down-sampled to 512Hz for analysis. EEG recordings were analysed using Letswave 6, which was run on MATLAB R2020b (Mathworks, USA). We followed FPVS processing procedures used by Swe et al. (2020). After FFT bandpass filtering around 0.1Hz and 120Hz using a Butterworth filter (order 4), and filtering electrical line noise at 50Hz plus two harmonics (100Hz and 150Hz) with fast Fourier transform multi-notch filter, EEG data was segmented to include 2s before and after each 40s sequence, (i.e., -1s to 42s). Noisy channels (with amplitude deviations greater than 200 μv, as determined through visual inspection) were replaced with the average of three neighbouring channels using interpolation. Nine child participants and five adult participants required interpolation, and no more than two channels (i.e., <3.13% of channels) were interpolated per participant. Blink correction was also applied at this stage using independent component analysis with square matrix (Retter & Rossion, 2016). Blink correction was applied for participants who blinked more than 0.2 times per second during the 40s trials (identified with the blink detection plugin for Letswave, based on Swe et al., 2020; Gwinn, Matera, O’Neil, & Webster, 2018; Retter & Rossion, 2016). All 64 channels were then re-referenced to the average of the 64 electrodes. EEG recordings were then segmented again from the stimulation onset until 40s, so they only included the 40 seconds of face presentation.

2.4.2 Frequency domain analysis

For each participant, all upright trials were averaged together and all inverted trials were averaged together, resulting in two wave forms for each participant – one for the upright condition and one for the inverted. A fast Fourier transform was then applied to the averaged time window, which allowed us to extract a normalised amplitude spectra for all channels. To quantify the responses of interest in microvolts for further analysis, we created baseline corrected amplitudes (BCAs), which represented the average voltage amplitude of the 20 surrounding bins (10 on each side; i.e., the noise) excluding the immediately adjacent bins and the local maximum and minimum amplitude bins, subtracted from the bin of interest (Retter & Rossion, 2016; Swe et al., 2020). The baseline correction allowed us to control for differences in baseline noise across participants and across the frequency spectrum within participants.

Based on previous research using this paradigm (Lochy et al., 2019; Swe et al., 2020) significant responses were considered as those at the fundamental frequency and its harmonics that had a Z score of >1.64 (p< .05, one tailed) at the predetermined region of interest (ROI) over the right occipital-temporal area, recorded by electrodes P8, PO8, and P10, which previous research has shown to be associated with face processing (Dzhelyova & Rossion, 2014; Retter & Rossion, 2016; Swe et al., 2020). Z-scores were calculated with the formula z = (x – baseline)/standard deviation of the baseline). Baselines for the z score calculation was determined using the same bin range described above (average voltage amplitude of the 20 surrounding bins, excluding the immediately adjacent bin), but the minimum and maximum amplitude bins were included for the Z-score calculation to obtain a more conservative test of statistical significance (Rossion et al., 2012; Swe et al., 2020).

In order to quantify the periodic oddball trustworthiness response distributed over several harmonics, the baseline corrected amplitudes were summed up to the highest significant consecutive harmonic for the adult group (5Hz; Table 1) (Dzhelyova & Rossion, 2014; Gwinn et al., 2021; Retter & Rossion, 2016). The same number of harmonics was summed for the child group, though results of analyses with the children's response summed to 2Hz (which was the highest consecutive significant harmonic for this group) are also included for interest in the Supplementary Materials. The harmonics of the baseline frequency (6Hz) were significant in the upright condition up to the 10th harmonic (66Hz) for adults and up to the 9th (60Hz) harmonic for children. These were not summed or analysed further.

We examined scalp topographies to understand the location of the oddball response in children's and adults' brains. Scalp topographies for both upright and inverted conditions are shown in *Figures 3* and *4*. Scalp topographies in *Figure 3* were created by summing epochs up to the highest consecutive significant harmonic for adults (5Hz) and then grand averaging the responses across participants. *Figure 4* shows scalp topographies of grand averages at each harmonic separately. In addition to the expected activity in the right occipito-temporal

ROI, activation in response to trustworthiness was also evident at the corresponding left occipito-temporal area in the upright condition for both child and adult groups. While face-specific responses tend to be localised in the right occipito-temporal scalp regions, it is not uncommon to also observe responses in left regions, as seen in Swe et al. (2020).

To assess the significance of responses at the individual level, and to attain the sum of the baseline corrected amplitudes in individual participants, “chunking” was used. To do this, we took “chunks” of 20 bins surrounding each bin of interest and then averaged the chunks. Then, the fundamental frequency and harmonics were summed up to the highest significant consecutive harmonic (5Hz), and Z-scores were calculated to test significance of the summed responses at the individual participant level.

Figure 2

Scalp topographies for overall trustworthiness oddball response (sum of baseline subtracted fundamental oddball frequency and its harmonics up to the last consecutive significant harmonic in adults – 5Hz), grand averaged across participants for upright and inverted conditions.

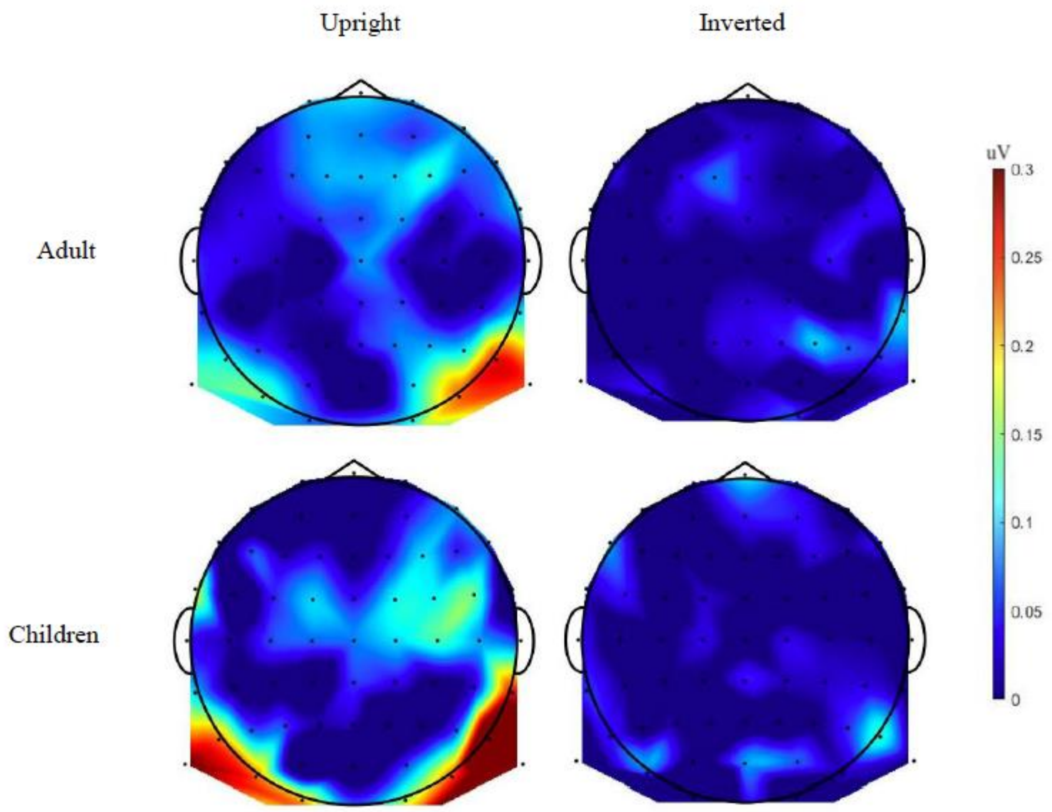
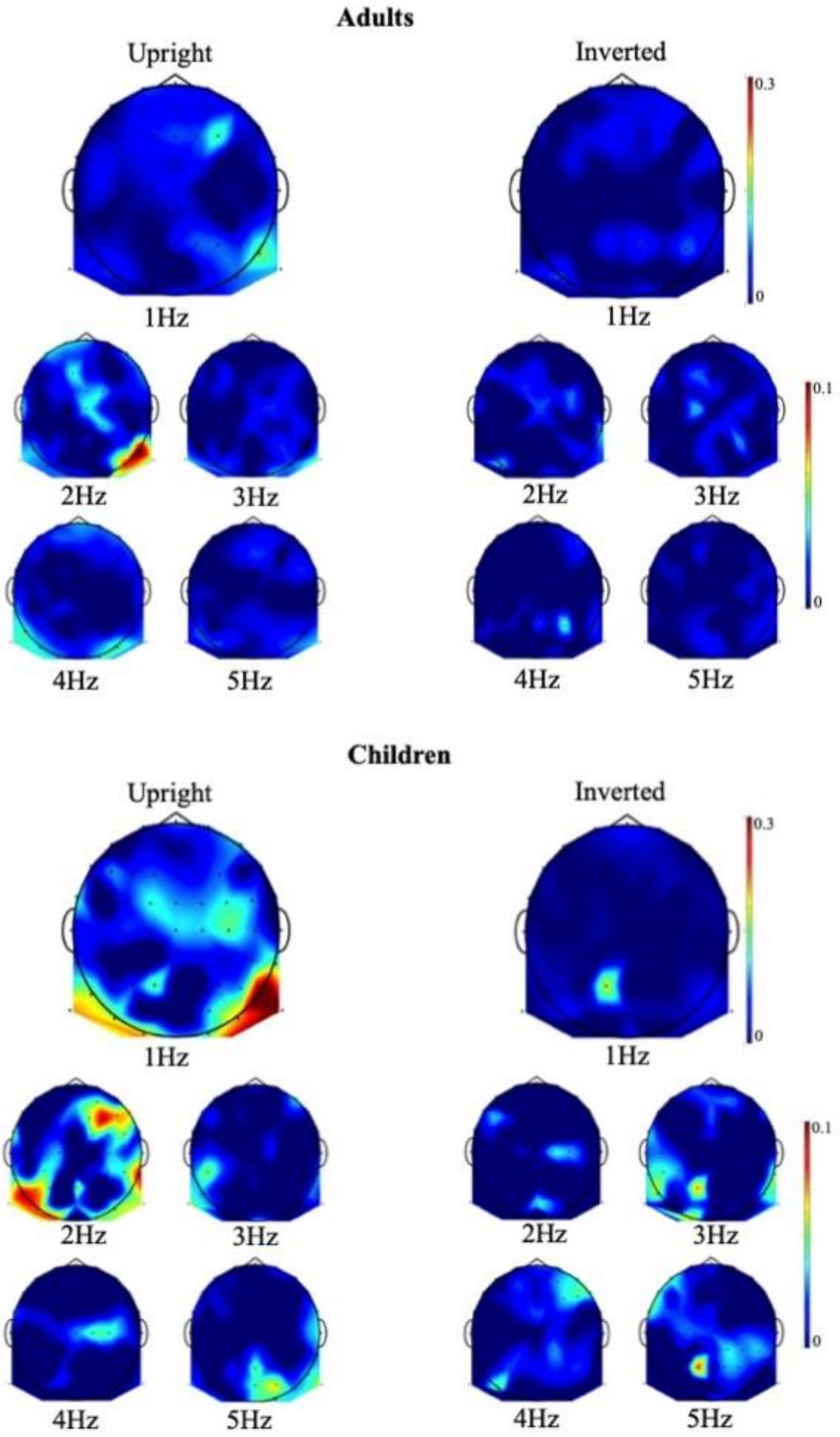


Figure 3

Scalp topographies for the trustworthiness oddball response at fundamental frequency (1Hz) and each harmonic up to the last consecutive significant harmonic in adults (5Hz) grand averaged across participants for upright and inverted conditions. Note. The fundamental frequency is presented on a different axis compared to the harmonics.


Adults
Upright
Inverted
0.3
0
1Hz
1Hz
0.1
0
2Hz
3Hz
2Hz
3Hz
4Hz
5Hz
4Hz
5Hz
Children
Upright
Inverted
0.3
0
1Hz
1Hz
0.1
0
2Hz
3Hz
2Hz
3Hz
4Hz
5Hz
4Hz
5Hz

To assess the significance of responses at the individual level, and to attain the sum of the baseline corrected amplitudes in individual participants, "chunking" was used. To do this, we took "chunks" of 20 bins surrounding each bin of interest and then averaged the chunks (Rossion et al., 2020). Then, the fundamental frequency and harmonics were summed up to the highest significant consecutive harmonic, and Z-scores were calculated to test significance of the summed responses at the individual participant level (Gwinn et al., 2018b; Swe et al., 2020).

3. Results

There was one minor deviation from the preregistered analyses in that the pre-registered analysis plan mistakenly outlined including a condition that does not exist. Specifically, we suggested including a condition for face type (base versus oddball face) when in fact the recorded oddball response already reflects the difference between responses to base and oddball faces. Therefore, instead of including face type in the analyses as an independent variable, we included the oddball response as the dependent variable, following Swe et al. (2020).

In addition to the preregistered analyses, we also ran the main hypothesis-related analyses on the children's data when neural responses were summed to 2Hz, which was the highest consecutive significant harmonic for the child group. These results are included in the Supplementary Materials. We additionally examined the internal reliability of participants' responses in the FPVS task; important given that this paradigm had not yet been used to examine children's neural responses to trustworthiness in faces. In addition to the between-groups comparisons made by ANOVA, we also ran Bayesian analyses to quantify group differences between children's and adults' neural responses, which were not preregistered. Given that examination of the scalp topographies revealed activity in the left-occipito-temporal region in response to changes in facial trustworthiness, statistical significance of the signal in the left occipito-temporal region at the fundamental frequency and its harmonics was assessed and a mixed ANOVA and a Bayesian mixed ANOVA were run to examine activity in this region. Lastly, we examined individual differences in participants' neural responses to facial trustworthiness, but since these analyses were not a part of the preregistered analyses, and did not directly answer the current hypotheses, their results and discussion are included in the Supplementary Materials.

3.1 Manipulation Check

To confirm that both children and adults perceived the trustworthy and untrustworthy faces as such, we first ran a mixed ANOVA on the explicit ratings data with Group (adults vs. children) as a between-subjects variable, and Facial Trustworthiness (trustworthy vs. untrustworthy) as the within-subjects variable. The main effect of Group (F (1,62) = 1.02, p = .316, η^2_p = .016) and the interaction effect between Facial Trustworthiness and Group (F (1,62) = 1.94, p = .169, η^2_p = .030) were non-significant. Therefore, we found no evidence of a difference between how adults and children rated trustworthy- and untrustworthy-looking faces. Importantly, there was a main effect of Facial Trustworthiness (F (1,62) = 222.32, p < .001, η^2_p = .782), such that overall, trustworthy faces were rated higher than untrustworthy faces (trustworthy M = 5.52, SD = 0.73; untrustworthy M = 3.58, SD = 1.11). Thus, the manipulation was successful.

3.2. Response at baseline frequency

The general visual response in the EEG recording at 6Hz and its harmonics reflects the neural response to the appearance of the face stimuli on the background. The visual response at 6Hz was significant for both children (BCA = 1.20, Z = 87.53, p < .001) and adults (BCA = 0.97, Z = 112.72, p < .001). The harmonics of the baseline frequency were significant up to the 10th harmonic (66Hz) for adults and up to the 9th (60Hz) harmonic for children. This data was not analysed further because it reflects the general visual response instead of the response of interest, which was to facial trustworthiness, but responses at the baseline frequency and its harmonics in both the upright and inverted conditions are included in the Supplementary Materials (Table S1).

3.3 Neural Discrimination Response to Facial Trustworthiness at The Group Level

Initial analyses showed similar responses regardless of oddball type (trustworthy and untrustworthy oddball trials). That is, there was no significant difference in the strength of the baseline corrected amplitudes for trustworthy and untrustworthy oddballs in either adults (t (32) = 0.43, p = .672) or children (t (30) = 0.97, p = .338). Therefore, for each participant, waveforms for the trustworthy oddballs and untrustworthy oddballs were averaged to improve the signal-to-noise ratio of the recordings, and therefore, all following analyses are collapsed across oddball type.

Critically, in the upright condition, for both adults and children, we found that grand-averaged BCAs at the fundamental frequency (1Hz) and some of the harmonics were significant (*Table 1* and *Figure 4*), indicating neural sensitivity to variations in facial trustworthiness. This pattern of results contrasted with the inverted control condition, in which adults’ grand-averaged BCAs were not statistically significant at the fundamental frequency, nor any of the harmonics. The grand-averaged BCA in the child group was statistically significant (although weaker) at the fundamental frequency in the inverted condition, but were not statistically significant at any of the harmonics (*Table 1* and *Figure 2*). Additionally, there was no significant difference between children’s and adults’ BCAs in the inverted condition itself (t (62) = -0.43, p = .671, d = -0.11).

As expected for adults (Swe et al., 2020; Verosky et al., 2020), the response was spread out over the harmonics in the adult group. In contrast, a very large percentage of the oddball response was at the fundamental frequency in the child group (*Figure 4*).

Table 1

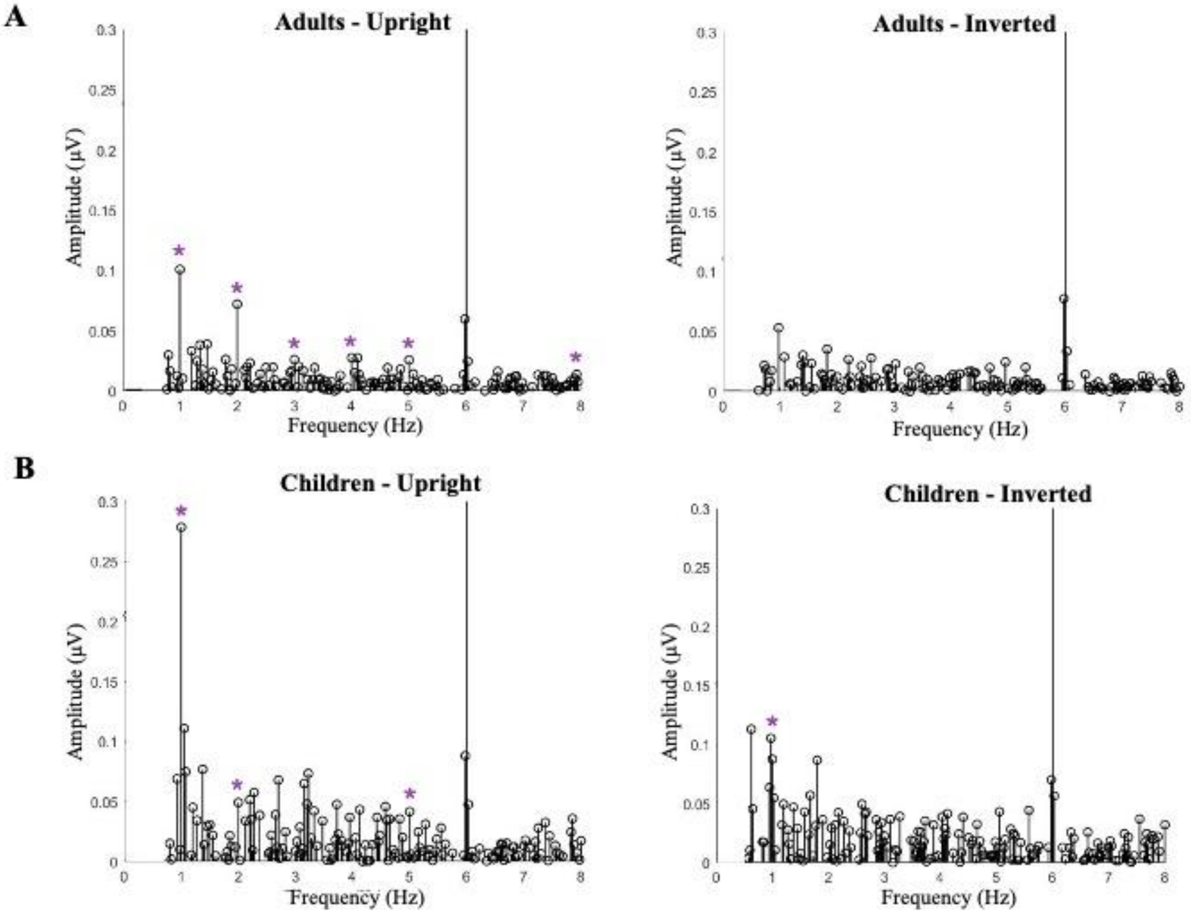
Z-scores for fundamental frequency and harmonics (up to the eighth harmonic) at the ROI (electrodes P8, P10, and PO8)

		1Hz	2Hz	3Hz	4Hz	5Hz	7Hz	8Hz
Adults	Upright	4.54***	3.78***	2.20*	2.55**	2.95**	0.73	2.26*
	Inverted	0.06	0.61	0.36	0.79	0.07	0.28	0.28
Children	Upright	5.24***	1.73*	0.69	1.61	2.27*	1.37	0.93
	Inverted	2.02*	-1.22	0.78	-0.44	-0.28	0.86	1.85

Note: *** p < .001, ** p < .01, * p < .05 (one-tailed).

Figure 4

Baseline subtracted amplitude spectra, averaged across both trustworthy and untrustworthy oddball face stimuli at the right occipito-temporal ROI (electrodes P8, P10, PO8). Significant harmonics are labelled with asterisks. Activity at 6Hz represents the non-face-selective response to the presentation of the stimuli. Panel **A** shows results for adults and **B** shows results for children.



We then examined the significance of the summed BCAs. We found that the summed oddball response in the upright condition was significant in both the adult (BCA = 0.24, *Z* = 4.83, *p* < .001), and child (BCA = 0.36, *Z* = 4.08, *p* < .001) groups, but non-significant in the inverted conditions (adults BCA = 0.01, *Z* = 0.17, *p* = .434; children's BCA = 0.04, *Z* = 0.58, *p* = .280). At the individual level, 30% of adults showed a significant response at the oddball frequency at the right occipito-temporal ROI, and 26% of children showed a significant response at the oddball frequency. Individual participants’ scalp topographies for the summed oddball response are included in the Supplementary Materials (Figure S1), as are plots showing density and spread of individual participants’ summed oddball responses (Figure S2).

3.4 Group Differences in Neural Responses

To test whether there was a significant difference between adults’ and children’s neural responses to facial trustworthiness, we ran a mixed ANOVA, with Group (adult vs. child) as the between-subjects factor and Face Orientation (upright vs. inverted) as the within-subjects factor. Importantly, neither the main effect of Group (F (1, 62) = 1.86, p = .177, η^2_p = .029), nor the interaction between Face Orientation and Group were statistically significant (F (1, 62) = 0.34, p = .561, η^2_p = .005). Therefore, we found no evidence of a difference between the strength of adults and children’s BCA to facial trustworthiness, and no difference in the way children and adults responded to upright versus inverted faces. In contrast, the main effect of Face Orientation was significant (F (1, 62) = 13.37, $p < .001$, η^2_p = .177). Specifically, both children and adults showed a stronger response for upright (M = 0.31, SD = 0.52) compared to inverted faces (M = 0.04, SD = 0.30). This reduced neural response in the inverted condition suggests that low-level visual differences in the stimuli likely do not account for the trustworthiness neural discrimination response that was observed in the upright condition in our samples.

To further quantify group differences, we ran a Bayesian mixed ANOVA (specifying a multivariate Cauchy prior on the effects) with Group (adults vs. children) as a between-subjects factor and Face Orientation (upright vs. inverted) as a within-subjects factor. For Bayesian analyses, first the model fit with each of the variables added was assessed by comparing to the null model (BF_{10}). Guidelines suggested by Lee and Wagenmakers (2014) suggest that Bayes factors < 0.33 indicate strong evidence for the null hypothesis, and Bayes factors > 3.0 indicate strong evidence for the alternative hypothesis. When evidence for the alternative hypothesis was considered inconsequential, these models were not followed up. However, when there was support for the alternative hypothesis, posterior odds were examined to determine how much evidence there was against the null hypothesis. The relative plausibility of each model before observing the data is described by the prior odds. The prior odds are multiplied by the Bayes factor to determine the posterior odds, which represents the relative probability of the models after observing the data. The posterior odds were corrected for multiple testing by fixing the prior probability to 0.5 so that the null hypothesis held across all comparisons (Westfall et al., 1997).

The analysis showed that our data were 0.31 times more likely under the model that includes Group as a predictor compared to the null model. The Bayes factor (BF_{10}) for our model containing Group (0.31) was smaller than the reported guidelines (0.33) for suggesting strong support for the null hypothesis of no effect of Group. Our data were 766.93 times more likely under the model that includes Face Orientation as a predictor compared to the null model. Follow-up analysis revealed posterior odds of 283.53 against the null hypothesis, which indicates strong evidence for the effect of Face Orientation on neural responses. The data were 259.91 times more likely under the model that includes the interaction between Group and Face Orientation than the null model.

While there was no significant difference between the strength of children’s and adults’ summed BCAs, the two groups’ responses to facial trustworthiness did differ in other ways. For example, the bulk of the response in children was accounted for by the first harmonic (the oddball frequency), whereas in adults, the response was more spread out over the harmonics (*Figure 4*). The concentrated response at the fundamental frequency in the child group has been observed in other developmental FPVS studies examining face perception (Lochy et al., 2019), and might indicate simpler or longer responses in children than in adults (Rossion et al., 2020). Additionally, the BCA at the fundamental frequency in the child group was significant in the inverted condition, whereas it was non-significant in the adult group (discussed further below). Lastly, while exploratory analyses did not identify any group differences in the strength of the activity in the left occipito-temporal region, left-sided activity was more apparent in the scalp topography for the child than the adult group. Thus, despite finding no significant difference between the strength of children’s and adult’s BCAs in the predefined ROI, which was our primary index of maturity, there were more nuanced differences in the quality, harmonic distribution, and location of the response, which suggests that 8-to-9-year-olds’ neural responses to facial trustworthiness are not identical to that of adults.

3.5 Location of Neural Responses

Our investigations (and pre-registered analyses) were focused on the right occipito-temporal ROI, given its importance to face processing. Inspection of the scalp topographies for both adult and child participants indicated that the strongest activity in response to changes in facial trustworthiness was indeed over the right occipito-temporal area. However, there were also other regions that displayed significant responses to trustworthiness in the upright condition (*Figure 3*). These channels were either located over the left occipito-temporal face processing area (electrodes P7, P9, PO7), or adjacent to the right occipito-temporal ROI (electrode TP8). An exploratory (not pre-registered) analysis based on *Figure 2* revealed that the pattern of activity on the left side, as calculated by grand-averaging participants’ responses, was statistically significant at the fundamental frequency in both adults (BCA = 0.04, Z = 2.02, $p = .022$) and children (BCA = 0.18, Z = 4.11, $p < .001$), and some of the harmonics in the upright condition (Z-scores for harmonic significance is included in Table S2 of the Supplementary Materials, and baseline subtracted amplitude spectra at the left occipito-temporal region are shown in Figure S4 of the Supplementary Materials). At the individual level, 21% of adults and 16% of children showed a significant response at the oddball frequency in the left occipito-temporal region. Mixed ANOVA examining activity in the left occipito-temporal region with Group (adult vs. child) as the between-subjects factor and Face Orientation (upright vs. inverted) as the within-subjects factor revealed a non-significant interaction effect of Face Orientation and Group (F (1, 62) = 1.51, p = .223, $\eta^2_p = 0.02$). There was also a non-significant main effect of Group (F (1, 62) = 2.01, p = .161, $\eta^2_p = 0.03$). There was, however, a significant main effect of Face Orientation (F (1, 62) = 12.74, $p < .001$, $\eta^2_p = 0.17$). That is, overall, participants showed a stronger response to upright (M = 0.19, SD = 0.29) than to inverted faces (M = 0.02, SD = 0.26) in the left occipito-temporal region.

We also ran a non-preregistered Bayesian mixed ANOVA with Group (adults vs. children) as a between-subjects factor and Face Orientation (upright vs. inverted) as a within-subjects factor to further examine group differences in activation in the left-occipito-temporal region. Results showed that the data were 0.41 times more likely under the model that includes Group as a predictor (BF_{10} of the model that included Group) compared to the null model (BF_{10} of the null model). Therefore, we found weak to moderate support for the null hypothesis of no effect of Group on activity in the left occipito-temporal area (Lee & Wagenmakers, 2014). The data were 135.46 times more likely under the model that contains Face Orientation. Follow-up analysis revealed posterior odds of 31.77 against the null hypothesis, which indicates strong evidence for the effect of Face Orientation on neural responses in the left occipito-temporal region. The data were 53.22 times more likely under the model that includes the interaction between Group and Face Orientation than the null model.

3.6 Reliability of Neural Responses

Finally, though not a preregistered analysis for this study, we were interested to see how reliable participants’ neural responses were in the FPVS task, given that this was the first time the current paradigm was used to examine children’s trustworthiness processing in faces. We calculated reliability at the individual participant level. To control for individual factors and low-level differences between stimuli, we calculated reliability of the upright condition after residualizing for the inverted condition (Swe et al., 2020). Therefore, we divided data from the 20 trials in the task into two blocks of 10 trials, each containing 5 upright trials and 5 inverted trials. The two blocks contained an equal number of trustworthy and untrustworthy oddball trials. We then ran a linear regression using the upright responses in each block as the dependent variable and the inverted responses as the independent variable. The residuals created from this analysis represented variance in the upright condition after controlling for the inverted condition. We then calculated the correlation between the residuals for each block. The split-half reliability for the adult group was ρ’= .44, and for the child group, was ρ’=. 66 (following Spearman-Brown correction to account for the reduced trial numbers relative to the task overall). Scatter plots showing correlations between residuals for each block are included in the Supplementary Materials (Figure S3). Therefore, we find reasonable evidence that our task was reliable in this sample, which was especially informative given that we examined a developmental population, wherein data is often comparatively less reliable than in adult samples. Further, we also employed only one block of the FPVS task in our study whereas Swe et al. (2020)’s participants completed the same block twice to increase reliability (and in their study, test re-test reliability across blocks was reasonably good: r (30) = .499). Given our results suggest reliable responses in both age groups, we can conclude that this shorter version of the experiment (20 trials/20 minutes) is sufficient. Furthermore, exploratory analysis of fewer FPVS task trials revealed only 4 or 5 upright trials are needed (i.e., approximately 5 minutes of EEG recording) to find a significant response in the right occipito-temporal area at the oddball frequency in the upright condition. BCAs and Z-scores for when fewer than 10 upright trials are analysed are included in the Supplementary Materials (Table S3).

4. Discussion

We investigated whether children display neural sensitivity to faces that visibly differ in how trustworthy they appear, and whether children’s neural responses were commensurate with those of adults. For the first time, we showed that changes in the trustworthiness of face stimuli induced a corresponding amplitude spike in children’s neural activity at the oddball frequency and its harmonics, revealing that children aged 8-to-9 years show neural sensitivity to variations in facial trustworthiness. Additionally, our results suggest that nine or less years of social experience, perceptual, and/or cognitive development may be sufficient for adult-like patterns to be observed in the strength of children’s neural responses to facial trustworthiness to emerge in the visual processing system. We also replicated recent findings that FPVS can reliably measure trust processing with adults (Swe et al., 2020; Verosky et al., 2020), even with a shorter task ideal for children.

Crucially, adults’ neural discrimination responses were reduced and non-significant in the inverted face condition across all harmonics, indicating that the significant response to upright faces in adults most likely represented a high-level face processing response and was not simply due to low-level visual differences between stimuli. Finding a significant response to inverted faces at the fundamental frequency in the child group is in line with a previous individual face discrimination FPVS study with children that also found only a small reduction in amplitude to inverted faces compared to upright faces (Lochy et al., 2019), as well as an overall weaker inversion effect in children in face perception research (Brace et al., 2001; Joseph et al., 2006; Meinhardt-Injac, Persike, & Meinhardt, 2014; Schwarzer, 2000). Importantly, this finding does not suggest that children’s oddball responses in the upright condition is accounted for by low-level visual cues alone, because although the effect of inversion was weaker in children than in adults, inverting the stimuli did have an impact on children’s responses. That is, the Z-score/effect size was smaller in the inverted condition compared to the upright condition, and the significance of the response at the fundamental frequency did not continue to higher harmonics. Therefore, it is unlikely that individual low-level features alone drive the oddball response in the upright condition. Furthermore, inverted faces are structured stimuli that also activate high-level visual regions of the brain, including face-selective areas of the fusiform gyrus (Haxby et al., 1999) and non-face selective but high-level visual areas of the brain (Rosenthal et al., 2017) and these regions may also contribute to the significant response we observed for children in the inverted condition. The significant oddball response in the inverted condition does, however, suggest that the upright trustworthiness response in children may also reflect appearance cues that are not disrupted by inversion (following logic in Rossion et al., 2020), which is an interesting result for future research to examine further.

The FPVS paradigm can be used to measure visual discrimination to the physical cues of different stimuli (Rossion, 2014), and therefore, we expected it to be sensitive to physical cues to facial trustworthiness. There are likely several different cues that underlie the neural response to facial trustworthiness observed in the current study, including resemblance to emotional expressions, facial masculinity/femininity, facial maturity, and attractiveness displayed in the face (Ewing, Sutherland, & Willis, 2019; Oosterhof & Todorov, 2008; Santos & Young, 2011; Todorov, Olivola, Dotsch, & Mende-Siedlecki, 2015; Zebrowitz, 2017). The stimuli used in the current study likely captured a mixture of these physical differences that are integral to visual trustworthiness processing. However, the stimuli used in the current study were originally created to maximally vary on the trustworthiness dimension (Todorov et al., 2013), and therefore, it is unlikely that any one of these underlying cues drive the entire oddball response. Rather, the oddball response likely reflects discrimination particular to trustworthiness, based on a holistic combination of multiple underlying cues (Vernon et al., 2014). It is also possible that different perceivers relied more, or less on different cues to trustworthiness from facial appearance (Hehman et al., 2017). Furthermore, given that judgements of trustworthiness closely approximate the primary facial first impressions dimension of valence (Oosterhof & Todorov, 2008), it may be inferred that the current results showing neural responses at the oddball frequency reflect neural responses underlying a global evaluation of how positive or negative a face is, approximated by trustworthiness judgements (Oliveira et al., 2020; Oosterhof & Todorov, 2008).

The ontogeny of adults’ face-based trust impressions and the mechanisms underlying their development has been a topic of considerable recent research interest (Over & Cook, 2018; Sutherland, Burton, et al., 2020; Sutherland, Collova, et al., 2020). Additionally, there has been some mixed evidence in the literature regarding the maturity of children’s face-based trust perception during the middle childhood period (8-to-9-years of age), with some finding adult-like patterns during this age range (Baccolo & Cassia, 2020; Charlesworth et al., 2019; Cogsdill et al., 2014; Ewing et al., 2019; Siddique, Jeffery, et al., 2022), and others finding relative immaturity (Mondloch et al., 2019; Siddique, Sutherland, et al., 2022). This variability in results has led to the theory that the middle-childhood period is a critical time for the development of face-based trustworthiness impressions (Siddique, Sutherland, et al., 2022). Finding no evidence of a difference in the strength of children’s and adults’ neural responses to facial trustworthiness in our study suggests that neural sensitivity to facial trustworthiness can already show mature patterns within the first ten years. We did, however, identify some differences in the quality and harmonic distribution of children’s and adults’ neural responses, indicating that the children’s responses may be shorter or less complex than those of adults’ (discussed further below; Lochy et al., 2019; Rossion et al., 2020). It is possible that age-related maturation of these neural responses, along with other factors, such as general cognitive, social, and emotional development that also occurs during this period (Baccolo & Cassia, 2020; Over & Cook, 2018; Siddique, Sutherland, et al., 2022) are involved in the maturation of trust impressions observed in previous research (Siddique, Sutherland, et al., 2022). As such, our results help to clarify our understanding of the ontogeny of adults' face-based trust impressions and their development across childhood. This evidence is especially valuable in light of how difficult it is to make these distinctions based on behavioural evidence that is inherently confounded by children's social and cognitive constraints, task demands, decisional processes, and social desirability (Hofmann et al., 2005; Rossion, 2014). Future studies might attempt to further examine factors such as general cognitive, emotional, and social capacity to determine the relative contributions of these different mechanisms in driving age-related development of trustworthiness processing from faces, as understanding the mechanisms underlying the development of trust impressions is a key priority in the literature (Sutherland, Burton, et al., 2020).

Similar to previous developmental research using the FPVS paradigm (Lochy, Schiltz, et al., 2019), we found a different pattern of activity across the harmonic frequencies in the child group compared to the adult group. A large percentage of the oddball response was at the fundamental frequency in children, while the response was dispersed more evenly over the harmonics in adults. Likewise, Lochy and colleagues found that their preschool-aged participants' face discrimination response was mainly accounted for by the first harmonic in the EEG spectrum (about 60% of the response), which was unlike patterns observed in adults in other studies using similar paradigms, wherein responses were distributed over several harmonics (Liu-Shuang et al., 2016; Swe et al., 2020; Verosky et al., 2020). Lochy and colleagues conjectured that the larger number of higher frequency components involved in adults' neural responses compared to the concentrated response at the fundamental frequency in children could suggest that neural responses are more complex in adults than they are in children (Lochy, Schiltz, et al., 2019), possibly due to age-related increases in myelination on white matter pathways across childhood. Greater myelination in adults may allow faster and sharper responses, which Lochy et al. (2019) suggested could explain the less-complex neural response observed in child groups (Lochy, de Heering, et al., 2019). Additionally, physical differences, such as age-related thickening of the skull, which diffuses the electrical activity, could lead to differences in how adults' and children's responses are distributed over the harmonics (Lochy, de Heering, et al., 2019). Our results are broadly supportive of Lochy and colleagues' (2019) proposal, although it would be valuable for future research to examine when this more distributed neural signal observed in adults first emerges in childhood, when it matures, and which specific possible mechanisms contribute to this maturation. Alternatively, the differences in responses of adults and children could also be driven by a change in the way that faces are processed over the course of development.

Our study confirms that the FPVS paradigm has great utility in reliably examining trustworthiness processing from faces in a developmental population and opens the door for further research on exactly how early in life mature neural responses to facial trustworthiness can be observed (discussed below in the *Future directions and limitations* section). Unlike many behavioural studies wherein children's cognitive constraints and difficulties with achieving a high level of experimental control can sometimes limit interpretation of results, the passive task used in the current study shows that face-based trustworthiness processing can be measured without requiring a verbal response from children, or their conceptual understanding of trustworthiness. This demonstration is a valuable first step in developmental research on trustworthiness processing, because it opens the possibility of comparing these processes in very disparate samples, such as preverbal infants and adults, in the same experiment. Such research would be particularly informative for tracking trustworthiness impressions across the lifespan, especially considering research suggesting that trustworthiness impressions develop throughout our lives (Siddique, Sutherland, et al., 2022; Sutherland, Burton, et al., 2020; Twele & Mondloch, 2022; Verosky & Todorov, 2010). Thus, our results add to the existing literature on using the FPVS methodology to examine children’s face perception and indicate that in addition to examining neural sensitivity to identity and emotional expression in children (Lochy, de Heering, et al., 2019; Lochy, Schiltz, et al., 2019; van der Donck et al., 2019; Vettori et al., 2020), this technique is also useful for examining children’s neural sensitivity to facial trustworthiness.

4.1 Future Directions and Limitations

Our results strengthen evidence for the effectiveness of the FPVS paradigm in measuring high-level face characteristics like trustworthiness in children. Here we set out to examine the pivotal age of middle childhood, but a next step for future researchers would be to examine a broader range of ages across childhood using this paradigm. Specifically, our current research now suggests that an intriguing future question is to establish exactly how early in childhood these adult-like patterns can be observed, how responses differ before children’s impressions are mature, and finally, to examine longitudinal patterns of development in the neural and behavioural underpinnings of impression formation. Our finding of largely adult-like patterns in the strength of children’s neural response to facial trustworthiness in the current study identifies an upper boundary to guide this work.

Given the objectivity and implicit nature of this paradigm, as well as the short time required for a high signal-to-noise recording, FVPS with EEG is an ideal technique to investigate younger children’s face-based trust processing. Future researchers may begin by testing a slightly younger age group (6-to-7-year-olds) on our current paradigm, provided younger children are given breaks and rewards to encourage motivation throughout the task, and then examine progressively younger groups (e.g., down to preverbal infants) based on the findings. It will be feasible to test even these younger populations because we find reliable results from our shorter 20-minute FPVS task (as opposed to the 40-minute version used in previous research with adults; Swe et al., 2020), with evidence that as few as 4 or 5 upright trials might be sufficient to observe a significant oddball response in both adults and children at the fundamental frequency in the right occipito-temporal region (see Table S3 in Supplementary Materials).

While we found strong right-hemispheric occipito-temporal activity in both the adult and child groups in response to facial trustworthiness in upright faces, both groups also showed significant activity in the left occipito-temporal region. This pattern of (some) bilateral activation is consistent with previous research on adults’ facial trustworthiness processing (Swe et al., 2020; Verosky et al., 2020) and with other studies examining children’s face perception (Golarai et al., 2007; Lochy, Schiltz, et al., 2019; Natu et al., 2016). Previous research in trustworthiness processing has suggested that a bilateral response may indicate that visual sensitivity to facial trustworthiness is not localised to right-sided face processing areas and instead, might extend across the entire posterior visual area of the brain (Swe et al., 2020). Further, findings from other FPVS studies examining children’s facial identity perception suggest a non-linear pattern of lateralisation across development, wherein face processing is less right-lateralised in childhood (Lochy, de Heering, et al., 2019) than in adulthood (Retter & Rossion, 2016) or infancy (de Heering & Rossion, 2015), which is in line with the current finding of greater right-sided lateralisation in adults in response to changes in facial trustworthiness than in children. Interestingly, recent research in infants has only found a left-lateralised latency advantage for trustworthy-looking faces at the P400 ERP component (thought to be a precursor of the adult N170, which is linked to face detection), and the Nc ERP component (which is linked to attention to visual stimuli) (Baccolo et al., 2021). Baccolo et al. (2021) argue that their left-lateralised result is in line with the approachwithdrawal model of emotion-related prefrontal cortex asymmetries, such that stimuli that trigger approach (versus avoid) behaviour are lateralised to the left (versus right) hemisphere. Given trustworthy-looking faces are appealing, under this account they are more likely to engage the left prefrontal cortex (Baccolo et al., 2021). Interestingly, in the current study, when trustworthy and untrustworthy oddball trials were analysed separately, scalp topographies showed greater bilateral activity in response to trustworthy-looking oddballs than to untrustworthy oddballs (see Figure S5 in Supplementary Materials). It will be interesting for future research to track the development of lateralisation in face-based trust processing throughout childhood, because it will clarify our understanding of when trust processing extends across the entire posterior visual area of the brain (see also Mattavelli, Andrews, Asghar, Towler, & Young, 2012; Swe et al., 2020), and how lateralisation in trustworthiness processing compares to other facets of face perception.

Our stimuli in this experiment were tightly controlled to minimise the potential for confounding factors to affect trustworthiness processing. Therefore, as in previous research (Swe et al., 2020), we controlled for facial identity, overt emotional expression, gender, ethnicity, colour, contrast, and luminance. Such controls were important because the FPVS paradigm records brain responses to an array of visual differences between images (e.g., differences in luminance across different genders of faces could induce an amplitude spike that confounds responses to trustworthiness). However, recent reviews have noted the lack of diversity in stimuli used in face perception research (Cook & Over, 2021; Foo et al., 2021; Sutherland & Young, 2022). Lack of diversity is a valid argument, especially because the faces we see in our daily lives are far more varied than the tightly controlled stimuli employed in the current study, which minimises the facial cues that might be used to infer trustworthiness (see also Sutherland et al., 2013; Zebrowitz, 2017). Furthermore, the current study employed only male faces as stimuli, which may limit the generalisability of the current results, though we do not have strong reasons to expect that including female faces would reveal a very different pattern of results, given the current results are in line with Verosky et al. (2020) who examined the same question in adults using both male and female faces. Moreover, we are not aware of any evidence to suggest that children are more, or less, sensitive to trustworthiness depending on face gender, than adults. Future research can address the limitation of including only male face stimuli, however, by examining children’s neural responses to trustworthiness in female faces as well. Further, a valuable avenue for future research would be to use the FPVS paradigm to examine the impact of specific facial characteristics (e.g., overt emotional expressions, ethnicity), on children’s and adult’s implicit trust processing (Baccolo et al., 2021; Jessen & Grossmann, 2019; Silvestri et al., 2022). Such research would be particularly valuable in light of recent evidence of different directions of modulation in 7-month-old infants’ P400 and Nc ERP components in response to trustworthiness in realistic-looking and CGI faces, which is thought to be driven by the realism of the stimulus faces (Baccolo et al., 2021; Jessen & Grossmann, 2019). One way to do this might be to use naturalistic or ambient images as stimuli, which contain the variability we see in faces in our everyday life, and therefore allow the examination of trustworthiness processing in a more ecologically valid way (Jenkins et al., 2011; Sutherland et al., 2015), like others have done in investigations of face detection and familiar face processing (Rekow et al., 2020; Rossion et al., 2015; Yan et al., 2020; Zimmermann et al., 2019).

4.2 Conclusion

For the first time, we show that children aged 8-to-9 years are sensitive to variations in facial trustworthiness, even in the absence of instructions to form judgements about these faces. We additionally find that the strength of children’s and adults’ neural responses were highly similar, with strong Bayesian evidence that they did not significantly differ, suggesting children’s neural sensitivity to implicit differences in facial trustworthiness can already show mature patterns by 8-to-9 years of age, though children’s neural responses may be shorter or less complex than adults’ overall. Our study also demonstrates the validity of using the FPVS methodology for examining children’s implicit face-based trust processing for the first time, which is especially valuable in a developmental population wherein strong experimental control can be difficult to achieve and constraints in children’s cognitive ability can impact task performance.

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References

Baccolo, E., & Cassia, V. M. (2020). Age-Related Differences in Sensitivity to Facial Trustworthiness: Perceptual Representation and the Role of Emotional Development. *Child Development*, *91*(5), 1529–1547. https://doi.org/10.1111/CDEV.13340

Baccolo, E., Quadrelli, E., & Macchi Cassia, V. (2021). Neural sensitivity to trustworthiness cues from realistic face images is associated with temperament: An electrophysiological study with 6-month-old infants. *Social Neuroscience*, *16*(6), 668–683.

Buchan, N. R., Croson, R. T. A., & Solnick, S. (2008). Trust and gender: An examination of behavior and beliefs in the Investment Game. *Journal of Economic Behavior and Organization*, *68*(3–4), 466–476. https://doi.org/10.1016/j.jebo.2007.10.006

Chang, L. J., Doll, B. B., van 't Wout, M., Frank, M. J., & Sanfey, A. G. (2010). Seeing is believing: Trustworthiness as a dynamic belief. *Cognitive Psychology*, *61*(2), 87–105. https://doi.org/10.1016/j.cogpsych.2010.03.001

Charlesworth, T. E. S., Hudson, S. T. J., Cogsdill, E. J., Spelke, E. S., & Banaji, M. R. (2019). Children use targets' facial appearance to guide and predict social behavior. *Developmental Psychology*. https://doi.org/10.1037/dev0000734

Cogsdill, E. J., & Banaji, M. R. (2015). Face-trait inferences show robust child-adult agreement: Evidence from three types of faces. *Journal of Experimental Social Psychology*, *60*, 150–156. https://doi.org/10.1016/j.jesp.2015.05.007

Cogsdill, E. J., Todorov, A. T., Spelke, E. S., & Banaji, M. R. (2014). Inferring Character From Faces. *Psychological Science*, *25*(5), 1132–1139. https://doi.org/10.1177/0956797614523297

Collova, J. R., Sutherland, C. A. M., & Rhodes, G. (2019). Testing the Functional Basis of First Impressions: Dimensions for Children's Faces Are Not the Same as for Adults'

Faces. *Journal of Personality and Social Psychology*. https://doi.org/10.1037/pspa0000167

de Heering, A., & Rossion, B. (2015). Rapid categorization of natural face images in the infant right hemisphere. *ELife*, *4*(JUNE), 1–14. https://doi.org/10.7554/ELIFE.06564

Dzhelyova, M., Jacques, C., & Rossion, B. (2017). At a Single Glance: Fast Periodic Visual Stimulation Uncovers the Spatio-Temporal Dynamics of Brief Facial Expression Changes in the Human Brain. *Cerebral Cortex*, *27*(8), 4106–4123. https://doi.org/10.1093/CERCOR/BHW223

Dzhelyova, M., & Rossion, B. (2014). The effect of parametric stimulus size variation on individual face discrimination indexed by fast periodic visual stimulation. *BMC Neuroscience*, *15*(1), 87. https://doi.org/10.1186/1471-2202-15-87

Engell, A. D., Haxby, J. v, & Todorov, A. (2007). Automatic coding of face properties that signal untrustworthiness in human amygdala. *Magnetic Resonance Imaging, 2002,* 1–39.

Ewing, L., Sutherland, C. A. M., & Willis, M. L. (2019). Children Show Adult-Like Facial Appearance Biases When Trusting Others. *Developmental Psychology*. https://doi.org/10.1037/dev0000747

Foo, Y. Z., Sutherland, C., Burton, N., Nakagawa, S., & Rhodes, G. (2021). Accuracy in Facial Trustworthiness Impressions: Kernel of Truth or Modern Physiognomy? A Meta-Analysis. *Personality & Social Psychology Bulletin*, 014616722110481. https://doi.org/10.1177/01461672211048110

Golarai, G., Ghahremani, D. G., Whitfield-Gabrieli, S., Reiss, A., Eberhardt, J. L., Gabrieli, J. D. E., & Grill-Spector, K. (2007). Differential development of high-level visual cortex correlates with category-specific recognition memory. *Nature Neuroscience 2007 10:4*, *10*(4), 512–522. https://doi.org/10.1038/nn1865

Gredebäck, G., Kaduk, K., Bakker, M., Gottwald, J., Ekberg, T., Elsner, C., Reid, V., & Kenward, B. (2015). The neuropsychology of infants’ pro-social preferences. *Developmental Cognitive Neuroscience*, *12*, 106–113. https://doi.org/10.1016/J.DCN.2015.01.006

Gwinn, O. S., Matera, C. N., O’Neil, S. F., & Webster, M. A. (2018a). Asymmetric neural responses for facial expressions and anti-expressions. *Neuropsychologia*, *119*, 405–416. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2018.09.001

Gwinn, O. S., Matera, C. N., O’Neil, S. F., & Webster, M. A. (2018b). Asymmetric neural responses for facial expressions and anti-expressions. *Neuropsychologia*, *119*, 405–416. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2018.09.001

Gwinn, O. S., Retter, T. L., O’Neil, S. F., & Webster, M. A. (2021). Contrast Adaptation in Face Perception Revealed Through EEG and Behavior. *Frontiers in Systems Neuroscience*, *15*. https://doi.org/10.3389/fnsys.2021.701097

Haxby, J. v., Ungerleider, L. G., Clark, V. P., Schouten, J. L., Hoffman, E. A., & Martin, A. (1999). The Effect of Face Inversion on Activity in Human Neural Systems for Face and Object Perception. *Neuron*, *22*(1), 189–199. https://doi.org/10.1016/S0896-6273(00)80690-X

Hehman, E., Sutherland, C. A. M., Flake, J. K., & Slepian, M. L. (2017). The Unique Contributions of Perceiver and Target Characteristics in Person Perception. In *Journal of Personality and Social Psychology*.

Hofmann, W., Gawronski, B., Gschwendner, T., Le, H., & Schmitt, M. (2005). A meta-analysis on the correlation between the Implicit Association Test and explicit self-report measures. In *Personality and Social Psychology Bulletin*. https://doi.org/10.1177/0146167205275613

Hooper, J. J., Sutherland, C. A. M., Ewing, L., Langdon, R., Caruana, N., Connaughton, E., Williams, N., Greenwell-Barnden, J., & Rhodes, G. (2018). Should I trust you? Autistic traits predict reduced appearance-based trust decisions. *British Journal of Psychology*, 1–18. https://doi.org/10.1111/bjop.12357

Jenkins, R., White, D., van Montfort, X., & Mike Burton, A. (2011). Variability in photos of the same face. *Cognition*. https://doi.org/10.1016/j.cognition.2011.08.001

Jessen, S., & Grossmann, T. (2016). Neural and behavioral evidence for infants' sensitivity to the trustworthiness of faces. *Journal of Cognitive Neuroscience*. https://doi.org/10.1162/jocn_a_00999

Jessen, S., & Grossmann, T. (2019). Neural evidence for the subliminal processing of facial trustworthiness in infancy. *Neuropsychologia*, *126*(April), 46–53. https://doi.org/10.1016/j.neuropsychologia.2017.04.025

Kragel, P. A., Zucker, N. L., Covington, V. E., & LaBar, K. S. (2015). Developmental trajectories of cortical-subcortical interactions underlying the evaluation of trust in adolescence. *Social Cognitive and Affective Neuroscience*. https://doi.org/10.1093/scan/nsu050

Liu-Shuang, J., Norcia, A. M., & Rossion, B. (2014). An objective index of individual face discrimination in the right occipito-temporal cortex by means of fast periodic oddball stimulation. *Neuropsychologia*, *52*(1), 57–72. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2013.10.022

Liu-Shuang, J., Torfs, K., & Rossion, B. (2016). An objective electrophysiological marker of face individualisation impairment in acquired prosopagnosia with fast periodic visual stimulation. *Neuropsychologia*, *83*, 100–113. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2015.08.023

Lochy, A., de Heering, A., & Rossion, B. (2019). The non-linear development of the right hemispheric specialization for human face perception. *Neuropsychologia*, *126*, 10–19. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2017.06.029

Lochy, A., Schiltz, C., & Rossion, B. (2019). The right hemispheric dominance for face perception in preschool children depends on the visual discrimination level. *Developmental Science*, *23*(3), e12914.

Ma, F., Xu, F., & Luo, X. (2015). Children’s and Adults’ Judgments of Facial Trustworthiness: The Relationship to Facial Attractiveness. *Perceptual and Motor Skills*, *121*(1), 179–198. https://doi.org/10.2466/27.22.pms.121c10x1

Mondloch, C. J., Gerada, A., Proietti, V., & Nelson, N. L. (2019). The influence of subtle facial expressions on children’s first impressions of trustworthiness and dominance is not adult-like. *Journal of Experimental Child Psychology*, *180*, 19–38. https://doi.org/10.1016/j.jecp.2018.12.002

Natu, V. S., Barnett, M. A., Hartley, J., Gomez, J., Stigliani, X. A., & Grill-Spector, K. (2016). *Systems/Circuits Development of Neural Sensitivity to Face Identity Correlates with Perceptual Discriminability*. https://doi.org/10.1523/JNEUROSCI.1886-16.2016

Oliveira, M., Garcia-Marques, T., Garcia-Marques, L., & Dotsch, R. (2020). Good to Bad or Bad to Bad? What is the relationship between valence and the trait content of the Big Two? *European Journal of Social Psychology*, *50*(2), 463–483. https://doi.org/10.1002/ejsp.2618

Oosterhof, N. N., & Todorov, A. (2008). The functional basis of face evaluation. *Proceedings of the National Academy of Sciences*, *105*(32), 11087–11092. https://doi.org/10.1073/pnas.0805664105

Over, H., & Cook, R. (2018). Where do spontaneous first impressions of faces come from? *Cognition*, *170*(April), 190–200. https://doi.org/10.1016/j.cognition.2017.10.002

Regan, D. (1966). Some characteristics of average steady-state and transient responses evoked by modulated light. *Electroencephalography and Clinical Neurophysiology*. https://doi.org/10.1016/0013-4694(66)90088-5

Rekow, D., Baudouin, J. Y., Rossion, B., & Leleu, A. (2020). An ecological measure of rapid and automatic face-sex categorization. *Cortex*, *127*, 150–161. https://doi.org/10.1016/J.CORTEX.2020.02.007

Retter, T. L., & Rossion, B. (2016). Visual adaptation provides objective electrophysiological evidence of facial identity discrimination. *Cortex, 80,* 35–50.

Rhodes, G., Brake, S., & Atkinson, A. P. (1993). What’s lost in inverted faces? *Cognition*, *47*(1), 25–57. https://doi.org/10.1016/0010-0277(93)90061-Y

Rosenthal, G., Sporns, O., & Avidan, G. (2017). Stimulus Dependent Dynamic Reorganization of the Human Face Processing Network. *Cerebral Cortex*, *27*(10), 4823–4834. https://doi.org/10.1093/CERCOR/BHW279

Rossion, B. (2014). Understanding individual face discrimination by means of fast periodic visual stimulation. In *Experimental Brain Research*. https://doi.org/10.1007/s00221-014-3934-9

Rossion, B., & Gauthier, I. (2002). How does the brain process upright and inverted faces? In *Behavioral and cognitive neuroscience reviews*. https://doi.org/10.1177/1534582302001001004

Rossion, B., Prieto, E. A., Boremanse, A., Kuefner, D., & van Belle, G. (2012). A steady-state visual evoked potential approach to individual face perception: Effect of inversion, contrast-reversal and temporal dynamics. *NeuroImage*, *63*(3), 1585–1600. https://doi.org/10.1016/j.neuroimage.2012.08.033

Rossion, B., Retter, T. L., & Liu-Shuang, J. (2020). Understanding human individuation of unfamiliar faces with oddball fast periodic visual stimulation and electroencephalography. *European Journal of Neuroscience*, *52*(10), 4283–4344. https://doi.org/10.1111/EJN.14865

Rossion, B., Torfs, K., Jacques, C., & Liu-Shuang, J. (2015). Fast periodic presentation of natural images reveals a robust face-selective electrophysiological response in the human brain. *Journal of Vision*, *15*(1), 18–18. https://doi.org/10.1167/15.1.18

Shen, X., Mann, Thomas. C., & Ferguson, M. J. (2020). Beware a dishonest face?: Updating face-based implicit impressions using diagnostic behavioral information. *Journal of Experimental Social Psychology*, *86*.

Siddique, S., Jeffery, L., Palermo, R., Collova, J. R., & Sutherland, C. A. (2022). *Children’s Dynamic Use of Face-and Behavior-Based Cues in an Economic Trust Game*. https://doi.org/10.1037/dev0001438

Siddique, S., Sutherland, C. A. M., Palermo, R., Foo, Y. Z., Swe, D. C., & Jeffery, L. (2022). Development of face-based trustworthiness impressions in childhood: A systematic review and metaanalysis. *Cognitive Development*, *61*. https://doi.org/10.1016/j.cogdev.2021.101131

Silvestri Id, V., Arioli, M., Id, E. B., Macchi, V., & Id, C. (2022). Sensitivity to trustworthiness cues in own- and other-race faces: The role of spatial frequency information. *PLOS ONE*, *17*(9), e0272256. https://doi.org/10.1371/JOURNAL.PONE.0272256

Sutherland, C. A. M., Burton, N. S., Wilmer, J. B., Blokland, G. A. M., Germine, L., Palermo, R., Collova, J. R., & Rhodes, G. (2020). Individual differences in trust evaluations are shaped mostly by environments, not genes. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1920131117

Sutherland, C. A. M., Collova, J. R., Palermo, R., Germine, L., Rhodes, G., Blokland, G. A. M., Burton, N. S., & Wilmer, J. B. (2020). Reply to cook and over: Social learning and evolutionary mechanisms are not mutually exclusive. In *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.2009587117

Sutherland, C. A. M., Liu, X., Zhang, L., Chu, Y., Oldmeadow, J. A., & Young, A. W. (2018). Facial First Impressions Across Culture: Data-Driven Modeling of Chinese and British Perceivers' Unconstrained Facial Impressions. *Personality and Social Psychology Bulletin*, *44*(4), 521–537. https://doi.org/10.1177/0146167217744194

Sutherland, C. A. M., Rhodes, G., Williams, N., Connaughton, E., Ewing, L., Caruana, N., & Langdon, R. (2019). Appearance-based trust processing in schizophrenia. *British Journal of Clinical Psychology*. https://doi.org/10.1111/bjc.12234

Sutherland, C. A. M., Rowley, L. E., Amoaku, U. T., Daguzan, E., Kidd-Rossiter, K. A., Maceviciute, U., & Young, A. W. (2015). Personality judgments from everyday images of faces. *Frontiers in Psychology*, *6*(OCT), 1–11. https://doi.org/10.3389/fpsyg.2015.01616

Sutherland, C. A. M., & Young, A. W. (2022). Understanding trait impressions from faces. *British Journal of Psychology*, 1–23.

Swe, D. C., Palermo, R., Gwinn, O. S., Rhodes, G., Neumann, M., Payart, S., & Sutherland, C. A. M. (2020). An objective and reliable electrophysiological marker for implicit trustworthiness perception. *Social Cognitive and Affective Neuroscience*, 337–346. https://doi.org/10.1093/scan/nsaa043

Todorov, A., Dotsch, R., Porter, J. M., Oosterhof, N. N., & Falvello, V. B. (2013). Validation of data-driven computational models of social perception of faces. *Emotion*, *13*(4), 724–738. https://doi.org/10.1037/a0032335

Todorov, A., Loehr, V., & Oosterhof, N. N. (2010). The obligatory nature of holistic processing of faces in social judgments. *Perception*, *39*(4), 514–532. https://doi.org/10.1068/p6501

Todorov, A., Pakrashi, M., & Oosterhof, N. N. (2009). Evaluating Faces on Trustworthiness After Minimal Time Exposure. *Social Cognition*. https://doi.org/10.1521/soco.2009.27.6.813

Twele, A. C., & Mondloch, C. J. (2022). The dimensions underlying first impressions of older adult faces are similar, but not identical, for young and older adult perceivers. *British Journal of Psychology*. https://doi.org/10.1111/BJOP.12568

van der Donck, S., Dzhelyova, M., Vettori, S., Thielen, H., Steyaert, J., Rossion, B., & Boets, B. (2019). Fast Periodic Visual Stimulation EEG Reveals Reduced Neural Sensitivity to Fearful Faces in Children with Autism. *Journal of Autism and Developmental Disorders*, *49*(11), 4658–4673. https://doi.org/10.1007/S10803-019-04172-0/FIGURES/4

Vernon, R. J. W., Sutherland, C. A. M., Young, A. W., & Hartley, T. (2014). Modeling first impressions from highly variable facial images. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1409860111

Verosky, S. C., & Todorov, A. (2010). Generalization of affective learning about faces to perceptually similar faces. *Psychological Science : A Journal of the American Psychological Society / APS*, *21*(6), 779–785. https://doi.org/10.1177/0956797610371965

Verosky, S. C., & Todorov, A. (2013). When physical similarity matters: Mechanisms underlying affective learning generalization to the evaluation of novel faces. *Journal of Experimental Social Psychology*, *49*(4), 661–669. https://doi.org/10.1016/j.jesp.2013.02.004

Verosky, S. C., Zoner, K. A., Marble, C. W., Sammon, M. M., & Babarinsa, C. O. (2020). Implicit responses to face trustworthiness measured with fast periodic visual stimulation. *Journal of Vision*, *20*(7), 29–29. https://doi.org/10.1167/JOV.20.7.29

Vettori, S., Dzhelyova, M., van der Donck, S., Jacques, C., Steyaert, J., Rossion, B., & Boets, B. (2020). Frequency-Tagging Electroencephalography of Superimposed Social and Non-Social Visual Stimulation Streams Reveals Reduced Saliency of Faces in Autism Spectrum Disorder. *Frontiers in Psychiatry*, *11*, 332. https://doi.org/10.3389/FPSYT.2020.00332/BIBTEX

Westfall, P. H., Johnson, W. O., & Utts, J. M. (1997). A Bayesian perspective on the Bonferroni adjustment. *Biometrika*, *84*(2), 419–427. https://doi.org/10.1093/BIOMET/84.2.419

Yan, X., Zimmermann, F. G., & Rossion, B. (2020). *Cognitive Neuroscience An implicit neural familiar face identity recognition response across widely variable natural views in the human brain An implicit neural familiar face identity recognition response across widely variable natural views in the human brain*. https://doi.org/10.1080/17588928.2020.1712344

Yovel, G., & Kanwisher, N. (2005). The neural basis of the behavioral face-inversion effect. *Current Biology*, *15*(24), 2256–2262. https://doi.org/10.1016/j.cub.2005.10.072

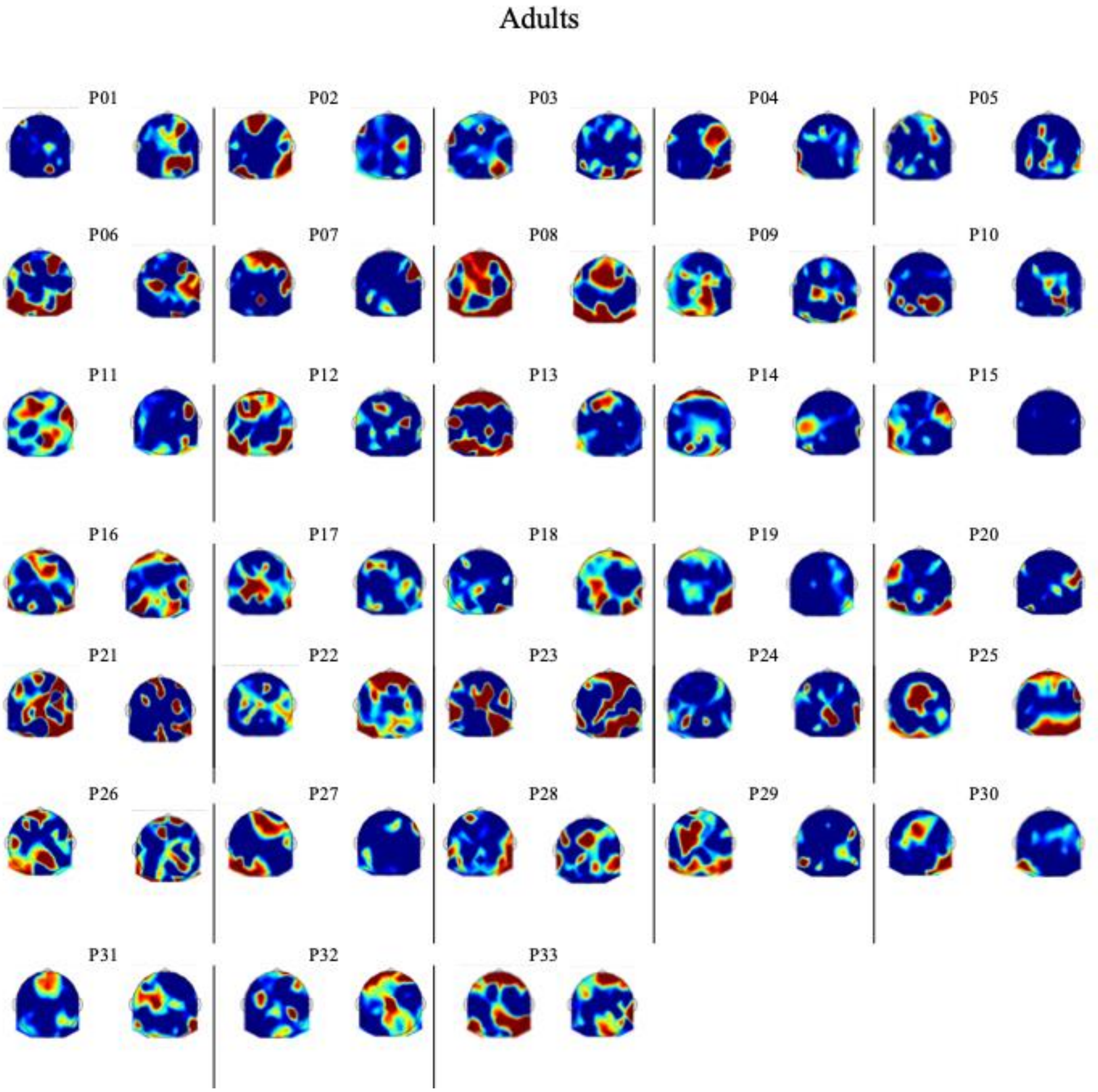
Zebrowitz, L. A., & Montepare, J. M. (2008). Social Psychological Face Perception: Why Appearance Matters. *Social and Personality Psychology Compass*, *2*(3), 1497–1517. https://doi.org/10.1111/j.1751-9004.2008.00109.x

Zimmermann, F. G. S., Yan, X., & Rossion, B. (2019). An objective, sensitive and ecologically valid neural measure of rapid human individual face recognition. *Royal Society Open Science*, *6*(181904). https://doi.org/10.1098/rsos.181904

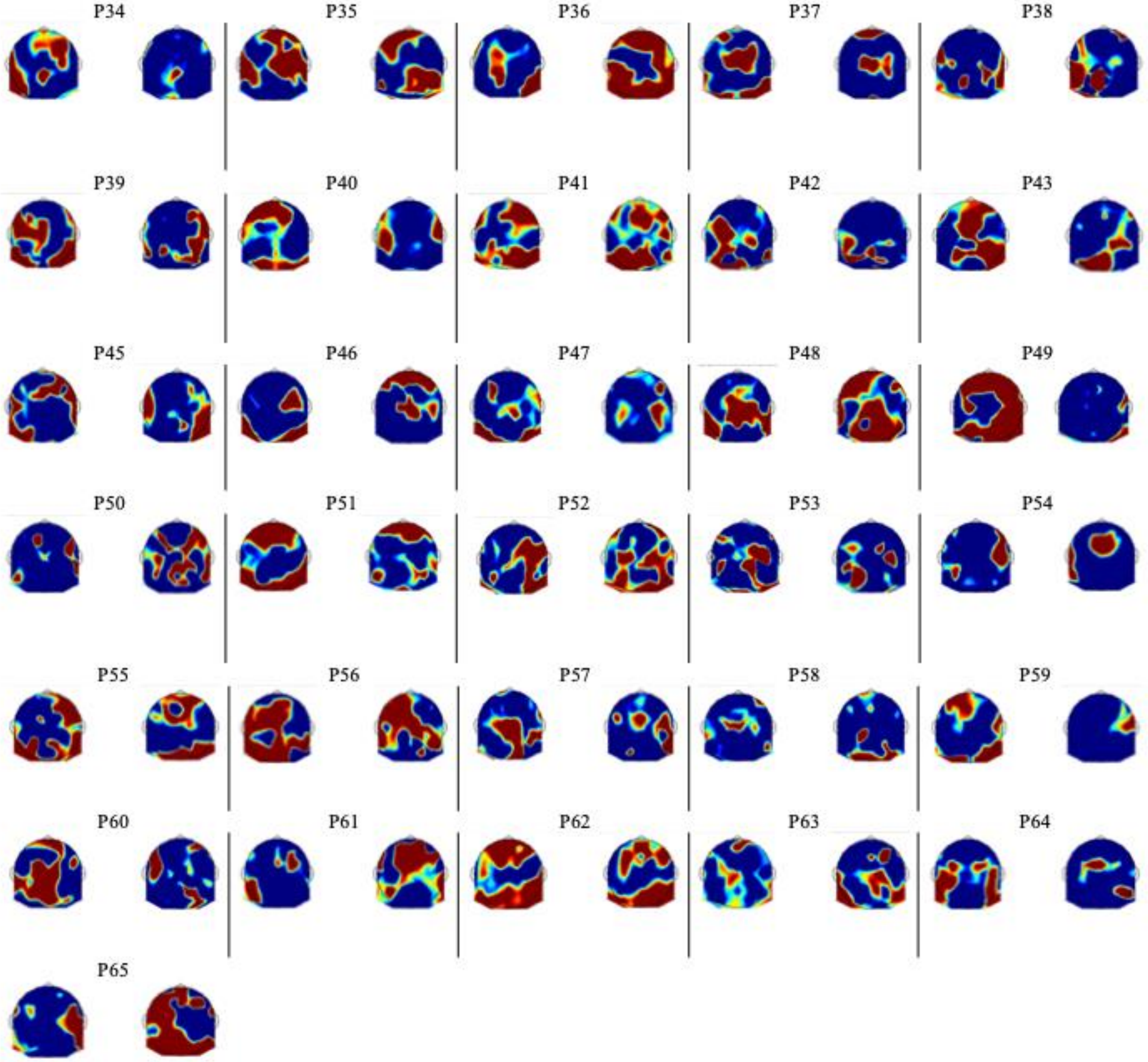
Children show neural sensitivity to facial trustworthiness as measured by fast periodic visual stimulation - Supplementary Materials

Figure S1

Individual participants’ scalp topographies for overall trustworthiness oddball response (sum of fundamental frequency and its harmonics up to the last consecutive signficant harmonic in adults – 5 Hz) for upright (left) and inverted (right) faces.



Children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Results of summing children's neural responses to highest consecutive significant harmonic in child group (2Hz)

In the main paper, we compared the significance of the summed BCAs for the adults and children using the same planned criterion (harmonics summed up until the last consecutive significant harmonic for either group, i.e. 5hz). However, given that the children's harmonics were only significant until 2Hz, as an unplanned analysis we also compared the groups based only on the highest consecutive significant harmonics for each group i.e., 5Hz for adults and 2Hz for children. We found that the summed oddball response in the upright condition for the child group was significant when harmonics were summed to 2Hz (BCA = 0.32, $Z = 4.38$, $p < .001$), but non-significant in the inverted condition (BCA = 0.04, $Z = 0.64$, $p = .261$). Adults' responses summed to 5Hz was used as the data set in the main paper, and therefore, significance of responses in the adult group is not repeated here.

To test whether there was a significant difference between adults' and children's neural responses to facial trustworthiness, we also ran a mixed ANOVA on the adults responses summed to 5Hz, and the children's responses summed to 2Hz. Group (adult vs. child) was the between-subjects factor and Face Orientation (upright vs. inverted) was the within-subjects factor. Importantly, neither the main effect of Group (F (1, 62) = 0.71, $p = .404$, $\eta^2_p = .011$) nor the interaction between Face Orientation and Group were statistically significant (F (1, 62) = 0.14, $p = .708$, $\eta^2_p = .002$). Therefore, we found no evidence of a difference between the strength of adults and children's neural responses to facial trustworthiness, and no difference in the way children and adults responded to upright versus inverted faces. In contrast, the main effect of Face Orientation was significant (F (1, 62) = 18.36, $p < .001$, $\eta^2_p = .228$). Specifically, participants showed a stronger response for upright (M = 0.28, SD = 0.44) compared to inverted faces (M = 0.03, SD = 0.24). The pattern of results of this ANOVA was identical to the mixed ANOVA in the main paper when children's responses were summed to 5Hz.

With regards to the activity in the left occipito-temporal region, when the children's response was summed to 2Hz the summed oddball response in the upright condition was significant (BCA = 0.32, $Z = 4.38$, $p < .001$), but non-significant in the inverted condition (BCA = 0.04, $Z = 0.64$, $p = .261$). Mixed ANOVA examining activity in the left occipitotemporal region with the children's response summed to 2Hz was also run. Group (adult vs. child) was the between-subjects factor and Face Orientation (upright vs. inverted) was the within-subjects factor. The analysis revealed a significant interaction effect of Face Orientation and Group (F (1, 62) = 5.36, $p = 0.024$, $\eta^2_p = 0.08$). That is, there was a greater difference between adults' responses to upright (M = 0.24, SD = 0.40) and inverted (M = 0.01, SD = 0.19) faces compared to children's responses to upright (M = 0.03, SD = 0.12) and inverted (M = -0.02, SD = 0.14) faces. There were also significant main effects of Group (F (1, 62) = 6.92, $p = .011$, $\eta^2_p = .100$) and Face Orientation F (1, 62) = 12.64, $p < .001$, $\eta^2_p = .169$), but these were subsumed by the interaction effect between these variables. While the directions of these effects are consistent with those reported in the main paper (where children's harmonics were summed to 5Hz), the main effects and interactions with the Group variable were slightly larger in the current analyses when children's harmonics were summed to 2Hz, leading to significant main effects and interactions with Group.

Individual Differences in Neural Sensitivity

As an additional exploratory analysis, given that there is increasing interest in understanding individual differences in impressions (Baccolo et al., 2021; Baccolo & Cassia, 2020; Baccolo & Macchi Cassia, 2019; Hehman et al., 2017; Hooper et al., 2018; Meconi et al., 2014; Sutherland et al., 2020; Young et al., 2015), we examined whether there was individual variation in the neural responses (with the caveat that the study was not powered for an individual differences measure). We found that there was individual variation in the neural response to trustworthiness in participants' Z-scores for upright faces (like previous work with adults; Swe et al., 2020). Specifically, in the current study, adults' upright Z-scores ranged from -1.52 to 7.82, and children's upright Z-scores ranged from -1.98 to 4.42. The range of adults' responses was comparable to that of Swe et al. (2020; -1.04 to 7.82) and had a wider range than that of the child group, though there was no significant difference in the variances in adult and child groups' Z-scores (Levene's test *F* (1, 62) = 0.00, *p* = .984). Scalp topographies for each individual participant are shown in *Figure S1* and violin plots for individual data are shown in *Figure S2* (note: data shown in *Figure S2* are the sum of baseline subtracted amplitudes, and not Z-scores).

While outside the scope of the current study, examination of individual differences would be a valuable avenue for future research using the FPVS paradigm, especially given growing evidence of individual variation in the wider trust perception literature (Baccolo & Macchi Cassia, 2019; Hehman et al., 2017; Hooper et al., 2018; Meconi et al., 2014; Sutherland et al., 2020; Young et al., 2015), and in particular, evidence of individual differences in children's trust impressions related to their emotion comprehension ability (Baccolo & Cassia, 2020), and infants' temperament (Baccolo et al., 2021). For example, extroverted children who have been to preschool, or children with siblings, may have more social experience (Blakemore & Choudhury, 2006) compared to socially anxious and shy children who seek less social interaction, and therefore accrue less experience with diverse facial appearances across the population. It would be valuable for future research to explore this idea by examining individual differences in visual sensitivity to facial trustworthiness in children because it would help us to better understand the role that individual experience plays in forming our trust impressions, and in the development of these impressions over the course of childhood (Hehman et al., 2017; Sutherland et al., 2020).

To examine whether strength of participants' baseline corrected amplitudes (BCA) was related to how trustworthy they perceived the stimulus faces to appear overall, we calculated the average overall trustworthiness ratings from the explicit trustworthiness rating task and ran a correlation between average ratings and participants' summed oddball BCAs. We did not find a significant relationship for either adults (r = .01, *p* = .967), or children (r = -.02, *p* = .896). Therefore, our sample did not reflect the significant negative correlation Swe et al. (2020) found between the explicit trustworthiness ratings and neural trustworthiness discrimination response, which suggested that in their sample, neural responses were stronger for participants who rated faces as less trustworthy overall (Swe et al., 2020). Although the relationship was not replicated in either our adult or child group, we note that neither ours nor Swe et al.'s studies were designed to examine individual differences, given that the face stimuli were specifically selected to display high or low levels of trustworthiness.

We additionally tested for an association between explicit trust ratings (difference scores between trustworthy and untrustworthy face ratings) and the baseline corrected amplitudes, but found only weak and non-significant associations (adults r = 0.16, *p* = .385; children's r = 0.28, *p* = .125). As noted above, given the explicit ratings task was included only as a manipulation check and stimuli were specifically selected to display high or low levels of trustworthiness, we did not expect the task to be sensitive enough to examine these associations effectively. Furthermore, our FVPS task was designed to look at group differences instead of individual differences. Future individual difference studies may wish to incorporate FVPS as a measure using tests tailored for sensitivity to individual differences.

Figure S2

Violin plots showing density and spread of individual participants' trustworthiness oddball responses (sum of fundamental oddball frequency and its harmonics up to the last consecutive significant harmonic in adults – 5 Hz) for both upright and inverted conditions in adult (N = 33) and child (N = 31) age groups.

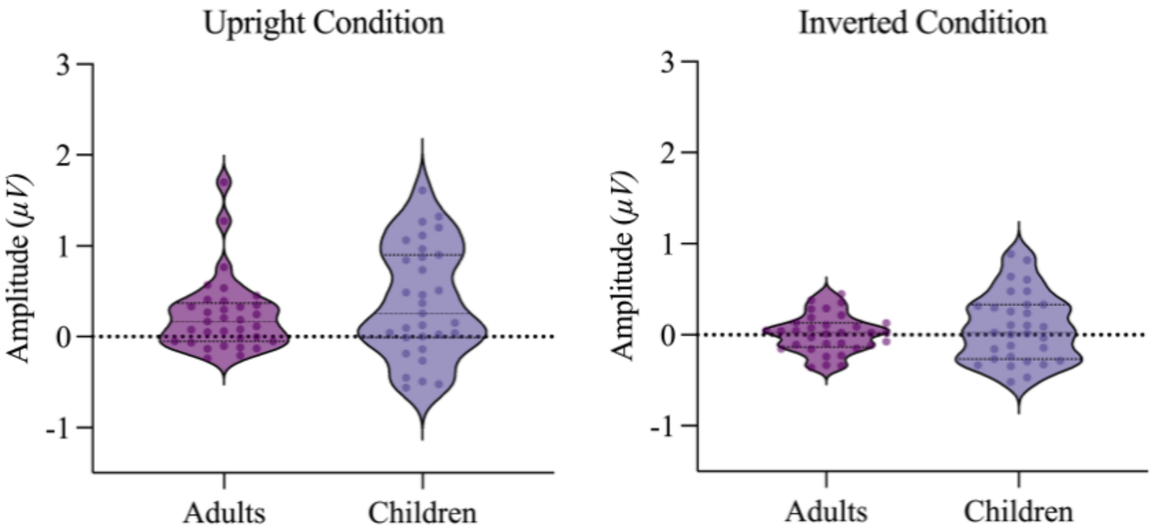


Figure S3

Scatter plots showing correlations between residuals for each block of the FPVS task. Residuals represent variance in the upright condition after controlling for the inverted condition. Plot on left shows adults' results (N = 33) and plot on right shows children's results (N = 31).

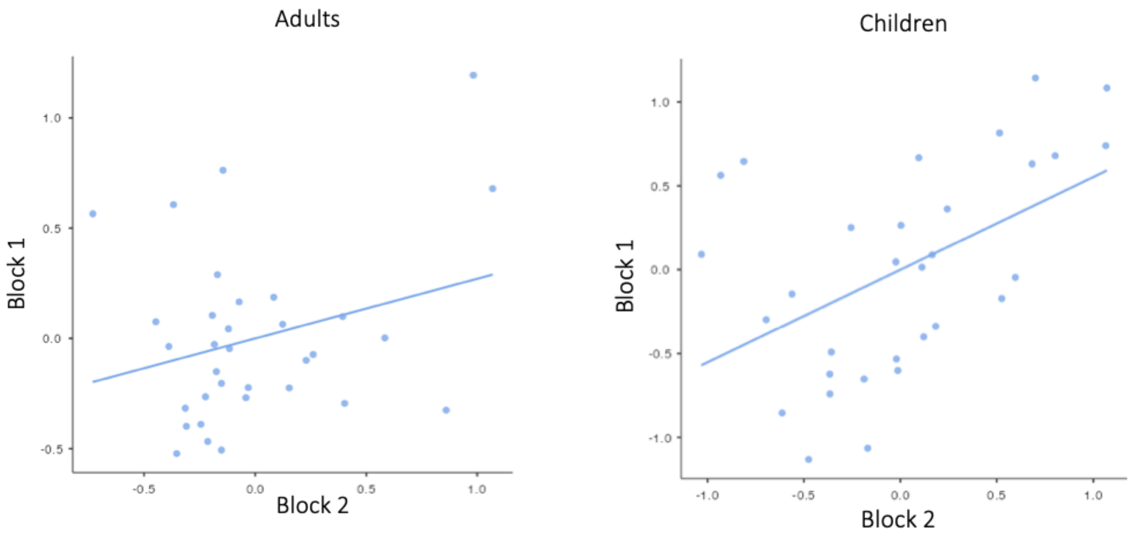


Table S1

BCA's and Z-scores for the baseline frequency (6Hz) and its harmonics (up to the eleventh harmonic) at the predetermined right occipitotemporal ROI (electrodes P8, P10, and PO8)

	Adults upright	Adults inverted	Children upright	Children inverted
	BCA (Z-score)	BCA (Z-score)	BCA (Z-score)	BCA (Z-score)
6 Hz	0.97 (112.72**)	0.80 (109.58**)	1.20 (87.53**)	1.02 (54.68**)
12 Hz	0.22 (35.44**)	0.26 (58.90**)	0.43 (49.77**)	0.45 (54.91**)
18 Hz	0.10 (30.55**)	0.09 (29.95**)	0.15 (36.56**)	0.13 (24.87**)
24 Hz	0.04 (13.70**)	0.04 (13.39**)	0.05 (11.77**)	0.06 (14.35**)
30 Hz	0.03 (10.28**)	0.03 (14.24**)	0.04 (11.89**)	0.04 (17.62**)
36 Hz	0.02 (9.91**)	0.02 (8.94**)	0.02 (7.71**)	0.02 (5.60**)
42 Hz	0.02 (8.16**)	0.01 (6.82**)	0.02 (8.14**)	0.01 (3.72**)
48 Hz	0.01 (5.92**)	0.01 (4.85**)	0.01 (4.12**)	0.01 (2.21*)
54 Hz	0.01 (6.03**)	0.02 (6.83**)	0.012 (7.15**)	0.01 (4.95**)
60 Hz	0.11 (10.18**)	0.10 (9.71**)	0.13 (10.03**)	0.13 (10.05**)
66 Hz	0.00 (1.97*)	0.00 (1.18)	0.00 (1.87)	-0.00 (-0.51)
72 Hz	0.00 (-0.19)	-0.00 (-0.63)	-0.00 (-0.67)	0.00 (0.47)

Note: ** p < .001, * p < .05 (one-tailed).

Figure S4

Baseline subtracted amplitude spectra, averaged across both trustworthy and untrustworthy oddball face stimuli at the left occipito-temporal region (electrodes P7, P9, PO9). Significant harmonics are labelled with asterisks. Activity at 6 Hz represents the non-face-selective response to the presentation of the stimuli. Panel **A** shows results for adults (N = 33) and **B** shows results for children (N = 31).

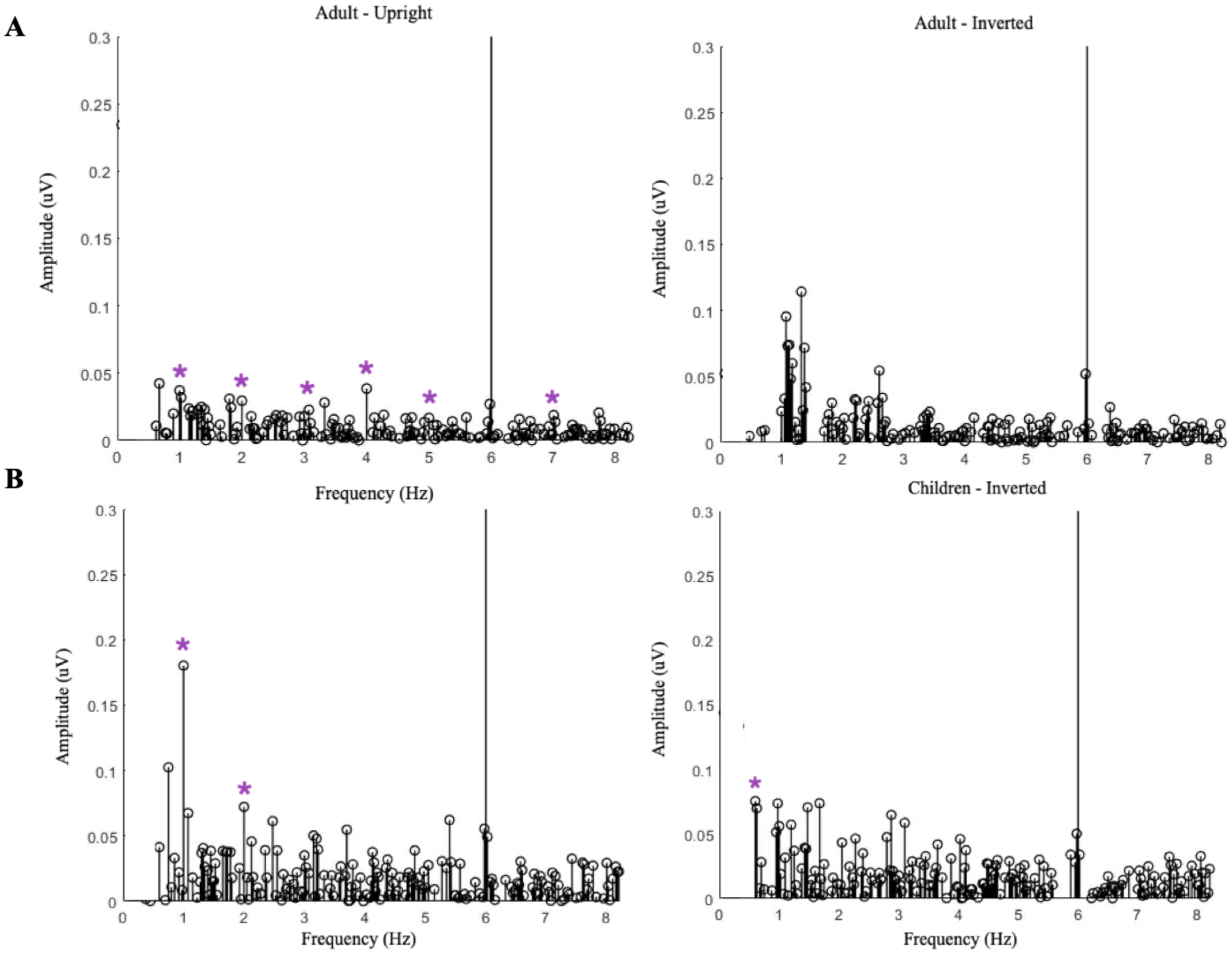


Table S2

Z-scores for fundamental frequency and harmonics (up to the eighth harmonic) at the left occipito-temporal region (electrodes P7, P9, and PO7)

		1Hz	2Hz	3Hz	4Hz	5Hz	6Hz	7Hz	8Hz
Adults (N = 33)	Upright	2.02*	2.01*	1.81*	4.24***	1.79*	82.56***	3.27***	0.69
	Inverted	0.46	0.31	0.06	0.25	-0.72	71.45***	0.49	-1.49
Children (N = 31)	Upright	4.11***	2.71**	1.27	0.49	1.30	45.72	1.12	1.81
	Inverted	1.78*	-0.23	0.39	0.47	-2.32*	48.32***	0.44	0.34

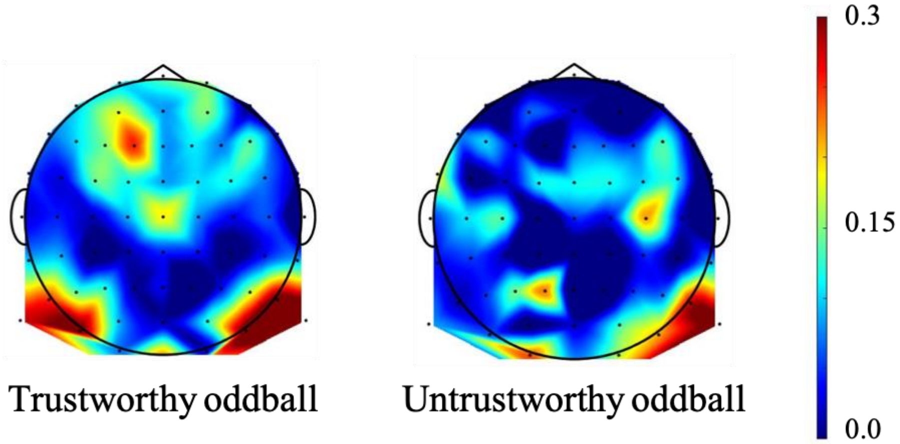
Table S3

Neural responses at the right occipito-temporal ROI at oddball frequency (1Hz) in the upright condition for adults (N = 33) and children (N = 31) when fewer numbers of trials are analyzed.

	Adults				Children			
Number of trials analysed	BCA	Z-score	p-value	Variance	BCA	Z-score	p-value	Variance
2	.042	1.333	.913	.092	.071	.552	.290	.300
3	.041	1.649	.051	.129	.215	2.446	.007	.251
4	.108	3.123	<.001	.082	.125	1.985	.024	.286
5	.066	2.246	.012	.063	.208	3.528	<.001	.183
8	.086	3.353	<.001	.052	.283	4.371	<.001	.171

Figure S5

Scalp topographies for children's (N = 31) neural response to trustworthy (left) and untrustworthy (right) oddball trials, grand averaged across child participants for upright condition.



References

Baccolo, E., & Cassia, V. M. (2020). Age-Related Differences in Sensitivity to Facial Trustworthiness: Perceptual Representation and the Role of Emotional Development. *Child Development*, *91*(5), 1529–1547. https://doi.org/10.1111/CDEV.13340

Baccolo, E., & Macchi Cassia, V. (2019). Individual differences in perceptual sensitivity and representation of facial signals of trustworthiness. *Journal of Experimental Psychology: Human Perception and Performance*, *45*(2), 224–236. https://doi.org/10.1037/xhp0000601

Baccolo, E., Quadrelli, E., & Macchi Cassia, V. (2021). Neural sensitivity to trustworthiness cues from realistic face images is associated with temperament: An electrophysiological study with 6-month-old infants. *Social Neuroscience*, *16*(6), 668–683.

Blakemore, S. J., & Choudhury, S. (2006). Development of the adolescent brain: Implications for executive function and social cognition. In *Journal of Child Psychology and Psychiatry and Allied Disciplines*. https://doi.org/10.1111/j.1469-7610.2006.01611.x

Hehman, E., Sutherland, C. A. M., Flake, J. K., & Slepian, M. L. (2017). The Unique Contributions of Perceiver and Target Characteristics in Person Perception. In *Journal of Personality and Social Psychology*.

Hooper, J. J., Sutherland, C. A. M., Ewing, L., Langdon, R., Caruana, N., Connaughton, E., Williams, N., Greenwell-Barnden, J., & Rhodes, G. (2018). Should I trust you? Autistic traits predict reduced appearance-based trust decisions. *British Journal of Psychology*, 1–18. https://doi.org/10.1111/bjop.12357

Meconi, F., Luria, R., & Sessa, P. (2014). Individual differences in anxiety predict neural measures of visual working memory for untrustworthy faces. *Social Cognitive and Affective Neuroscience*, *9*(12), 1872–1879. https://doi.org/10.1093/SCAN/NST189

Sutherland, C. A. M., Burton, N. S., Wilmer, J. B., Blokland, G. A. M., Germine, L., Palermo, R., Collova, J. R., & Rhodes, G. (2020). Individual differences in trust evaluations are shaped mostly by environments, not genes. *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1920131117

Young, S. G., Slepian, M. L., & Sacco, D. F. (2015). Sensitivity to Perceived Facial Trustworthiness Is Increased by Activating Self-Protection Motives. *Social Psychological and Personality Science*, *6*(6), 607–613. https://doi.org/10.1177/1948550615573329