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Subliminal affective priming changes the ‘feeling’ towards neutral objects in infancy

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ABSTRACT
In everyday life, our preferences are governed by influences that we are frequently not aware of. Studies investigating visual subliminal priming have shown that emotions are particularly able to modulate the affective judgments both at a behavioural and neural level. In this study, we investigated whether emotional unconscious learning is a core feature of human development, by testing infants as young as 3 months of age on a subliminal affective priming task, in which infants were primed with subliminal happy and angry faces (Experiment 1) or subliminal neutral and scrambled faces (Experiment 2), followed by two neutral objects. We found that arousal to the neutral objects – as indexed through skin conductance – changed when they were primed with faces displaying emotional valence, and particularly anger, but not when the face had a neutral expression. This change in physiological state only partially corresponded to a change in explicit behaviour – as indexed through looking times – suggesting that emotional unconscious learning likely influences explicit behaviour at later stages of development, when subcortical-to-cortical connections have strengthened.

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Subliminal affective priming; learning; development; infancy; skin conductance; emotions

Introduction

The question as to whether individuals are able to process information unconsciously has puzzled many researchers and triggered many studies, which have almost all converged in concluding that even when participants report no conscious experience of a stimulus or event, the brain may nevertheless be able to process it (Bar & Biederman, 1998; Dehaene et al., 2001, 1998).

Various empirical evidence has revealed that also information conveyed by emotional faces can be processed unconsciously: unconscious emotional faces can change judgment and behaviour (Murphy & Zajonc, 1993; Winkielman et al., 2005; J. Yang et al., 2011), and alter physiological activity, as measured with electromyography (Dimberg et al., 2000), skin conductance (Esteves et al., 1994) and functional magnetic resonance (fMRI, see Tamietto & De Gelder, 2010 for a review). Neuroimaging studies have also shown that when processing emotional faces at an unconscious level, individuals commonly recruit subcortical regions of the brain, such as the amygdala (Diano et al., 2017; J. S. Morris et al., 1998; Whalen et al., 2004), which is a core region for the control of behaviour, and is involved in emotion processing and regulation, in the discrimination of positive or negative valence of stimuli, but also in reward and motivation (see Janak & Tye, 2015 for a recent review).

Recently, developmental studies have demonstrated that the unconscious processing of emotional faces may well be a very early emerging feature of the human brain, shedding light on the possible mechanisms of emotional learning. For example, Gelskov and Kouider (2010) were the first to investigate the temporal threshold of visibility (i.e., the lowest duration at which a stimulus can be seen/reported) in preverbal infants aged 5-, 10- and 15-month-old. In their study, the authors presented two streams on the left and right side of the screen: one side depicting different female faces presented at short durations (from 50 ms to 300 ms in steps of 50 ms) followed by a mask (i.e., scrambled images of objects), the other side depicting only masks. Given the very early developing preference for faces in infants (Farroni et al., 2005; Valenza et al., 1996), the authors hypothesized that infants would look longer to the side in which the face was presented, selectively at those durations in which the face was actually detectable. On the contrary, the lowest duration at which infants looked at both sides equally, was taken as evidence of visibility threshold. The results showed that while 5-month-old infants’ visibility threshold was between 100 ms and 150 ms, 15-month-olds presented a visibility threshold at 50 ms, which was very similar to the one displayed by adults.

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More recent studies (Jessen et al., 2016; Jessen & Grossmann, 2015) investigated infants' neurophysiological responses to emotional faces (i.e., happy and fearful faces) when presented at a subliminal vs supraliminal thresholds. In particular, in the 2016 study, using a backward masking paradigm similar to the one employed by Gelskov and Kouider (2010), but presenting stimuli in a single, central stream, the authors found that 7-month-olds' pupillary responses were greater in response to happy than fearful faces, irrespective of conscious perception suggesting that early in development, emotion discrimination occurs outside conscious perception. Similarly, in an ERP study, Jessen and Grossmann (2015) found differential activity over central areas when 7-month-old infants were presented with supraliminal and subliminal happy and fearful faces, suggesting that the processing of conscious and unconscious stimuli relies on distinct neural processes that are similar to those observed in adults.

Notably, similar findings were also documented at the level of the autonomic system. By testing 3 month-old infants using skin conductance, Nava et al. (2016) assessed unconscious processing of emotional faces by adopting a two-stream backward masking technique, similar to Gelskov and Kouider (2010). In the first experiment, the authors assessed the temporal visibility threshold in 3 month-old infants for detecting happy and angry faces, which was found to correspond to 100 ms. In their second experiment, infants were presented with a single, centrally presented stream depicting a 100 ms (subliminal) or 200 ms (supraliminal) face followed by a mask and a neutral face, during which skin conductance responses were assessed. The results showed that as young as 3 months of age, infants cannot consciously detect stimuli presented at 100 ms, but their skin conductance response signaled that both happy and angry faces elicited a physiological response even outside conscious awareness.

Overall, these studies suggest that unconscious processing especially of emotional information is present very early in development.

Adult studies have shown that unconscious processing of information can influence social judgments and behavioir, that is, unconsciously perceived affective information concurrently presented with a target stimulus, changes the perceptual analyses that individuals do, to an extent that the final perception of the target stimulus is subjected to influences that the individual is unaware of. For example, Sweeny et al. (2009) presented adults with an affective prime depicting a happy, angry or fearful face for 30 ms, immediately backward-masked by a surprise face for 300 ms. Participants were asked to judge the valence of the surprised face, and results showed that not only the prime modulated the perception of the surprise face according to the type of emotional prime presented (e.g., happy primes made the participants judge the surprised face as more positive than when the prime was an angry face), but this alteration in perception lasted for 24 hours, as assessed in a follow-up conducted the day after the first experimental day. Thus, unconsciously processed emotions alter the perception of other stimuli in a long-lasting fashion. In a similar vein, Anderson et al. (2012) used the continuous flash suppression paradigm, by which participants are presented with dynamic visual images to one eye, while the other eye is presented with static images, leading to consciously experience only the dynamic image. The static, unseen image displayed either a smiling or frowning expression, while the dynamic image displayed a neutral face. The results showed that the unconscious, affective static image changed the pleasantness of the neutral face, in line with the feelings-as-information approach to affect and cognition (Clore et al., 2001), by which affect assigns value to any stimulus that appears to be causing it. Using this approach, Winkielman et al. (2005) explored the possibility that (subliminal) affect could influence the consumption of beverages in young adults: after presenting participants with images of beverages preceded by subliminal faces, participants preferred to drink more of a beverage that was previously associated with a happy than angry face, and were also more willing to pay more for a beverage after exposure to a happy than an angry face. Interestingly, these behavioural data are accompanied by neurophysiological findings too, showing that early perceptual analysis of targets, as well as evaluation and selection of targets, are affected by subliminal affective information, as observed in different studies (Boukarras et al., 2019; Li et al., 2008; Lu et al., 2011; Ponsi et al., 2017).

Despite the evidence in adults of the influence of unconscious processing of emotions on behaviour and judgment, to date, it remains still unknown whether unconscious processing of emotional faces also influences infants' everyday learning of their surrounding environment.

Thus, in this study, we aimed at investigating this issue by measuring 3–4 month-old infants' arousal through skin conductance using a subliminal affective priming paradigm, in which infants saw a neutral object primed with a positive (i.e., happy) or negative (i.e., angry) face. Furthermore, to observe whether subliminal emotional stimuli also influence conscious behavior, we measured looking times, i.e., the amount of time infants looked at the primed objects as a function of the type of facial expression associated with it.

In line with evolutionary perspectives of the role of emotions, by which threat-related information often engages privileged processing, irrespective of conscious perception (Cosmides & Tooby, 2000; J. E. LeDoux, 2012), as well as with previous studies (Nava et al., 2016), we expected infants to show more sensitivity to objects primed with angry than happy faces.

Method

Participants

A total sample of 33 infants was tested. Eight infants were excluded from the final analysis because they did not complete the task (N = 5) or because of technical problems with recording of the skin conductance (N = 3), leading to a final sample of 25 healthy and full-term infants (15 females, mean age = 112 days, range: 88–126).

Infants were recruited via a written invitation sent to parents based on birth records provided by the neighboring cities. Parental written informed consent was obtained before testing began. The protocol was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and approved by the Ethics Committee of the University of Milano-Bicocca (Italy).

Stimuli

The stimuli consisted of blue and yellow wooden bricks (5 cm x 3.5 cm), put together to form two distinct objects ('Object 1' and 'Object 2', see Figure 1). Note that the number of blue and yellow bricks was identical in the two objects and the space occupied by them was approximately identical between the two objects.

The other two stimuli consisted of a happy and angry face of the same female adult (see Figure 1), taken from the "Nim Stim Face Stimulus Set" (Tottenham et al., 2009). The two faces were placed inside an oval to hide distracting features, such as the colour of the hair and ears. They were both presented in frontal view and were matched for luminance and contrast. Finally, we created a mask that was construed by scrambling the pixels of the two faces and was placed inside an oval so that it had the same size of the faces. Faces, masks, and objects were 15 cm in height and 10 cm in width and presented on a 24-inch monitor.

Procedure

Infant were seated on their mother's lap and the experimenter placed the electrodes for skin conductance measurement on the right foot (see description of the skin conductance below). The infant was then positioned at approximately 60 cm from the computer monitor, from which s/he saw the presentation of the two objects, one after the other, for 2 times ("pre-priming phase"; total trials: 4). The presentation of each object lasted 5000 ms, followed by a 1000 ms fixation cross placed at the center of the screen (see Figure 1 for a schematic representation of the procedure).

After the familiarization of these two objects, the subliminal affective priming phase started, which consisted of a subliminal happy or angry face of the duration of 100 ms, immediately followed by a mask (100 ms) and one of the two objects (3000 ms). Note that the choice of using 100 ms-long subliminal stimuli was motivated by

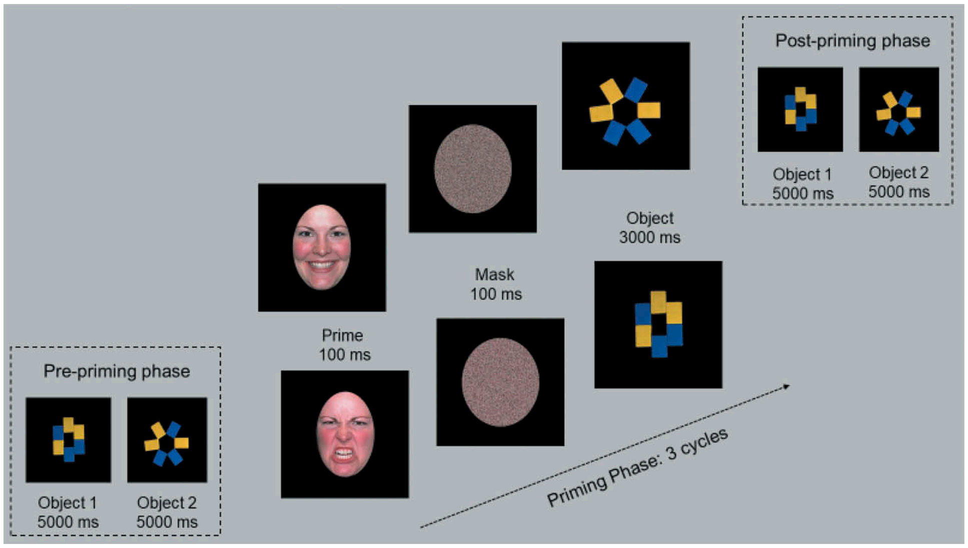

Figure 1. Schematic representation of the stimuli and procedure used in the experiment.

the fact that the same durations were also adopted in Nava et al. (2016), in which authors showed that by 3–4 month of age, infants can discriminate (consciously) emotional faces if presented at 200 ms, but not at 100 ms. This is also in line with previous studies (see Gelskov & Kouider, 2010) that have demonstrated that 5-month-old infants have face visibility thresholds around 100–150 ms.

The happy and angry face was coupled with one of the two objects throughout the cycle, and counterbalanced across infants, so that half of them saw Object 1 coupled with the happy face and Object 2 coupled with the angry face, while the other half saw Object 1 coupled with the angry face and Object 2 coupled with the happy face. The priming phase was composed of 20 trials (i.e., 10 trials with the association happy-object and 10 trials with the association angry-object), and each trial comprised three repetitions of the same event (3 cycles) and lasted approximately 10 seconds. The trials in the priming phase were semi-randomized so that infants could not see over 3 trials of the same association in a row. At the end of the priming phase, infants saw again Object 1 and 2 presented in alternation for a total of 4 trials ("post-priming phase").

Data acquisition with skin conductance

The skin conductance (SC) activity was acquired by applying two pre-gelled, self-adhesive electrodes with circular contact areas 1 cm in diameter, directly on the plantar surface of the infant's foot (heel and outer edge, see Ham & Tronick, 2008).

SC activity was recorded using an MP160 biosignal amplifier working with the specific acquisition module for skin conductance activity GSR100-C (Biopac Systems, Inc). The amplifier was connected to the computer through an optical connection. The gain parameter was set at 5 μmho/V and the signal sampled at 100 Hz. The analysis of the SC response was conducted using the AcqKnowledge Software provided by Biopac System, and the signal bandpass filtered at 0.5 Hz (lower bound) and 2.0 Hz (upper bound, Figner & Murphy, 2011).

Each epoch was measured from the onset of the trial for 8 seconds, within which we extracted the peak-to-peak value, which is the difference between the maximal and minimal value recorded in the given epoch. Artifacts produced by excessive movements of the infant were manually removed from the final data.

Looking times

Looking times were recorded throughout the experimental session through a video camera placed just above the monitor. The looking times were then offline coded, frame-by-frame, using Virtual Dub by two experimenters blind to the condition presented (i.e., they were not aware to which object the angry and happy face were associated). The mean estimate of reliability between the two coders was 0.91 (Pearson correlation, $p < 0.05$).

Skin conductance and looking times were only extracted and analyzed if infants watched at least 1000 ms of each trial.

Results

Skin conductance response

In a first analysis, we tested whether infants' SC responses to the two primed objects changed between the pre- and post-priming phase, and whether the happy or angry face modulated such change. To this aim, mean SC responses in the pre-priming and post-priming phase were entered in a repeated measures ANOVA, with Emotion (happy vs. angry face) and Phase (pre- vs. post-priming) as within-subjects factors. The analysis showed a main effect of Phase, $F(1, 24) = 8.67$, $p = 0.007$, partial $\eta^2 = 0.26$, in that SC responses appeared higher in the post-priming phase with respect to the pre-priming phase following priming to both the happy (pre-priming: $M = 0.60$, $SD = 0.50$; post-priming: $M = 0.86$, $SD = 0.66$) and angry face (pre-priming: $M = 0.60$, $SD = 0.40$; post-priming: $M = 0.90$, $SD = 0.69$, see Figure 2).

Note that SC responses did not differ between objects in the pre-priming phase ($p = 0.17$ on paired t-test), that is, the different responses to the two objects in the post-priming phase seemed not to depend on a different perception of the objects *per se*. There was also no

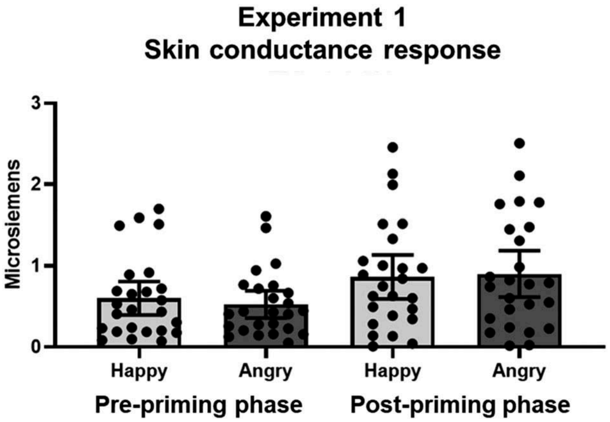

Figure 2. Distribution of mean SC responses in Experiment 1. Error bars indicate 95% confidence intervals.

difference between objects in the post-priming phase (p = 0.17 on paired t-test).

Even if we did not find any significant result in this first analysis, we conducted further regression analyses to observe whether the SC responses changed in time and whether changes in arousal during the priming phase could predict.

Because the ANOVA was run on only 4 trials for each infant, we conducted two further analyses to better explore the effects of the priming on the SC responses to the objects, and specifically to assess whether (a) infants present changes in arousal when the object is presented with its prime; (b) infants' mean SC responses to the objects primed with the happy or angry face can predict increased arousal to the object alone in the post-priming phase.

To analyze the responses within the priming phase, we first conducted a t-test between the mean SC responses to the happy and angry faces but did not find any difference (p = 0.66). Then, we conducted a linear regression analysis between the mean SC responses of the infants and Time (i.e., each single trial of the priming phase), separately for the object primed with the happy or angry face. Because SC response increases when the gland activity signaling arousal also increases, we hypothesized that a linear increment of arousal could index an increasing learning of the association between the object and the emotional face.

Linear regression analysis showed that this was the case only when objects were primed with the angry, F(1, 19) = 12.31, p = 0.003, see Figure 3, right panel) but not with the happy face, F(1, 19) = 1.66, p = 0.21 (Figure 3, left panel). Indeed, the arousal increased to about 0.023 microsiemens (unstandardized coefficients) on each trial.

To establish whether the affective subliminal priming predicts the change in arousal observed in the post-priming phase, we conducted another linear regression analysis between the mean SC response of each infant in the priming phase, and the arousal index of each object, calculated as the difference between the SC response to the object presented alone in the pre- and post-priming phase.

This analysis revealed that only objects primed with angry faces predicted higher arousal when presented alone, F(1, 24) = 6.29, p = 0.02, partial $\eta^2 = 0.21$ (see Figure 4, right panel); on the contrary, objects primed with happy faces did not alter the perception of the object when presented in the post-priming phase, F(1, 24) = 0.46, p = 0.50 (Figure 4, left panel).

Looking time analyses

To observe whether subliminal affective priming also affected looking times, i.e., a behavioural index of spontaneous preference, we performed a series of analyses on this index, similar to the ones performed with the SC responses.

First, to assess whether looking times changed between the pre- and post-priming phase, mean looking times were entered in a repeated measures ANOVA, with Emotion (happy vs. angry face) and Phase (pre- vs. post-priming) as within-subjects factors. Contrary to the physiological data, we did not find any main effect or interaction (all p > 0.10, see Figure 5 for the distribution of responses).

Note that looking times did not differ between objects in both the pre-priming and post-priming phase (both p > 0.19 on paired t-test).

Similarly, as in the analysis conducted for SC response, we conducted a t-test between mean looking times to happy and angry faces during the priming phase, which did not prove significant (p = 0.87).

In order to fully capture if there was an influence of the priming on the post-priming phase, we performed two further linear regressions to observe whether subliminal affective priming changes behaviour at a more explicit level.

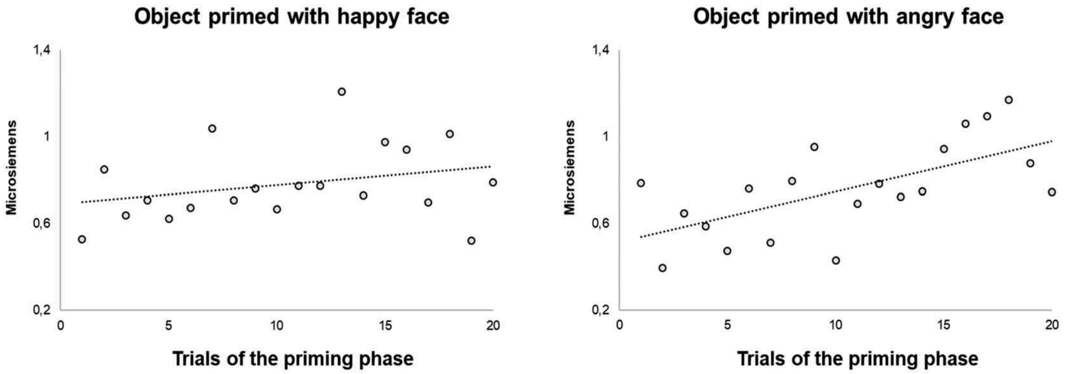

Figure 3. Objects primed with either the happy or angry face during the priming phase. Note that only the subliminal priming with angry faces significantly increased the arousal of infants throughout the priming phase.

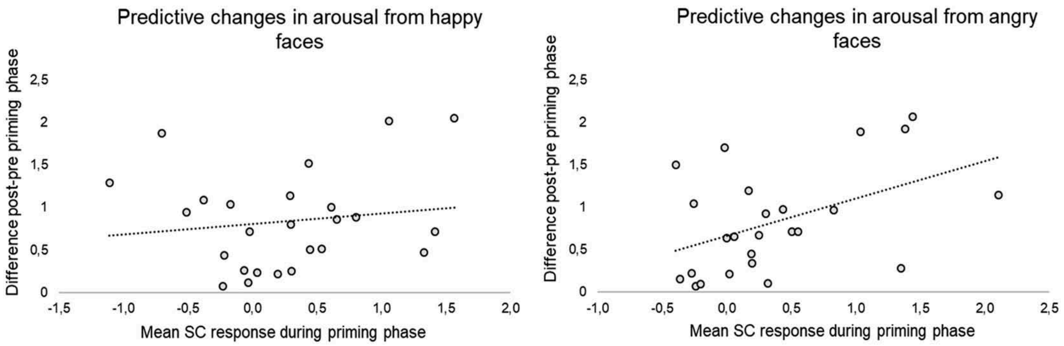

Figure 4. Changes in arousal to objects subliminally primed with either happy or angry faces. Note that only angry faces altered the arousal of infants to the object.

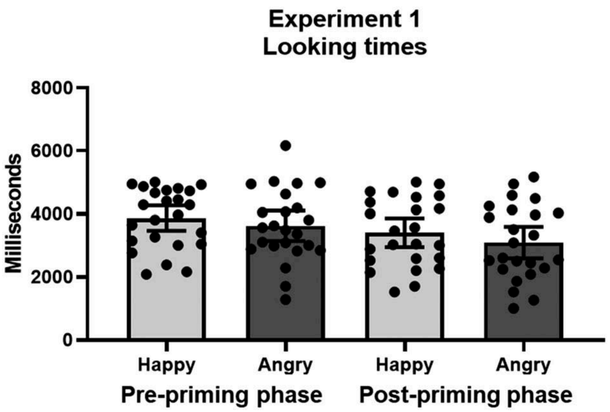

Figure 5. Distribution of looking times in Experiment 1. Error bars indicate 95% confidence intervals.

A linear regression conducted on the priming phase showed that when the object was primed with the happy face, no changes emerged, F(1, 19) = 0.71, p = 0.40. On the contrary, when primed with the angry face, looking times changed throughout the priming phase, F(1, 19) = 12.74, p = 0.002. As depicted in Figure 6, the looking times decreased throughout the priming phase by −67.69 milliseconds per trial (unstandardized coefficients); that is, infants gradually avoided looking at the object primed with the angry face.

We found no relation between the change in looking time in the priming phase and the difference between pre- and post-priming phase, irrespective of emotion (both $p > 0.50$); that is, the priming did not modulate the post-priming behavioural response.

Finally, to observe the relationship between SC responses and looking times during the priming phase, we performed a correlation between these two measures, and found a negative correlation between looking times and SC responses when the faces were angry ($R = -0.79$, $p < 0.001$, see Figure 7), but not when they were happy ($R = -0.12$, $p = 0.54$, see Figure 7).

Interim discussion

Evidence provided by the present experiment seems to indicate that both angry and happy emotions altered the arousal of infants to the neutral objects. Nevertheless, angry faces predicted more strongly than happy faces higher SC responses following subliminal priming, and they also influenced the looking times during the priming phase.

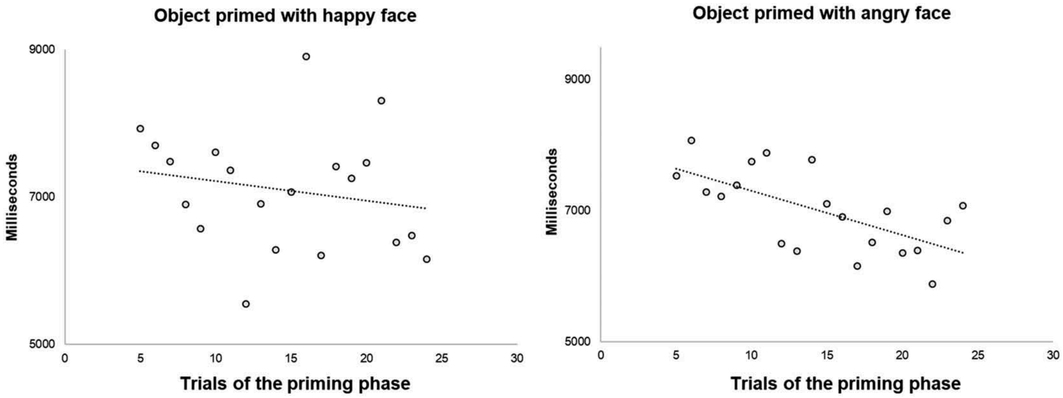

Figure 6. Subliminal priming with angry faces significantly decreased the looking times of infants throughout the priming phase. This effect was not found for subliminal priming with happy faces.

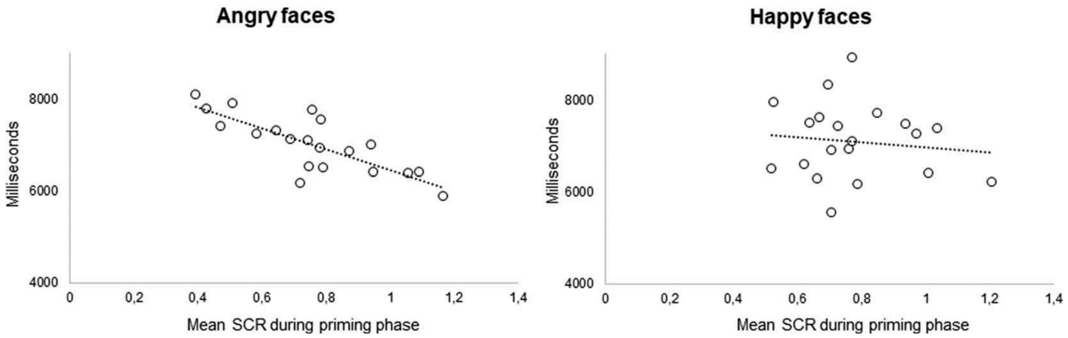

Figure 7. Correlation between SC responses and looking times during the priming phase in Experiment 1, for both angry (left panel) and happy faces (right panel).

Still, one may claim that infants' higher sensitivity to emotional faces may not be driven by the emotional content of the face stimuli but by a generally higher sensitivity to the "face" category (present in both emotional stimuli) that facilitates their learning, even if subliminal.

In order to verify this possibility, we run a second experiment with a new sample of infants of the same age as in Experiment 1, in which we used the exact same procedure, but only changed the stimuli associated with the two objects. The objects were primed with a neutral face of the same identity of Experiment 1, and a scrambled face, that we used as control stimulus to the neutral face. We hypothesized that if subliminal priming of neutral objects is modulated by faces, we would observe a modulation of SC responses following the priming phase for the neutral face but not for the scrambled face.

It is important to note that Experiment 2 also served as control for the possibility that infants' arousal may change following repeated exposure to the objects themselves, and not because of the subliminal affective priming. Indeed, if this were the case, we would observe in Experiment 2 higher SC responses in the post-priming phase similar as in Experiment 1.

Method

Participants

A new sample of 33 infants was recruited and tested in Experiment 2. Ten infants were excluded from the final analysis because they did not complete the task (N = 8) or because of technical problems with the skin conductance (N = 2), leading to a final sample of 23 healthy and full-term infants (10 females, mean age = 121 days, range: 97–132).

Infants were recruited via a written invitation sent to parents based on birth records provided by the neighboring cities. Parental written informed consent was obtained before testing began. The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki and approved by the Ethics Committee of the University of Milano-Bicocca (Italy).

Stimuli and procedure

The stimuli and procedure were identical to Experiment 1, with the following differences with respect to the stimuli (see Figure 8 for a representation of stimuli and procedure): instead of presenting two faces with emotional valence, we presented a neutral face (with same identity with respect to Experiment 1) and a scrambled face, obtained by scrambling pixel blocks with Matlab (see Figure 8 for images of the stimuli).

As in Experiment 1, the two faces were placed inside an oval to hide distracting features, presented in frontal view, interleaved by a mask, obtained by scrambling the pixels of the two stimuli. Stimuli, masks and objects were 15 cm in height and 10 cm in width and presented on a 24-inch monitor.

Results

Skin conductance response

The analyses mimicked the ones performed in Experiment 1. An ANOVA conducted on the mean SC responses in the pre- and post-priming phase showed no main effect or interaction (all $p > 0.08$). As depicted in Figure 9, though there was no difference between phases and between the neutral and scrambled face, it is worth noting that SC responses to neutral faces slightly increased between the pre- (M = 0.44, SD = 0.46) and post-priming phase (M = 0.60; SD = 0.64) in comparison to SC responses to the scrambled face (pre-priming: M = 0.38, SD = 0.39; post-priming: M = 0.48; SD = 0.45).

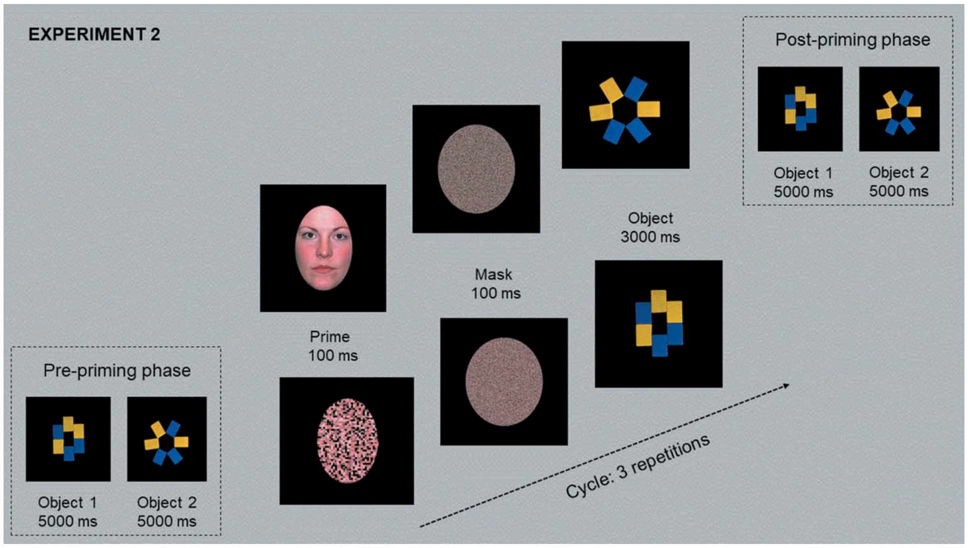

Figure 8. Schematic representation of the stimuli and procedure used in Experiment 2.

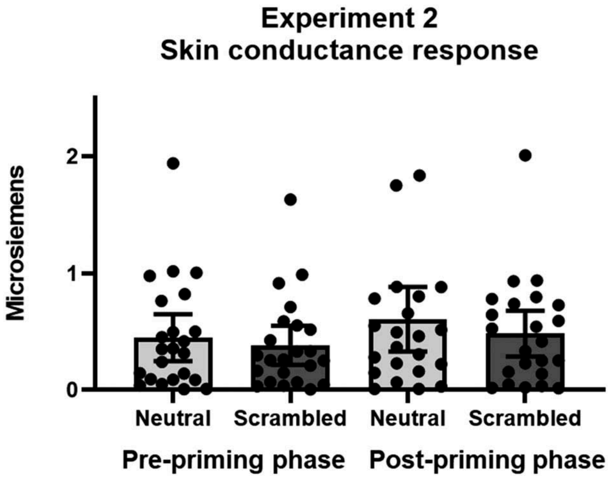

Figure 9. Distribution of mean SC responses in Experiment 2. Error bars indicate 95% confidence intervals.

Looking time analyses

ANOVA mimicked the results reported for the SC responses, as no main effect or interaction emerged (all $p > 0.09$). As depicted in Figure 10, the looking times in the pre- and post-priming phases were similar for neutral (pre-priming: M = 3810 ms, SD = 1058 ms; post-priming: M = 3329 ms, SD = 936) and scrambled faces (pre-priming: M = 3554 ms, SD = 1212 ms; post-priming: M = 3644 ms, SD = 1086).

Discussion

In this study, for the first time, we showed that infants as young as 3 months of age are influenced by subliminal affect to an extent that this can modulate their perception of neutral objects. Indeed, when presented with a (neutral) object primed with an emotionally valenced face, infants' arousal to the object itself changed. This was particularly true when the prime had negative valence (i.e., an angry face), then when it had a positive one. This novel finding represents an important extension to the results of Nava et al. (2016), in that they reveal that the unconscious processing of emotions is not limited to the presentation of the subliminal emotion itself, but can be transferred to the perception of other stimuli that do not have emotional valence themselves. The fact that we found higher arousal to the sole object (i.e., in the post-priming phase) suggests that this physiological change was likely due to associations made with the emotions during the priming phase. Indeed, if the arousal to the object was only due to carry-over effects from the emotion, they would have not lasted until the post-priming phase.

Results from Experiment 2 showed that the face alone, presented with no emotional expression, does not modulate the response to the object both at a physiological and behavioural level. It is important to note that Experiment 2 also served as control for the possibility that infants' arousal in the post-priming phase could be the result of repeated exposure to the object themselves and not the association with the subliminally presented faces. If this were the case, we would have observed in Experiment 2 higher SC responses following the priming phase; however, this was not the case, suggesting that infants can be subliminally primed, but only when an affective stimulus is present.

Interestingly, analysis performed on the changes in arousal during the priming phase showed that the

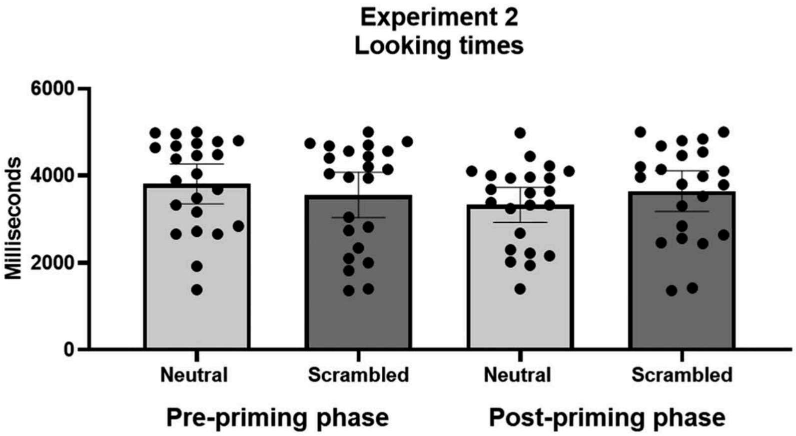

Figure 10. Mean looking times in Experiment 2. Error bars indicate standard error of the mean.

subliminal affective priming increased in time, suggesting that infants learned the association between angry face and object in a linear fashion. Alternatively, it could be that angry faces, in comparison to happy faces, may become more visible after repeated exposure, i.e., angry faces may provide a more rapid access to conscious processing. Nonetheless, as suggested by Öhman (1997), threat is processed pre-attentively, "as fast as the blink of an eye", and this basic, very fast level of mental functioning remains inaccessible to conscious awareness. While we cannot exclude that infants gradually had access to conscious processing of angry faces, it is worth noting that this specific sensitivity to negative emotions is in line with previous developmental studies, which have shown that SC responses to angry faces are higher compared to happy faces in 3–4 month-olds, irrespective of whether the stimulus was perceived inside or outside conscious awareness (Nava et al., 2016).

The fact that infants' arousal to a neutral object was modulated by a subliminally presented emotion adds an important piece of information to the notion that negative emotions can unconsciously change our perception, and that it starts very early in development. In line with evolutionary models of emotions, it could be claimed that the higher influence of negative vs positive emotions is due to their adaptive meaning. Indeed, humans may have evolved specialized neural systems that favour the processing of negative vs. positive signals without the need for conscious awareness (Williams, 2006). Thus, it may be more adaptive for the body to learn to signal higher stress when it is faced with objects that were previously perceived as potentially threatening.

Interestingly though, our data suggest that subliminal affective priming only modulated the physiological response to the neutral object but not the post-priming behavioural response, as measured with looking times. Looking times in infants commonly signal a preference toward a certain stimulus, and a decrease in looking times is used in classical habituation paradigms to assess whether infants are losing their interest in the stimulus (Oakes, 2010). This gradual lack of interest toward the stimulus is taken as an assumption that the infant has learned what type of stimuli s/he is presented with. In our study, infants did not show a change in looking time between the pre- and post-priming phase, irrespective of emotion. That is, subliminal affective priming did not modulate their preferences toward one of the objects. However, the analysis of the looking times conducted in the priming phase suggested that infants underwent more rapid learning of objects primed with the angry than the happy face, as signaled by their decrease in interest toward objects primed with angry faces. How can this lack of interest be explained? We found a negative correlation between looking times and SC responses, that is, decreasing looking time that corresponded to a gradual increase in arousal. It could be argued that, in line with adult studies, emotionally charged stimuli gain a preferential access to awareness (E. Yang et al., 2007). In this vein, it could be that infants' decrease in looking time and increase in SC response was gradually improving the awareness to the angry faces. Or, it could be that angry faces are more subjected to what is called a 'mere repeated exposure phenomenon', by which individuals' emerging preference for a specific object is only due to repeated presentation of that object, even if this occurs outside conscious awareness (Zajonc, 2001).

What are the possible mechanisms underlying the different influences of the subliminal affective priming on arousal and behaviour? Some adult studies have shown that subliminal presentation of valenced emotions can cause participants to change their behaviour or judgment towards a certain object (Murphy & Zajonc, 1993; Winkielman et al., 2005). However, this was not the case for infants. Although it is difficult to compare an adult judgment with infants' looking times, we suggest that the dissociation observed between behaviour and arousal may find its answer in how the brain develops and organises conscious and unconscious experiences. In other words, there are models of emotion processing suggesting that emotions are initially processed to a great extent in subcortical areas of the brain (J.S. Morris et al., 1999; J. E. LeDoux, 1990; Öhman et al., 2007). According to this view, particularly the amygdala does a"quick and dirty" processing of all emotionally valenced stimuli, before the information is sent to more high-order, cortical level of processing (Tamietto & De Gelder, 2010). In line with this, there appears to be a subcortical and cortical route for processing faces, the first involved in face detection, and the second one involved in face identification (De Gelder et al., 2003). Indeed, converging evidence from neuroimaging adult studies suggest that the subcortical processing precedes the cortical pathway, which activity is possible through a sustained activation in the amygdala that spreads to occipitotemporal, anterior-temporal and orbitofrontal circuits (Krolak-Salmon et al., 2004).

In newborns, face-related looking behavior appears to be mediated by a subcortical pathway (see Johnson, 2005), likely responsible for the preference for face-like stimulus that is seen in the first year of life (Valenza et al., 1996). Overall, although speculative, it could be claimed that processing of subliminal affective stimuli is not only initiated but also remains in subcortical regions of the infant's brain. Influence on overt behaviour may become more evident at later stages of development, when other circuits supporting priming mechanisms become more adult-like.

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Disclosure statement

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Author contribution

E.N. and C.T. designed the study. E.N. conducted the study and analyzed the data. E.N. wrote the paper and C.T. provided feedback.

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