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The developmental origins of subliminal face processing

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ABSTRACT

Sensitive responding to facial information is of key importance during human social interactions. Research shows that adults glean much information from another person's face without conscious perception, attesting to the robustness of face processing in the service of adaptive social functioning. Until recently, it was unclear whether such subliminal face processing is an outcome of extensive learning, resulting in adult face processing skills, or an early defining feature of human face processing. Here, we review recent research examining the early ontogeny and brain correlates of subliminal face processing, demonstrating that subliminal face processing: (1) emerges during the first year of life; (2) is multifaceted in response to transient (gaze, emotion) and stable (trustworthiness) facial cues; (3) systematically elicits frontal brain responses linked to attention allocation. The synthesized research suggests that subliminal face processing emerges early in human development and thus may play a foundational role during human social interactions. This offers a fresh look at the ontogenetic origins of unconscious face processing and informs theoretical accounts of human sociality.

1. Introduction

Sensitive responding to facial information is of key importance during human social interactions. Research with adults shows that much information from another person's face can be gleaned independent of conscious perception of the face (for review, see Axelrod et al., 2015). Such information includes assessment of variant facial features such as another person's emotional state (Tamietto and de Gelder, 2010) and gaze direction (Sato et al., 2007), but also stable facial features including character traits like trustworthiness (Stewart et al., 2012) and dominance (Stein et al., 2018). The unconscious processing of these facial cues during face-to-face interactions is thought to be vital for successfully navigating our social environment and in enabling adaptive behaviors (Tamietto and de Gelder, 2010).

Evidence for unconscious processing in adults can be observed both on the behavioral (Yang et al., 2011) and the neural level. Converging evidence from functional imaging (Freeman et al., 2014) and brain stimulation studies (Janssens et al., 2020; Jolij and Lamme, 2005) suggests that the unconscious processing of socially relevant facial information can bypass visual cortical areas and is primarily realized through subcortical processes, involving in particular the amygdala (Whalen et al., 2004). Furthermore, closely connected subcortical areas such as the insula and the hippocampus (for review, see Pessoa and Adolphs, 2010; Tamietto and de Gelder, 2010) contribute to a subcortical network involved in unconscious (facial) information processing.

While unconscious face processing has been investigated extensively in adults, its developmental origins have long eluded us. Until recently, it was unknown whether unconscious face processing is an outcome of extensive learning and development beyond infancy, or whether it is an early defining feature of human facial information processing already present in infancy. Yet, answering this question is of vital importance for a better understanding of the nature of face processing and its role for social interaction and communication in humans.

Importantly, before beginning our review of the empirical evidence from studies in infants, we need to more clearly define the notion of unconscious processing and our focus on subliminal processing and distinguish it from closely related but not identical concepts. The notion of conscious(ness) has the broadest implications and has been defined as a "reportable subjective experience" (Dehaene and Changeux, 2011); this raises an epistemic problem when investigating conscious processes in infants, who cannot provide verbal report, which could potentially differentiate between *conscious* and *unconscious* processing. From an empirical point of view, an important approach to investigate (un) conscious processing has been the use of *subliminal* compared to *supraliminal* stimulus presentation. According to this approach, some form

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Table 1
Overview of foundational studies probing face visibility thresholds, neural correlates of conscious perception of faces, and the unconscious processing of different types of facial information in infancy.

	Method	Information	Type of Stimulus	Presentation duration	Age of Infant
Gelskov and Kouider, 2010	Behavioral (preferential looking)	Face vs. Non-Face	Face, Scrambled Face	50 – 300 ms	5, 10, 15 mo
Kouider et al., 2013	EEG	Face vs. Non-Face	Face, Scrambled Face	17 – 300 ms	5, 10, 15 mo
Jessen and Grossmann, 2014	EEG	Emotion (happiness, fear), Gaze direction	Eyes	50 ms	7 mo
Jessen and Grossmann, 2015	EEG	Emotion (happiness, fear)	Face	50, 100, 500 ms	7 mo
Jessen and Grossmann, 2016b	EEG	Emotion (happiness, fear)	Eyes	50 ms	5, 7 mo
Jessen et al., 2016	Eyetracking, pupillometry	Emotion (happiness, fear)	Face	50 ms	7 mo
Nava et al., 2016	Skin conductance	Emotion (happiness, anger)	Face	100 ms	3 – 4 mo
Jessen and Grossmann, 2019	EEG	Trustworthiness	Face	50 ms	7 mo
Nava and Turati, 2020	Skin conductance	Emotion (happiness, anger)	Face	100 ms	3–4 mo

of sensory threshold (such as presentation duration but also contrast, Dehaene and Changeux, 2011) is used, below which a stimulus fails to be consciously perceived by an observer. Finally, unconscious processing can be seen as one property of *automatic* (in contrast to *effortful* or *controlled*) information processing, which is primarily defined as processing that does not require the allocation of cognitive resources (Schneider and Shiffrin, 1977). Automatic processing implies further properties beyond processing outside of conscious awareness, for instance, the independence from attention allocation (Anderson et al., 2003). For the purpose of the present review, we will focus on the processing of subliminally compared to supraliminally presented information in infancy, as one specific type of evidence for both unconscious and automatic processing in early development.

In what follows, we will review recent research examining the early ontogeny and brain correlates of subliminal face processing, providing evidence for the unconscious processing of facial information (Table 1). In particular, an emerging body of recent work with infants will be presented, demonstrating that subliminal face processing: (1) emerges during the first year of life, (2) is multifaceted in response to transient (gaze, emotion) and stable (trustworthiness) facial cues, and (3) systematically elicits frontal brain responses linked to attention allocation. The research synthesized in this review suggests that subliminal face processing emerges early in human development and may therefore play a foundational role during human social interactions.

2. What we know about face processing in infancy

Faces are among the most prominent and early developing social channels; already newborns show a preference for human faces in general (Johnson et al., 1991; Macchi Cassia et al., 2001; Turati et al., 2002), but also for specific features of faces such as direct eye gaze (Farroni et al., 2002). Recent work suggests that even prenatally, humans show a sensitivity to basic facial configurations (Reid et al., 2017), raising the possibility that a preferential orientation towards faces not only develops within the first hours after birth, but may represent a biological predisposition. In any case, the early presence of a face preference supports the notion that little to no experience is needed to detect faces.

With respect to the neural underpinnings of such early face processing abilities, most research points to a fast and coarse subcortical processing route (e.g. Johnson, 2005). It has been suggested that these early existing subcortical processing abilities pave the way for the development of more sophisticated cortical processing of face information (Morton and Johnson, 1991). The predominance of subcortical face processing in early infancy furthermore implies that early face processing might show comparable features as have been associated with adult subcortical face processing. Such features may be automaticity, and, relatedly, processing outside of conscious awareness (Tamietto and de Gelder, 2010). However, the possibility that infants process faces and facial information outside conscious awareness has only recently come into focus.

Importantly, while basic aspects of faces such as their presence and direction of gaze are detected from birth (e.g., Farroni et al., 2002; Macchi Cassia et al., 2001), the differentiation and processing of more complex features takes time to develop and depends on experience. In the second half of the first year of life, infants begin to show face discrimination abilities that are, for instance, tuned to facial cues of race (Quinn et al., 2019), emotion (Kaiser et al., 2017; Peltola et al., 2009, see below for further discussion of emotion discrimination), and trustworthiness (Jessen and Grossmann, 2016a). Moreover, the development of face processing abilities has been shown to extend beyond infancy and continue well into childhood (Batty and Taylor, 2006). Yet infancy is considered a sensitive period in the development of face processing, where experience plays a particularly important role (for recent overviews of infant face processing in general, see e.g. Johnson et al., 2015; Simion and Di Giorgio, 2015).

By the end of the first year of life, infants are able to extract a wide array of information from faces. However, most of the work discussed so far has focused on faces that were presented for at least 500 ms, which, to our current knowledge, should be sufficient for an infant to consciously perceive a face (Gelskov and Kouider, 2010; Kouider et al., 2013). This raises the questions whether such a conscious perception is necessary for face processing, or how much of this information can still be processed if faces are presented subliminally, that is, below the perceptual threshold of the infants. We will thus now discuss how to examine unconscious face processing in infants.

3. How can we probe unconscious face processing in infants?

As outlined above, research with adults supports the existence of unconscious face processing and has provided detailed insights into its neural correlates. In infants, in spite of a growing body of research on supraliminal social information processing during infancy using neuroscience methods (see Dehaene-Lambertz and Spelke, 2015; Grossmann, 2015), research on subliminal processing of social information has only just begun. This can be attributed to two specific challenges working with infants.

First, the determination of perceptual thresholds in a population that is unable to provide verbal report or follow verbal instructions proved challenging and required methodological innovation. Gelskov and Kouider's (2010) research has opened up the possibility to systematically investigate subliminal face processing by determining the face visibility thresholds for different age groups over the course of infancy. Specifically, Gelskov and Kouider (2010) used a behavioral preferential-looking paradigm in which they presented infants with faces and scrambled control stimuli side by side for varying durations. Five- and 10-month-olds showed a looking preference to faces over non-faces only for presentation durations of 150 ms and longer, which the authors interpreted as indicative of a perceptual threshold between 100 ms (the next-shortest presentation duration investigated) and 150 ms in this age group. These behavioral findings were subsequently used to identify the neural signatures of conscious face processing in a seminal study by the same research team (Kouider et al., 2013).

Using comparable face-stimuli in an EEG-paradigm, Kouider et al. (2013) observed that the late slow wave (LSW) was evoked only in response to faces presented above the perceptual threshold (supraliminal; 150 ms in 5-month-olds and 50 ms in 12- and 15-month-olds) but not seen in response to subliminally presented faces (i.e., below the before-mentioned thresholds, Gelskov and Kouider, 2010). Importantly, the work by Kouider et al. (Gelskov and Kouider, 2010; Kouider et al., 2013) has opened the door to examining subliminal face processing by providing compelling information regarding face visibility thresholds during infancy.

All studies discussed below refer to the threshold values established by Kouider et al. (Gelskov and Kouider, 2010; Kouider et al., 2013), and use face stimuli presented for 50 ms (Jessen et al., 2016; Jessen and Grossmann, 2014, 2015, 2016b) or 100 ms (Jessen and Grossmann, 2015; Nava et al., 2016) when investigating subliminal processing.

Second, it is not only behavioral approaches that are difficult to directly translate from research with adults to preverbal infants, but this also applies to neuroscience methods. In particular, studying visual information processing in awake infants using functional magnetic resonance imaging (fMRI) is difficult and its common use is unlikely (see Deen et al., 2017, for a recent exception). Electroencephalography (EEG), event-related brain potentials (ERPs) and functional near infrared spectroscopy (fNIRS) are promising methodological alternatives to study the developing infant brain at work (for review, see e.g., Gervain et al., 2011; Hoehl and Wahl, 2012; Saby and Marshall, 2012). However, these methods offer a poorer spatial resolution than fMRI, are limited to cortical processes, and thus do not provide information about responses in subcortical regions. However, subcortical regions are considered to play a predominant role in unconscious face processing (see above). Given these constraints, using EEG-based or fNIRS-based brain measures will not allow us to directly study subcortical processes which have been implicated in unconscious face processing in adults. Rather, EEG and NIRS enable us to examine connected or indirect effects on cortical processes linked to, for example, differential allocation of attention (Jessen and Grossmann, 2014, 2015).

Nevertheless, the described important advances in the study of supraliminal face processing and its neural correlates during infancy have opened the door to investigate the developmental origins of subliminal face processing.

4. What information can infants glean from subliminally presented faces?

Based on this initial research, recent studies have started to delineate the extent to which subliminal facial information is processed in infancy.

4.1. Emotional information

The most investigated aspect in this context is emotional information.

While some studies have reported a sensitivity to happy facial expressions within days after birth (Addabbo et al., 2018; Farroni et al., 2007; Rigato et al., 2011), infants typically start to show an enhanced response to negative, in particular fearful expressions, as they grow older (Bayet et al., 2017; Grossmann, 2010; Peltola et al., 2009). Most studies suggest that such a fear bias cannot be robustly observed before 7 months of age (Grossmann, 2010; Peltola et al., 2009; Xie et al., 2018), though some recent studies using dynamic stimuli and potentially more sensitive measures report a fear bias in infants as young as 3.5 months of age (Bayet et al., 2017; Heck et al., 2016). While most work regarding emotion perception in infancy focuses on the processing of fearful expressions (e.g. Bayet et al., 2017; Peltola et al., 2009; van den Boomen et al., 2019), several studies suggest that infants also show differential processing of other emotional expressions, for instance anger compared to sadness (Soken and Pick, 1999), happiness (Grossmann et al., 2007), or disgust (Ruba et al., 2017).

By seven months of age, infants reliably discriminate supraliminally presented happy and fearful expressions (Peltola et al., 2009), and a growing number of studies suggest that this is also true when the face is presented subliminally. Considering ERPs, 7-month-olds show an enhanced response to fearful faces, regardless of whether they were presented subliminally or supraliminally (Jessen and Grossmann, 2015). In this study, infants showed an effect of emotion on the Negative Component (Nc) over frontal and central electrode sites. The Nc response reflects allocation of attentional resources to a visual stimulus (Webb et al., 2005) and has been localized to the prefrontal cortex (Reynolds and Richards, 2005) as well as the posterior cingulate cortex and precuneus (Guy et al., 2016; Xie et al., 2018). The findings from Jessen and Grossmann (2015) therefore demonstrate that facial emotion discrimination occurred for both, sub- and supraliminally presented faces, and evokes brain processes linked to attention allocation, likely associated with prefrontal cortex involvement. Importantly, the observed effect on the Nc presumably reflects the influence of subliminal information processing instantiated by fast subcortical processing on later cortical processing, namely the allocation of attention.

An important question arising from the finding that infants discriminate between subliminal facial emotions was to identify what allowed infants to distinguish between fearful and happy facial expressions. One critical feature of fearful faces when compared to other facial expressions are the wide-open eyes (exposing large areas of white sclera). Indeed, previous research using fMRI with adults shows that amygdala responses are greater to fearful eye whites (large sclera) than happy eye whites (small sclera) when presented subliminally (Whalen et al., 2004).

Based on these findings with adults, Jessen and Grossmann (2014) examined infants' brain responses to fearful and happy eye whites (and eye blacks as control stimuli) when presented subliminally. This study showed that 7-month-old infants distinguish between fearful and happy eye whites, but not the polarity-inverted control stimuli (eye blacks), as reflected in a modulation in the already discussed infant ERP component, the Nc. In a follow-up study, it was shown that differential brain processing of fearful eyes at the level of the Nc was only observed at 7 months but not at 5 months of age (Jessen and Grossmann, 2016b), suggesting that subliminal emotional face processing based on information from the eyes develops between 5 and 7 months of age. This is in line with prior work using supraliminal presentations of faces, showing that fear processing develops around the same time in infancy (Peltola et al., 2009), indexing that fearful face processing undergoes development during this period in infancy.

Interestingly, evidence for the processing of subliminal facial emotions in infancy not only arises from measuring cortical brain responses but processing of subliminal information has also been linked to changes in infants' peripheral physiological responses. Happy facial expressions compared to fearful facial expressions have been shown to result in an increased pupil dilation irrespective of whether the face displaying the emotion was presented subliminally or supraliminally (Jessen et al., 2016). Pupil dilation is primarily controlled by subcortical regions, especially the locus coeruleus, which is also closely connected to the amygdala (Van Bockstaele et al., 1998). Therefore, the effect of subliminally presented facial emotions on pupil dilation described above (Jessen et al., 2016) provides indirect evidence for a role of subcortical brain region involvement in the processing of subliminal facial emotional information in infancy.

Recent studies by Nava and colleagues (Nava et al., 2016; Nava and Turati, 2020) provides further evidence to support the point that changes in infants' peripheral physiological responses are elicited by subliminally presented faces. Specifically, in this study, 3- to 4-month-old infants showed increased skin conductance responses to angry when compared to happy faces for both subliminal and supraliminal face presentations (Nava et al., 2016). Interestingly, increases in both pupil dilation and skin conductance have been attributed to activation of the sympathetic nervous system as a part of the autonomic nervous system.

However, the exact response patterns obtained in these two studies with infants are somewhat inconsistent. Specifically, Jessen et al. (2016) found an increased pupil dilation, indicative of a higher arousal, for positive compared to negative emotions, whereas Nava et al. (2016) observed an increased arousal (indicated by increased skin conductance) for negative compared to positive faces. Note, however, that the two studies investigated different age groups (3 − 4 months vs. 7 months), emotions (happy/fearful vs. happy/angry), and used a different methodology (pupil dilation vs. skin conductance response). Thus, future studies contrasting the two measures in comparable designs and age groups are warranted to further investigate the involvement of the autonomic nervous system in the processing of subliminal facial information in infants. Nevertheless, both studies point to a sensitivity of autonomic responses to subliminal emotional facial information.

4.2. Gaze information

Infants' processing of subliminal facial information extends beyond emotional cues. Similar to what is known from adults, infants process several other social cues from faces even when faces are presented subliminally (Jessen and Grossmann, 2014, 2019). For example, in response to subliminally presented images of eyes displaying direct and averted gaze, 7-month-olds show an enhanced Nc response to direct gaze when compared to averted gaze (Jessen and Grossmann, 2014). This further supports the notion that eye gaze cues play an important role in social cognitive and communicative development in infancy (Csibra and Gergely, 2009; Grossmann, 2018). In conjunction with the work discussed above, it provides evidence that by 7 months of age, infants process emotional and gaze cues independent of conscious perception.

4.3. Trustworthiness Information

The discussed emotional and gaze cues are both characterized by specific and clearly identifiable featural changes contained in the eyes (gaze is indexed by the position of the iris and pupil; fear is indexed by wide-open eyes with large sclerae). Yet adults have also been shown to unconsciously process more complex, configural facial cues, contributing to character judgments and decision-making. For example, adults judge a person as more or less trustworthy based on their facial appearance alone (Oosterhof and Todorov, 2008; Todorov et al., 2008) and process facial trustworthiness even if faces are not consciously perceived (Freeman et al., 2014; Stewart et al., 2012).

Infants at the age of 7 months have been shown to detect changes in facial trustworthiness and preferentially look at trustworthy faces when presented supraliminally (Jessen and Grossmann, 2016a). While it is unlikely that infants possess an elaborate concept of trustworthiness, they do differentiate between trustworthy and untrustworthy faces based on subtly different featural combinations (see Jessen and Grossmann, 2016a, and Jessen and Grossmann, 2019, for a discussion of potential underlying mechanisms). More recently, 7-month-old infants have also been shown to process trustworthiness from subliminally presented faces as seen in an enhanced negative slow wave response to untrustworthy faces in their ERPs (Jessen and Grossmann, 2019). In contrast to previous infant work (Jessen and Grossmann, 2014, 2015), infants' processing of subliminal facial trustworthiness was not reflected in the Nc response as found for emotion and gaze detection but seen in an ERP component linked to familiarity or memory processing (Nelson and Collins, 1991, 1992). In this context, it is important to consider that facial trustworthiness detection is based on invariant (stable) facial information rather than the variant (transient) facial information that underpins fear and gaze detection. Taken together, these findings from infants suggests that, while all three aspects (emotion, gaze, and trust) are detected from subliminally presented faces, only emotion and gaze direction directly impact infants' attention allocation.

5. Next steps: two proposed approaches of investigation

As outlined above, recent findings provide evidence for the existence of unconscious face processing in infancy, as indicated by responses to subliminally presented faces. The reviewed findings show that infants are sensitive to a number of different facial features when processing faces subliminally and this sensitivity is reflected in both cortical brain responses and peripheral autonomic responses. Considering the evidence reviewed here, subliminal processing does not appear to be the consequence of extensive learning processes over the first years of life but might represent an early-developing and important feature of facial information processing. This critically adds to the notion that humans are adapted to social life from early in ontogeny and possess social and cognitive abilities that are more sophisticated than previously thought (Tomasello, 2019). To better characterize the developmental origins of unconscious face processing we propose that investigations should be focused on two essential questions at different levels of analysis.

5.1. Developmental level

Despite the progress that has been made in studying subliminal face processing in infants, it remains largely unknown when exactly subliminal social and facial information processing comes online and how it relates to the development of supraliminal face processing. There is only one existing study to date showing that there is a developmental change between 5 and 7 months that enables 7-month-old infants to process subliminal fearful eyes (Jessen and Grossmann, 2016b), which occurs at a similar age as when supraliminal fearful face processing emerges in infancy (Peltola et al., 2009). However, it is unclear whether this developmental change reflects the general onset of subliminal face processing at around 7 months or whether this effect is specific to emotion processing and the processing of other social cues such as gaze from subliminal faces emerges earlier in infancy. It is thus important to extend existing work by systematically mapping subliminal face processing abilities for different facial information across age during infancy. By comparing different age groups, potentially different developmental trajectories for different features can be assessed and directly compared to findings from supraliminal face processing.

Furthermore, as alluded to above, due to methodological constraints, it is difficult to investigate subcortical responses in infants and the existing work primarily relies on cortical (ERP) measures. Thus, the possibility cannot be ruled out that even before 7 months of age, infants show differentiation at the subcortical level as seen in adults (Whalen et al., 2004). It therefore appears critical to examine the developmental emergence of subliminal face processing and whether it precedes or follows the discrimination of supraliminal faces by testing across ages in infancy and including different facial cues.

Whichever develops first might be a fundamental prerequisite and provide the basis for the development of the other. Alternatively, both may rely on fundamentally distinct processes, which are only linked later in life. Subliminal processing may for instance be rooted in an automatic detection of diagnostic cues (such as wide open eye, indicating fear, or symmetry of the pupil in the eye, indicating direct gaze), whereas supraliminal processing may be the result of extensive experience with faces and elaborate learning of facial features (see next point). A temporally synchronized development in contrast might point to shared neural structures and common mechanisms.

Importantly, experience with faces, especially with different facial expression, is likely necessary for both, sub- and supraliminal processing of complex features. However, little is known about how much experience with emotional expressions infants actually have at which point in development and how variance in experience might contribute to variance in emotion discrimination ability (see e.g., Campos et al., 2000; de Haan et al., 2004; Quinn et al., 2019). Future studies systematically assessing infants' experience with different types of faces are clearly warranted to determine a potentially different impact on the processing of sub- and supraliminal information.

Relatedly, it is also of interest whether the development of subliminal face processing follows the same developmental trajectory in all infants, or whether it is subject to interindividual differences (see Jessen and Grossmann, 2015, who report an impact of individual variability on perceptual sensitivity on brain responses to subliminal emotions in infants). Future research identifying potential influences of genetic, experiential, or epigenetic factors will improve our understanding of the developmental processes involved in the emergence of subliminal face processing. Furthermore, interindividual differences in physical development (such as development of visual contrast sensitivity, Peterzell, 1993) might impact sub- and supraliminal face processing differently and should be considered in future studies.

Finally, a closer look at individual differences might be fruitfully extended into the clinical realm. Several neurodevelopmental disorders such as autism spectrum disorder (ASD) are characterized by difficulties in social functioning and behavior, which can only be diagnosed beyond infancy. Examining individual variability in the processing of subliminal social (facial) information in infancy might represent a way to detect variability in implicit social perceptual processes from early in ontogeny. In prior work, adult participants with ASD have been shown to exhibit deficits in conscious as well as unconscious emotional face processing (Prehn-Kristensen et al., 2019; Vukusic et al., 2017). Critically, recent work shows that young children (2–5 years) affected by ASD display impaired subliminal (but not supraliminal) processing of emotional face information as measured through pupil dilation (Nuske et al., 2014). It would therefore be useful to investigate whether similar selective effects on subliminal emotional face processing can be observed at an even earlier age during infancy. More generally, mapping variability in subliminal face processing during infancy promises to shed light on the developmental importance of automatic social perception and cognition.

5.2. Perceptual-cognitive Level

To arrive at a better understanding of subliminal face processing in infancy, there are at least two related questions that need to be systematically addressed: (1) what types of information do infants detect from subliminal faces; and (2) how does this detection impact cognitive processes such as attention allocation, memory, or decision making. We will address both questions in turn.

As seen for supraliminal face processing, different types of information can be gleaned from different features of the faces. While the eye region plays a prominent role in the detection of salient cues such as fear and gaze direction, other aspects of facial information, such as facial trustworthiness, likely require a more holistic processing of face information. In addition to these three features – emotion, gaze, trustworthiness – a number of other facial characteristics might be processed on an unconscious level, including familiarity, gender, and race, which are known to be processed subliminally (unconsciously) in adults (Gobbini et al., 2013; Khalid et al., 2013; Yuan et al., 2017). Assessing to what degree these kinds of information are processed based on subliminal faces in infancy is crucial also because developmental changes have been observed for supraliminal face processing during infancy. For example, the emergence of the own-race bias, the fear bias and a shift from a familiarity to a novelty preference have all been observed during the second half of the first year (see e.g., Jessen and Grossmann, 2016b; Quinn et al., 2019; Reynolds and Roth, 2018). An unconscious, subliminal detection of these kinds of facial information might precede a shift in conscious, supraliminal processing. Such a pattern is for example suggested by work demonstrating peripheral responses to subliminal emotional faces at 3–4 months of age (Nava et al., 2016), which occurs earlier than when discrimination of supraliminal emotional faces is typically seen in infancy (Peltola et al., 2009).

While most work on supraliminal emotion processing in infancy, as well as the previously discussed work on subliminal emotion processing, focuses on the processing of fear, it should be noted that infants can also detect other emotional expressions, including anger (Grossmann et al., 2007), sadness (Soken and Pick, 1999), and disgust (Ruba et al., 2017). Furthermore, while fearful (or generally threatening) expressions are also the most extensively investigated emotional expressions in adult research on subliminal processing (Tamietto and de Gelder, 2010), more recent studies suggest that subliminal processing in adults is not limited to threat signals (Smith, 2012). Therefore, future studies should address the question to what degree emotions other than fear are processed subliminally in early development.

With respect to the subliminal processing of facial emotions but also facial trustworthiness, it is also unclear to what degree infants possess some conceptual understanding of the relevant categories. The same holds true for most studies investigating the processing of supraliminal facial information (see Ruba and Repacholi, 2019, for a recent overview). Again, future studies are clearly needed to shed light on the question of how infants interpret the information contained in faces and whether this understanding goes beyond mere discrimination as examined in most current studies.

Another important question is to what degree subliminal facial information impacts cognitive processes such as attention, memory and decision-making. For instance, in adults, subliminal priming studies suggest that subliminally presented faces influence the processing of subsequent information; the affective judgment of a priori neutral objects can be biased by preceding subliminal emotional faces (e.g., Almeida et al., 2013) and subliminal emotional information can impact memory processes (e.g., Yang et al., 2011). A similar impact on cognitive (or evaluative) processes in infancy would provide evidence for the functional integration of subliminal information early in ontogeny. To date, the existing evidence points to an impact of subliminal facial information on at least one cognitive process, namely attention allocation, as reflected in the infant Nc response (Jessen and Grossmann, 2014, 2015). Future studies will have to show whether this also holds for more complex socio-cognitive processes such as overtly displayed behavioral preferences or decision-making processes. Importantly, a more comprehensive assessment of the influence subliminal stimuli might have on subsequent processes such as attention allocation could provide further evidence for the relevance of subliminal processing on the development of early social skills. If, for instance, subliminal gaze cues can elicit allocation of attention to the cued location, as has been suggested for adults (Greene et al., 2009; Hietanen et al., 2006), such a mechanism might facilitate the development of joint attention skills.

Furthermore, a better understanding of the brain mechanisms underlying unconscious processing in infancy may shed light on the involvement of different perceptual and cognitive processes. While adult work suggests that unconscious processing relies heavily on subcortical structures, activations in these structures are difficult to measure with the neuroscientific methods commonly used in infancy research. Prior research suggests a prominent role of subcortical processing routes for face processing in early infancy (Johnson, 2005), but it remains difficult to directly access subcortical activations to specific stimuli in infants. One viable approach to tackle this limitation is to rely on indirect peripheral measures. This can be peripheral measures such as pupil dilation (Jessen et al., 2016) or skin conductance (Nava et al., 2016), which index the involvement of the sympathetic autonomic nervous system and subcortical areas (Laeng et al., 2012). The combined use of such measures can provide at least initial evidence for the involvement of subcortical regions similar to what has been seen in adults.

Finally, the question arises whether the subliminal processing of social information in infancy is specific to faces or whether it extends to other types of social information. For example, unconscious processing of body expressions has been documented in adults (see e.g., Tamietto et al., 2009). Yet, while infants around the age of 8 months reliably detect emotional body expression from point-light displays and body posture during supraliminal presentation (see e.g., Missana et al., 2014; Rajhans et al., 2016), it is unclear whether they differentiate subliminal emotional body expressions.

6. Conclusion

Infants show evidence for the processing of subliminal facial information on multiple levels, including transient cues characterized by dynamic changes of facial features such as seen for emotional expressions and direction of gaze but also for stable features characterized by differences in the holistic appearance of faces as seen for trustworthiness. The finding that such processes can be observed already within the first year of postnatal life suggests that a) only little exposure and social learning is necessary for these processes to emerge and b) it may be a crucial feature of early social interactions, which guides learning and behavior.

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