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Developmental changes in the critical information used for facial expression processing

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ABSTRACT

Facial expression recognition skills are known to improve across childhood and adolescence, but the mechanisms driving the development of these important social abilities remain unclear. This study investigates directly whether there are qualitative differences in child and adult processing strategies for these emotional stimuli. With a novel adaptation of the Bubbles reverse-correlation paradigm (Gosselin & Schyns, 2001), we added noise to expressive face stimuli and presented sub-sets of randomly sampled information from each image at different locations and spatial frequency bands across experimental trials. Results from our large developmental sample: 71 young children (6 –9 years), 69 older children (10–13 years) and 54 adults, uniquely reveal profiles of strategic information-use for categorisations of fear, sadness, happiness and anger at all ages. All three groups relied upon a distinct set of key facial features for each of these expressions, with fine-tuning of this diagnostic information (features and spatial frequency) observed across developmental time. Reported variability in the developmental trajectories for different emotional expressions is consistent with the notion of functional links between the refinement of information-use and processing ability.

1. Introduction

The ability to interpret emotional signals in faces critically facilitates interpersonal interactions by helping us understand and respond appropriately to those around us. This capacity is observable from early infancy, with generalized discrimination of facial expressions from at least 6–7 months (de Haan & Nelson, 1997; Walker-Andrews, 1997), yet these early skills are far from adult-like (Widen, 2013). Facial expression recognition abilities improve across childhood and adolescence (e.g., De Sonneville et al., 2002; Gao & Maurer, 2009; Herba & Phillips, 2004), particularly for complex and subtle expressions (Johnston, Kaufman, Bajic, & Sercombe, 2011; Thomas, Graham, & LaBar, 2007), with different developmental trajectories observed for different emotions (e.g., Lawrence, Campbell, & Skuse, 2015; Rodger, Vizioli, Ouyang, & Caldara, 2015).

The mechanisms driving the development of these abilities remain unclear. As in the face *identification* literature, debate continues as to whether improvements in *expression* processing reflect broad or face-selective development. Some propose that face-processing mechanisms are mature qualitatively (and perhaps quantitatively, Crookes & Robbins, 2014) as young as 3–6 years and any development improvement reflects broader perceptual and cognitive change, e.g., concentration, spatial attention and meta-memory (Crookes & McKone, 2009; McKone, Crookes, Jeffery, & Dilks, 2012). Consistent with this account, hallmarks of specialist face processing are observed in the youngest ages tested, e.g., configural/holistic processing (de Heering, Houthuys, & Rossion, 2007; Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007), adaptive norm-based coding (Burton, Jeffery, Skinner, Benton, & Rhodes, 2013; Jeffery et al., 2010). Rival proponents of face-selective development highlight structural and functional change in brain regions associated with expression processing across childhood, e.g., pre-frontal cortex, amygdala, fusiform gyrus (Golorai, Liberman, Yoon, & Grill-Spector, 2010; Kanwisher, McDermott, & Chun, 1997; Lobaugh, Gibson, & Taylor, 2006; Thomas et al., 2001) and EEG variability in neural sensitivity to emotional expressions in children, adolescents and adults (Batty & Taylor, 2006). Still, finding clear qualitative developmental

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differences has proven challenging (see McKone et al., 2012 for a review).

In adults, computational models and empirical studies employing reverse-correlation approaches have revealed that a complex, distinctive pattern of *information-use* underlies facial expression processing (e.g., Dailey, Cottrell, Padgett, & Adolphs, 2002; Susskind, Littlewort, Bartlett, Movellan, & Anderson, 2007). Correct categorisations of basic facial expressions are characterised by a critical or 'diagnostic' subset of visual information that differs across emotions (e.g., furrowed brow for anger, wide-open eyes for fear) and may be optimized to disambiguate these categories (Smith, Cottrell, Gosselin, & Schyns, 2005).

Little is known about the information that children use to categorise facial expressions and crucially, whether they show the hallmark adult sensitivity to available information and associated flexibility in information-use across emotions. Refinement of information-use with age and face experience may account for improved processing ability by helping children learn to focus on the most reliable cues for their judgments (Johnston et al., 2011). Preliminary (but contradictory) evidence indeed suggests developmental differences in information-use. Pollux, Hall, and Guo (2014) reported that adults are more biased than 8–9 year olds to look at the eye region during a free-viewing expression categorisation task. However, Karayanidisa, Kellya, Chapmana, Mayes, and Johnston (2009) reported that the value of the mouth region increased significantly with age for 5–12 year olds during a 'feature selection' style expression-categorisation task. As with adults, it is unlikely that simplistic accounts of information-use (e.g., eyes vs. mouth, upper face vs. lower face) that fail to consider the variable importance of different features for different emotion categories can fully characterise qualitative changes over developmental time.

Differences in children's reliance upon information from across the range of spatial frequencies (SF) could also contribute to their outcomes (relative to adults) on face tasks. For adults, the mid-band (8–25 cycles per face) provides the optimal information for judgments of face identity (Costen, Parker, & Craw, 1994, 1996; Näsänen, 1999; Ruiz-Soler & Beltran, 2006) and expression, although the specific diagnostic spectra may vary with emotion category (Smith & Schyns, 2009) and task particulars (Smith & Merlusca, 2014). To our knowledge, only two studies have investigated SF biases in children's expression processing, with contrasting results. Deruelle and Fagot (2005) used the hybrid faces technique to explore how 5–8 year olds and adults extract emotion and gender information from low- and high-passed faces (no mid-band condition). They revealed that all three groups relied on high SF more than low SF information for expression categorisations (smile vs. grimace) with the reverse profile for gender categorisations. The second SF study assessed the drop-off in contrast thresholds associated with adding low-, mid- and high-SF noise to expressive faces in 10-year-olds, 14-year-olds and adults (Gao & Maurer, 2011). All three groups relied heavily upon mid- and low-SF information to perform emotion categorisations, with the key developmental difference being a need for greater contrast in the younger samples to counter the added noise. A crucial need remains for further developmental investigations of SF biases in facial expression categorisation.

The Bubbles paradigm (Gosselin & Schyns, 2001) provides an elegant methodology to characterise the SF specific information used by children to categorise facial expressions. This reverse-correlation technique pinpoints the most critical information for categorical judgments by presenting sub-sets of visual information via randomly positioned apertures ('Bubbles'), at different locations and spatial frequencies. Reverse-correlating categorisation performance (correct vs. incorrect) with the information presented allows researchers to establish the critical SF-specific visual information driving performance.

Hitherto the Bubbles technique has predominantly been used with adults (cf., Humphreys, Gosselin, Schyns, & Johnson, 2006), in part because bias-free, comprehensive sampling of a stimulus requires a considerable number of trials. Here, by testing a large number of participants over a relatively small number of trials we are able to provide the first full developmental characterisation of information-use for expression judgments. We tested two groups of children: young (6–9 years) and older (10–13 years), to encompass age ranges where changes in expression-processing ability occur for four basic expressions: fear, sadness, happiness, anger (Gao & Maurer, 2009; Rodger et al., 2015), and compared their performance to that of adults.

The diagnostic information for a particular categorisation is said to represent a bridge between the visual information that is useful for making the categorisation (termed "available information") and internal representations of that category in memory ("represented information", Gosselin & Schyns, 2002; Schyns & Oliva, 1997). This framework predicts that observers will not encode the same information across all contexts, but rather change their strategy as a function of their current task. Emotion categorisation in adults shows exactly this, with behavioural (Smith & Merlusca, 2014; Smith et al., 2005) and neural evidence (Schyns, Petro, & Smith, 2007, 2009) supporting encoding of emotion-specific diagnostic information from the earliest stages (170 ms post stimulus onset). The small amount of developmental evidence available (e.g., Deruelle & Fagot, 2005) points possibly to a similarly variable and strategic processing strategy in children. Our study tests directly whether children draw upon a fixed or varied set of facial features for their categorisations across emotions.

To the extent that a small number of facial expressions might be critically adaptive for successful development (e.g., happiness as a cue to approval and a guide to learning, Wu, Gopnik, Richardson, & Kirkham, 2011) and for survival (e.g., fear as a cue to danger, Tamietto & de Gelder, 2010), we might expect that even young children will process these particular emotional expressions in a sophisticated and potentially adult-like manner. For example, we predict that children, like adults, will make use of the mouth region across SF bands for happiness, (Smith et al., 2005). For fearful faces, we expect children to make use of the wide-open eyes, an important visual cue that is sufficient to activate the amygdala even when presented subliminally (Breiter et al., 1996; Whalen et al., 1998). This cue has important functions for the sender (faster saccadic reaction times, increased field of view, Susskind et al., 2008), making it a consistent, reliable cue.

Predictions regarding information-use for judgments of sad and angry expressions are less obvious. Some studies report that sensitivity to these expressions develops gradually (Gao & Maurer, 2009; Rodger et al., 2015), which could signal idiosyncratic information-use profiles that become increasingly adult-like with age. Critically, however, other studies have identified little or no developmental change in accuracy for recognition of sadness or anger (Lawrence et al., 2015). Thus it remains an empirical question whether information-use in young and older children will resemble that of adults for these expressions.

2. Methods

2.1. Participant information

Participants comprised 54 adults (18–43 years, $M = 26.6$, $SD = 5.0$; 16 males), 71 6–9-year-olds ($M = 8.5$, $SD = 0.9$; 35 males, hereafter 'young children') and 69 10–13-year-olds ($M = 11.3$, $SD = 0.8$; 37 males, hereafter 'older children'). An additional 1 adult, 21 young children and 13 older children were excluded due to poor performance on the emotion categorisation task