CHILDREN'S PERCEPTION OF FACIAL EXPRESSIONS

DEVELOPMENTAL CHANGES

IN

CHILDREN'S PERCEPTION OF FACIAL EXPRESSIONS

By

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Preface

This thesis is in part comprised of four manuscript chapters (Chapters 2-5). The research in Chapter 2 has been published in *Journal of Experimental Child Psychology*, with Daphne Maurer as a co-author. The research in Chapter 4 has been published in *Journal of Experimental Child Psychology*, with Daphne Maurer (second author) and Mayu Nishimura (third author) as co-authors. The two published chapters have been reprinted with permissions from the copyright owner Elsevier and from the co-authors. The research in Chapter 3 has been written as a manuscript and submitted to *Journal of Experimental Child Psychology* with Daphne Maurer as a co-author. The research in Chapter 5 has been written as a manuscript and submitted to *Vision Research* with Daphne Maurer as a co-author. For all these chapters, I took the major responsibility for all aspects of the studies including formulating the questions, creating the stimuli, designing and programming the experiments, testing the participants, analyzing the data, and preparing the manuscripts for publication. My supervisor, Daphne Maurer, is a co-author on all manuscripts in recognition of her helpful comments and insights throughout all stages of the studies. Mayu Nishimura is a co-author on the manuscript described in Chapter 4. She was involved in designing the experiment, analyzing the data, and interpreting the results.

Abstract

The ability to recognize facial expressions facilitates social interactions. In my Ph.D. thesis, I took three approaches to compare the sensitivity of adults and children aged 5 to 14 years to the six basic facial expressions: 1) the influence of intensity on the recognition of facial expressions; 2) the perceived similarities among facial expressions; and 3) the selective use of spatial frequency information in recognizing facial expressions. Collectively, these studies reveal different developmental trajectories for different expressions, with sensitivity to happy expressions already adult-like at age 5, but changes for some negative expressions continuing even past age 10. The slow development of adult-like proficiency with negative expressions may lead children to make errors in judging the intentions of others.

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Chapter 1

Introduction

The ability to recognize facial expressions quickly and accurately facilitates our inferences about other people's feelings, thereby guiding our social behaviour. Regardless of culture, the facial expressions associated with the six basic emotions (happiness, sadness, fear, surprise, disgust, and anger) are recognized by adults (e.g., Ekman, 1993; Ekman & Friesen, 1971; Ekman, et. al., 1987; Izard, 1971; Etcoff & Magee, 1992). However, the degree of universality is still open to debate (Ekman, 1994; Izard, 1994; Russell, 1994; 1995). Russell (1994) pointed out several methodological limitations (e.g., forced choice format, within-subject design, posed facial expressions, etc.) in the previous cross-cultural studies of the recognition of facial expressions that may have led to an overestimation of the degree of cross-cultural agreement. Nevertheless, a recent meta-analysis (Elfenbein & Ambaby, 2002) demonstrated that these six basic emotional expressions are recognized across cultural boundaries at levels significantly greater than chance: after correction for guessing, the mean accuracy across all emotion categories was 58%, and only 5 out of the 162 studies reported chance level accuracy. However, this meta-analysis also demonstrated that cultural differences can modulate the recognition of facial expressions. Adults are on average 9.3% more accurate in judging facial expressions of posers from the same cultural group than posers from other cultural groups. This in-group advantage is smaller for groups with greater exposure to each other. For cultural groups that live together, people from the minority groups are more accurate in recognizing the emotional facial expressions of the majority group members than vise versa. Therefore, while the recognition of the six basic emotions seems universal, cultural differences do exist. In the following chapters of this thesis, I will be presenting studies conducted at McMaster University, Canada, where the majority of the participants were North American Caucasian.

Although adults accurately recognize the six basic emotional facial expressions, it takes a remarkably long time for children to reach adult levels of speed and accuracy in recognizing facial expressions. This thesis investigated developmental changes in children's ability to recognize facial expressions between age 5 and 14. In the studies reported in Chapters 2 and 3, I examined children's thresholds to discriminate expressions from neutral and rates of misidentifications among facial expressions. To do so, I used facial expressions of the six basic emotions with 20 intensity levels that cover subtle, intermediate, and extreme versions of each facial expression. In the studies reported in Chapter 4, I mapped the perceptual structure of facial expressions from judgments of similarity among facial expressions using multidimensional scaling and compared the structures between children and adults. In the studies reported in Chapter 5, I used a noise masking paradigm to compare spatial frequency tuning in the recognition of facial expressions and facial identity in children and adults.

Sensitivity to facial expressions with varying intensities

A long developmental course

Sensitivity to the six basic emotional facial expressions emerges early in life. Infants just 1-4 days old look longer at a happy face than at a fearful face (Farroni, Menon, Rigato, & Johnson, 2007). By 6-7 months of age, infants categorize surprised expressions across different individual faces and discriminate surprise from happy (Caron, Caron, & Myers, 1982) and anger (Serrano, Iglesias, & Loeches, 1992) expressions. Around the same age (7 months), infants categorize fearful expressions across different individual faces, look longer at such fearful faces than happy faces, and disengage attention more slowly from intense fearful faces than from neutral or happy faces (Nelson & Dolgin, 1985; Peltola, Leppänen, Mäki, & Hietanen, 2009; Peltola, Leppänen, Palokangas, & Hietanen, 2008). By 12 months of age, infants are able to use the mother's facial expressions to disambiguate situations and respond differently to sad than they do to happy, fearful, or angry expressions (Sorce, Emde, Campos, & Klinnert, 1985). By 14 months of age (the youngest age tested), infants appear to understand the meaning of disgusted expressions: they are less likely to search in a box associated with a disgusted expression than a box associated with a happy expression (Repacholi, 1998). However, this early emerging ability has a long developmental course. It takes many years before children reach adult levels of speed and accuracy in recognizing facial expressions (e.g., De Sonneville et al., 2002; Durand, Gally, Seigneuric, Robinchon, & Baudouin, 2007; Kolb, Wilson, & Taylor, 1992).

Children's performance in recognizing facial expressions improves with age (Herba & Phillips, 2004), with happy expressions recognized earlier and more accurately than negative expressions (Boyatzis, Chazan, & Ting, 1993; Camras & Allison, 1985; Widen & Russell, 2003). Overall, this improvement can be characterized by a large increase in accuracy between 3 and 7 years (Camras & Allison, 1985; Durand et al., 2007; Markham & Wang, 1996; Vicari, Reilly, Pasqualetti, Vizzotto, & Caltagirone, 2000) and an increase in speed between 7 and 10 years (De Sonneville et al., 2002). Children's accuracy in recognizing facial expressions from still photographs does not reach adult levels until early adolescence for some facial expressions (e.g., fear and disgust: Durand et al., 2007; sadness: Kolb et al., 1992). Even though children are adult-like on behavioural measures of recognition by early adolescence, their corresponding brain activity still differs from that of adults until late adolescence. Fourteen- to 15-year-olds' event-related potentials (ERPs) for the six basic emotional expressions differ from those of adults (Batty & Taylor, 2006) and in 11-year-olds, the amygdala activation revealed by functional magnetic resonance imaging (fMRI) is stronger for neutral than fearful faces, the opposite pattern from that shown by adults (Thomas et al., 2001).

Intensity of facial expressions

The literature on the development of children's sensitivity to facial expressions consists largely of studies using stimuli that depict prototypical expressions from different emotion categories. These prototypical expressions usually are posed by trained actors/actresses, using strictly prescribed muscle movements (e.g., Pictures of Facial Affect, Ekman & Friesen, 1976). The posed expressions are usually high in intensity. However, in everyday life, we see less intense expressions more frequently than intense facial expressions. The ability to recognize less intense facial expressions and subtle changes in the intensity of facial expressions are important skills for smooth social interaction. Therefore, it is important to investigate children's ability to recognize facial expressions of lower intensity.

The intensity of a facial expression is determined by the amount of muscle displacement away from a neutral state (Hess, Blairy, & Kleck, 1997). For example, the intensity of a happy expression can be characterized by the degree of displacement of Zygomaticus Major and Orbicularis Oculis muscles, relative to their relaxed states (Duchenne, 1990). Only a few studies have tested children with facial expressions at varying levels of intensity. One method is to select expressions based on adults' ratings of their intensity. Gosselin and Pelissier (1996) used this method: they selected expressions at three intensities based on ratings of the intensity of activation of Facial Action Coding System (FACS, Ekman & Friesen, 1978) action units. FACS defines 32 action units describing a contraction or relaxation of one or more facial muscles. Nine- to 10-year-old children were as accurate as adults in recognizing happy expressions at all three intensities but were not as good as adults in recognizing disgusted expressions of low intensity. No other age groups or expressions were tested.

A second way to control the intensity of facial expressions is to create blends between a neutral face and an expressive face using a morphing technique (Benson, 1994; Hess et al., 1997), which simulates facial muscle movement in a linear manner. Three studies have used this technique to study developmental differences. Thomas et al. (2007) tested with static photos representing 6 levels of fearful or angry expressions. Two other studies tested children with 4-10 levels of intensity of 5 basic expressions (all except surprise) using a morphing technique in which the child saw animated sequences moving from neutral to successively higher intensities with a fast (20 frames/second, Montirosso, Peverelli, Frigerio, Crespi, & Borgatti, 2010) or a slow (1 frame/second, Herba et al., 2008) frame rate and the measure was the frame at which the expression was first recognized. The reported pattern of improvement with age varies with expression and method. For example, Thomas et al. found that both children (7-13 years) and adolescents (14-18 years) are less sensitive than adults (25-57 years) in discriminating static photos of anger and fear from neutral expressions, while Montirosso and colleagues found that sensitivity to animated expressions is already adult-like for anger at age 7 and for fear at age 10. Unlike Gosselin and Pelissier (1996), Montirosso et al. found no age changes in sensitivity to disgusted expressions.

They also reported that sensitivity to happy expression is already adult-like at age 7, while sensitivity to sad expressions is not adult-like until age 13. In contrast, Herba et al. (2008) found improvement in sensitivity for happy and fearful expressions between 4 and 15 years of age for photographs of both familiar and unfamiliar adults, with no facilitatory effect of familiarity. With facial expressions at varying intensities, these three studies found developmental changes in children's sensitivity to five of the six basic emotional expressions (all except surprise, which was not tested in any of these studies). However, they do not agree on the age when children's sensitivity is adult-like for each expression. For two of the three studies (Herba et al., 2008; Montirosso et al., 2010), it is also not clear whether the improvements with age with their animated technique reflect increased sensitivity to low intensity expressions or in the speed of processing that allows the expression to be recognized after less exposure/fewer frames.

Open questions

Although the few previous studies provide some insight into children's ability to recognize less intense facial expressions, it remains unclear when children's sensitivity to these less intense facial expressions reaches adult levels, given the inconsistent findings among the studies. In the studies reported in Chapter 2 and 3, I tested children aged 5, 7, and 10, and a comparison group of adults, with the six basic emotional facial expressions with 20 levels of intensity. Unlike some previous studies, which only measured the intensity level at which the expression was first recognized, I collected children's accuracy at all levels of intensity tested. Based on the accuracy scores, I calculated children's threshold to discriminate expressions from neutral and their rates of misidentifications. I also investigated the effect of expression groupings by testing different groups of participants with different expression groupings. With the current methods and experimental design, I was able to address the following questions in a more systematic way than previous studies: (1) Do children need more intensity (i.e., have a higher threshold) than adults to discriminate expressions from neutral? (2) Do the thresholds differ according to the target facial expressions in the same way for adults and children? (3) Are children able to discriminate between two intensities of the same facial expression as well as adults? (4) what patterns of confusion do children make when they are categorizing facial expressions with varying intensities and is the pattern of confusion similar to that shown by adults?

Perceptual structure of facial expressions

Besides our ability to sort facial expressions into different categories, we can also perceive a relationship among different facial expressions. The perceived relationship among facial expressions has been modeled with a small number of underlying dimensions derived from similarity judgments about facial expressions, using multidimensional scaling techniques.

Multidimensional scaling

Multidimensional scaling (MDS, Shepard, 1962) is a statistical procedure that represents similarities between objects as distances in a multidimensional space. MDS can detect the hidden structure underlying complex constructs that are not obvious in the raw similarity judgments (Kruskal & Wish, 1978). MDS is widely used to map the perceptual structure of facial expressions without *a priori* assumptions of the underlying dimensions (Abelson & Sermat, 1962; Bimler & Kirkland, 1997, 2001; Nummenmaa, 1990; Russell & Bullock, 1985, 1986; Shah & Lewis, 2003). To minimize the influence of language, in many studies no verbal labels were used and MDS was based on similarity judgments about facial expressions (e.g., Abelson & Sermat, 1962; Russell & Bullock, 1985, 1986), or reaction times to discriminate among them (e.g., Shah & Lewis, 2003). The MDS solutions suggest that adults represent facial expressions in a circular arrangement with two underlying dimensions, namely, pleasure and arousal (Alvarado, 1996; Bimler & Kirkland, 1997, 2001; Russell & Bullock, 1985, 1986; Shah & Lewsi, 2003). In this structure, different exemplars of the same expression category cluster together.

The circumplex model

The results from studies mapping the perceptual structures of facial expressions fit well with the so-called circumplex model of affect, which holds that the structure of affective states can be represented by a circular pattern in a two-dimensional space with pleasantness and arousal as the underlying dimensions (Russell, 1980). Besides facial expression, this model also is supported by studies with emotion words (Russell, 1980), emotional experiences (reviewed by Remington, Fabrigar, & Visser, 2000), emotional voices (Green &

Cliff, 1975), and emotion-eliciting music (Bigand, Vieillard, Madurell, Marozeau, & Dacquet, 2005).

Developmental studies reveal that even young children show a perceptual structure of facial expressions that is similar to that of adults. Russell and Bullock (1985) used a sorting paradigm to collect similarity judgments among intense facial expressions from preschoolers, and mapped the underlying perceptual structure using MDS. The structure was similar to that of adults and can be characterized by a circular arrangement along the two dimensions of pleasure and arousal. However, there was less clustering in the children's structures: unlike in the structure of adults, where different exemplars of the same expression category were close to each other and there was a clear boundary between categories, in the structure of children, there was more overlapping between some expression categories. With a smaller stimulus set, Russell and Bullock (1986) found the same two-dimensional structures in children as young as 2 years as seen in adults. These findings are somewhat surprising given that other studies suggest that it takes a remarkably long time for children to acquire adult levels of sensitivity to facial expressions. Because 2-year-olds do not yet know the verbal labels for the six basic expressions, the early-emerging structure is not an artifact of language structure. Instead, the early structure seen at 2 years of age may seem similar to that of adults but may reflect a less differentiated concept of emotion or reflect children's perception of physical differences among the facial images rather than their perception of the emotions conveyed by the facial expressions (Russell & Bullock, 1986).

Limitations of the circumplex model

The circumplex model represents adults' perceptual structure of emotions with two meaningful underlying dimensions, pleasure and arousal. However, this model has difficulty in representing adults' perception of the difference between fear and anger. Although fear and anger are not conceptually or perceptually similar to each other, they fall next to each other in the circumplex model. On the pleasure dimension, both fear and anger are on the unpleasant side, whereas on the arousal dimension, both fear and anger are on the high-arousal side. Some researchers suggest a potency dimension as a third dimension for adults' perceptual structure of facial expressions (Fontaine, Scherer, Roesch, & Ellsworth, 2007; Osgood, May, & Miron, 1975). On the potency dimension, high values relate to feelings of power, dominance, and impulses to act, whereas low values relate to feelings of weakness, submission, and refraining from action. Anger and fear would fall on different sides of the potency dimension. However, previous studies mapping the perceptual structure of facial expressions based on MDS did not find a potency dimension and usually found the third dimension hard to interpret (Abelson & Sermat, 1962; Bimler & Kirkland, 1997; Shah & Lewis, 2003).

Another limitation of the circumplex model is that it does not include an explicit representation of intensity. Plutchik (1980) proposed an intensity dimension running in a direction orthogonal to the circular structure. This model was supported by adults' similarity judgments and intensity ratings of emotion words. Also using emotion words, later researchers (Reisenzein, 1994) demonstrated that intensity could be determined by the proportion of pleasantness and arousal, with the center of the two-dimensional space representing zero intensity with medium arousal. Studies using facial expressions at different intensities suggest a fractal property in the underlying structures representing adults' perception of facial expressions (Takehara, Ochiai, & Suzuki, 2002; Takehara & Suzuki, 2001; Takehara, Ochiai, Watanabe, & Suzuki, 2007). In such structures, low-intensity expressions form a similar circumplex arrangement as their high-intensity counterparts but at a smaller scale. Although Takehara and colleagues mapped the structure within each intensity level and compared the structures between intensity levels, they did not ask participants to compare expressions with different intensity levels or construct a single structure that included different intensity levels. Furthermore, they predict that the structure of the lower intensity expressions should fall within the circumference of the structure of the higher intensity expressions, with neutral expression being the center of the structure. However, they did not include neutral expressions in the test stimuli, and this prediction is not consistent with previous findings that neutral expressions are located on the periphery of the circumplex structure (Shah & Lewis, 2003).

The only previous study with children suggests that intensity is represented in children's perceptual structure of facial expressions in a similar way as in the structure of adults. When tested with dynamic stimuli of happy and angry expressions with two intensity levels, the perceptual structure of children aged 6-8 years is similar to that of adults (Vieillard & Guidetti, 2009). In these structures, intensity was represented as the proportion of pleasantness and arousal. However, it is not clear whether the children benefited from the use of dynamic stimuli, the inclusion of body information, and/or the ease of the task given the limited number of expressions tested.

Open questions

It remains unclear how intensity is represented in the perceptual structure of facial expressions, and how anger and fear are differentiated in this structure. By testing both children and adults with facial expressions of the six basic emotional expressions with 4 levels of intensity, in the work presented in Chapter 4, I was able to map more complex perceptual structures of facial expressions than in the previous studies. Those more complex structures allowed me to detect subtle differences between the structures of children and adults.

Spatial frequency tuning of face perception

Human faces carry rich information. Even from static images of faces, we are able to make many judgments, including judgments about identity, facial expression, age, sex, ethnicity, direction of eye gaze, and attractiveness. It is possible that children's inferior ability to recognize facial expressions compared to adults is related to their suboptimal use of information in faces. One way to examine how children use information in faces is to look at their selective use of information carried by different spatial frequencies. The spatial frequency information in faces is usually defined as the number of sinusoidal transitions across the face, measured in cycles per face width (c/fw), rather than the number of transitions across the retina, which is measured in cycles per degree. Unlike cycles per degree, cycles per face width remain constant as the face is viewed from different distances. The majority of the previous studies have investigated how adults use spatial frequency information in the recognition of facial identity. Only a few studies have examined how adults use spatial frequency information to recognize facial expressions. Even fewer studies have tested how children use spatial frequency information to recognize facial identity and facial expressions.

Spatial frequency tuning in adults

Facial identity. Previous studies have revealed that adults rely on a limited range of mid spatial frequencies to recognize facial identity (Costen, Parker, & Carw, 1994, 1996; Fiorentini, Menon, Rigato, & Johnson, 1983; Gold, Bennett, &

Sekular, 1999; Näsänen, 1999; Ojanpää & Näsänen, 2003; for review, see Ruiz-Soler & Beltran, 2006). Although it is generally agreed that the mid spatial frequency bands contain the critical information for face identification, the estimates of the critical center frequency vary from study to study, probably because of different ways of manipulating the available spatial frequency information. Pixelizing was one of the earliest approaches used to manipulate spatial frequency information in faces. In this approach, a grid was put on a face image and the grey level within each block (pixel) was set to the mean grey level of the block. Studies using this approach reported that accuracy for recognition of facial identity dropped when the image quality dropped below 16 (Harmon, 1973), 18 (Bachmann, 1991), 21 (Costen et al., 1994), and 23 (Costen et al., 1996) pixels per face (8-11.5 c/fw). However, pixelizing introduces additional high spatial frequencies into the image, which may affect the estimates of the critical spatial frequency bands for face identification. As a better way to manipulate spatial frequency information than pixelizing, filtering is a commonly used approach, because it allows the selective removal of certain spatial frequencies without adding extra spatial frequencies to the image. Using low-pass filtered faces, in which higher spatial frequencies were removed, Fiorentini et al. (1983) found that adults were less accurate in recognizing facial identity when the cutoff frequency dropped from 8 to 5 c/fw. Using low-pass and high-pass filtered faces, Costen and colleagues (1994, 1996) found that the most useful information for face identification is carried by a spatial frequency band between 8 and 16 c/fw.

In contrast, using band-pass filtered faces, which only contain information in a narrow range of spatial frequencies, Hayes, Morrone and Burr (1986) found that the most critical information is located around 20 c/fw. An alternative approach to selectively removing certain bands of spatial frequency by filtering is to add noise in the target spatial frequency band, a procedure called noise masking. Using narrow band additive Gaussian noise, Näsänen (1999) found that adults asked to recognize the identity of faces are most sensitive to spatial frequency information centered around 8-11 c/fw. Similar to noise masking, Fourier phase randomization selectively disrupts information in a certain spatial frequency band by scrambling the phase information in that band. This method has the advantage of leaving the distribution of contrast energy at different spatial frequencies of the face constant because no noise is added to the image. Using Fourier phase randomization, Näsänen (1999, Experiment 2) reported similar results (8-11 c/fw) to those found with noise masking (Näsänen, 1999, Experiment 1, 8-11 c/fw) for the critical spatial frequency band used by adults in face identification. Also using Fourier phase randomization, Ojanpää and Näsänen (2003) reported similar results (8-11 c/fw) when a visual search paradigm was used.

Facial expression. The far fewer studies on the recognition of facial expressions generally agree that the mid spatial frequency band is also critical. Using low-pass and high-pass noise masking, Schwartz, Bayer and Pelli (1998) found that the critical spatial frequency band for recognizing facial expression is located around 8 c/fw. Using hybrid faces, which contained a face with information below 8c/fw superimposed on a face with information above 24 c/fw, Schyns and Oliva (1999) reported a low spatial frequency bias in categorizing facial expressions. The same low frequency bias was also found when the participants categorized facial identity in hybrid faces. Using filtered systhetic faces representing different facial expressions, Goren and Wilson (2006) found that when the spatial frequency band shifted from mid (10 c/fw) to low (3.3 c/fw) spatial frequency, discrimination thresholds increased for most of the expressions, especially for sadness, but not for anger. No change in threshold was found when the spatial frequency band shifted from mid to high (30 c/fw) spatial frequency. The difference in critical spatial frequency among expressions is also suggested by Smith and Schyns (2009)'s finding that different facial expressions are represented by different diagnostic spatial frequency spectra. In this study, the critical spatial frequency band for recognizing each expression revealed by the bubbles technique (Gosselin & Schyns, 2001) was related, to some extent, to observers' sensitivity to that expression at different viewing distance. Expressions that had lower critical spatial frequencies (happy, surprise, disgust) were recognized better in smaller images simulating a longer distance than expressions that had higher critical spatial frequencies (neutral, sad).

Are the two systems separate at the level of spatial frequency tuning?

Several researchers have proposed that the recognition of facial identity and facial expression involve two separable systems tuned to the invariant versus changeable aspects of faces, respectively (Bruce and Young, 1986; Haxby, Hoffman, & Gobbini, 2000). This proposal is supported by evidence from behavioural measures (Young, McWeeny, Hay, & Ellis, 1986), neuropsychological studies (Etcoff, 1984; Young, Newcombe, de Haan, Small, & Hay, 1993; Tranel, Damasio, & Damasio, 1988; Hornak, Rolls, & Wade, 1996), functional imaging in normal adults (George, et al., 1993; Sergent, Ohta, MacDonald, & Zuck, 1994; Winston, Henson, Fine-Goulden, & Dolan, 2004), and single cell recordings in monkeys (Hasselmo, Rolls, & Baylis, 1989). Although previous studies agree that the mid spatial frequency band is critical for both facial identity and facial expression, without a direct comparison using the same methods, the amount of variation across methods and studies makes it impossible to ascertain whether the critical bands are completely or only partially overlapping. Therefore, a direct comparison is necessary to ascertain whether the two systems separate at the level of spatial frequency tuning.

Spatial frequency tuning in children

Little is known about how children use spatial frequency information in face perception. Contrast sensitivity is adult-like by age 7 (Ellemberg, Lewis, Liu, & Maurer, 1999; but see Benedek, Benedek, Kéri, & Janáky, 2003, for continued change until age 11-12). However, children's ability to recognize facial expressions and facial identity continues to improve until early adolescence (e.g., De Sonneville et al., 2002; Durand, et al., 2007; Herba & Phillips, 2004; Kolb et al., 1992; Mondloch, Dobson, Parsons, & Maurer, 2004; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grand, & Maurer, 2002). Some of this late improvement might be related to using a different, and less optimal, band of spatial frequencies for discrimination than used by adults, or to lower sensitivity within the critical band. The only previous study with children (Deruelle & Fagot, 2005) compared children aged 5-8 years to adults using a hybrid face paradigm similar to Schyns and Oliva (1999) in which a face filtered to have spatial frequencies only below 12 c/fw was superimposed on a face filtered to have frequencies only above 36 c/fw. The two superimposed faces with different filtering differed in identity or in expression (smile or grimace). Adults judged facial identity from the low-pass face and showed no bias when asked to judge whether the facial expression was a smile or a grimace. Children also judged facial identity from the low-pass face but, unlike adults, judged facial expression from the high-pass face. It is difficult to interpret these results because only two fairly large spatial frequency bands were contrasted, because the likely optimal mid spatial frequency band was not included, and because the faces were presented for a sufficiently long duration (400 ms for children and 100 ms for adults compared to 50 ms in the original study by Schyns and Oliva, 1999) that the participants may have been able to process both faces in the hybrid image and use more analytic higher-level strategies to make the decision.

Open questions

In the studies reported in Chapter 5, I used a noise masking technique to compare the spatial frequency tuning for the recognition of facial identity and facial expressions in children and adults. The direct comparison between identity and expression allowed me to ascertain whether adults use the same critical spatial frequency band to recognize facial identity and facial expressions. By comparing children and adults, I was able to obtain information about whether children use the same spatial frequency information as adults in recognizing facial identity and facial expressions.

Organization of the thesis

This thesis investigated developmental changes in children's sensitivity to facial expressions with three approaches. In the studies reported in Chapter 2 and 3, I examined the influence of intensity on children's sensitivity to facial expressions of the six basic emotions. Based on the NimStim face stimulus set (Tottenham et al., 2009), I created a new face stimulus set with four models (two female), each having facial expressions of the six basic emotions at 20 levels of intensity. With this stimulus set, I measured children's (aged 5, 7, and 10) thresholds to discriminate the six basic emotional expressions from neutral, their misidentification rates, and their accuracy in discriminating different intensities of the same expression (only for happiness, sadness, and fear). I also investigated the effect of expression groupings with three groups of facial expressions (Chapter 2: happiness, sadness, and fear; Chapter 3: happiness, fear, and surprise; sadness, disgust, and anger). I found that by age 5, children are adult-like, or nearly adult-like, for happy expressions on most of the measures. Children's sensitivity to other expressions continues to improve between age 5 and 10 (surprise, disgust, fear) or even after 10 (anger, sadness). The results indicate slow development of sensitivity to the facial expression of all basic emotions except happy.

In the studies reported in Chapter 4, I explored the perceptual structure of facial expressions in children and adults with the six basic emotional expressions, each with 4 levels of intensity. I collected similarity judgments using a child-friendly odd-man-out paradigm from a group of 7-year-olds and using a conventional similarity-rating paradigm from a group of 14-year-olds. For comparison, I also collected similarity judgments from two groups of adults each tested with one of the two paradigms I used with children. Multidimensional scaling suggested three- or four-dimensional structures were optimal for all groups. The two groups of adults demonstrated almost identical structures, which had dimensions representing pleasure, potency, arousal, and intensity, despite the fact that they were tested with two different paradigms. When tested with the odd-man-out paradigm, the 7-year-olds showed systematic structure, which differed from that of adults in both the meaning of some dimensions and the proximities among some of the expression categories. When tested with similarity judgments, the 14-year-olds showed an adult-like pattern on all measures except that their similarity judgments were more influenced by physical differences than were those of adults.

In the studies reported in Chapter 5, I investigated how adults and children use spatial frequency information to recognize facial identity and facial expressions. I measured contrast thresholds for the identification of faces with varying expression and for the recognition of facial expressions across varying identity as a function of the center spatial frequency of narrow-band additive spatial noise. In five adults, the critical band for recognizing facial identity was around 11 c/fw. The critical band for recognizing facial expressions was significantly higher for recognizing facial expressions than for recognizing facial identity. Both critical bands shifted to slightly lower values when the viewing distance increased from 60 cm to 120 and 180 cm, a pattern indicating only partial scale invariance. Children aged 10 and 14 years showed similar tuning for facial identity as that shown by adults but flatter functions for facial expression. The results suggest that adults use finer details for recognizing facial expressions than for identifying faces, a tuning that takes many years to develop.

Collectively, a prolonged developmental course is revealed by all three approaches. During childhood, the system to recognize facial expressions becomes more efficient as less signal (intensity of facial expression, Chapter 2 and 3) is required, and becomes more specific (additional dimensions added, Chapter 4; narrowly tuned to a specific spatial frequency band, Chapter 5). This slow development of children's sensitivity to facial expressions may limit their ability in social interactions. I will discuss the possibly impacts of children's immature sensitivity to facial expressions on their social interactions in the general discussion.

Each chapter is written as an independent manuscript and hence there is some overlap in the background material presented.

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Chapter 2

Preface

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The research investigated developmental changes in children's sensitivity to happy, sad, and fearful facial expressions at varying intensity. Previous studies have shown a long developmental trajectory of children's sensitivity to facial expressions. However, the majority of the studies only examined children's ability to recognize intense facial expressions. Little is known about children's ability to recognize subtle facial expressions, which may be seen more frequently in real life than intense expressions. In the current research, we developed a new stimulus set of facial expressions with 20 levels of intensities based on faces from the Nimstim face database. With a child-friendly procedure, we asked children at 5, 7, and 10 years, and a comparison group of adults to sort facial expressions of happiness, sadness, and fear, each with 20 intensities (10 intensities for the 5-year-olds) into categories of neutral, happiness, sadness, and fear. We also measured their accuracy in discriminating between different intensities of happy, sad, and fearful faces. By measuring thresholds to discriminate expressions from neutral and rates of misidentification among expressions, we found that 5-year-olds are as sensitive as adults to subtle happy expressions, while sensitivity to subtle sad and fearful expressions was not adult-like until 10 (fear) or even after 10 (sad). For all expressions, including even happy expressions, the 5- and 7-year-olds were less accurate than adults in judging which of two expressions was more intense. These results indicate that there is slow development of accurate decoding of subtle facial expressions.

Running Head: CHILDREN'S SENSITIVITY TO SUBTLE FACIAL EXPRESSIONS

Influence of Intensity on Children's Sensitivity to Happy, Sad, and Fearful Facial Expressions

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Abstract

Most previous studies investigating children's ability to recognize facial expressions used only intense exemplars. Here we compared the sensitivity of children aged 5, 7, and 10 to that of adults (*n* = 24/age group) for less intense expressions of happiness, sadness, and fear. The developmental patterns differed across expressions. For happiness, by age 5, children were as sensitive as adults even to low intensities. For sadness, by age 5, children were as accurate as adults in judging that the face was expressive (i.e., not neutral), but even at age 10, children were more likely to misjudge it as fearful. For fear, children's thresholds were not adult-like until age 10, and at age 5, children often confused it with sadness. For all expressions, including even happy expressions, the 5- and 7-year-olds were less accurate than adults in judging which of two expressions was more intense. Together, the results indicate that there is slow development of accurate decoding of subtle facial expressions.

Keywords: facial expressions, development, children, intensity, happy, sad, fearful

Introduction

Facial expressions are an important source of social information. Accurate recognition of facial expressions allows us to make inferences about other people's feelings, thereby guiding our social behavior. Normal human adults are fast and accurate at recognizing facial expressions, even from still photographs (Ekman, 1993). This ability is seen universally: there is high agreement among adults from different cultures on what emotion is shown in still photographs of facial expressions of basic emotions (happiness, sadness, anger, surprise, fear, and disgust) (Ekman & Friesen, 1971; Ekman et al., 1987; Elfenbein & Ambady, 2002; Izard, 1971). However, the development of this ability remains largely unclear.

Most previous studies investigating children's ability to recognize facial expressions used photographs of intense facial expressions of basic emotions. Children's performance in identifying emotion from such photographs improves with age (reviewed in Herba & Phillips, 2004), with positive expressions recognized earlier and more accurately than negative expressions (Boyatzis, Chazan & Ting, 1993; Camras & Allison, 1985; Widen & Russell, 2003). Overall, the improvement can be characterized by a large increment in accuracy between 3 and 7 years (Camras & Allison, 1985; Durand, Gallay, Seigneuric, Robichon & Baudouin, 2007; Markham & Wang, 1996; Vicari, Reilly, Pasqualetti, Vizzotto & Caltagirone, 2000) and an increment in speed between 7 and 10 years (De

Sonneville et al., 2002). The developmental patterns for intense emotional expressions are similar across studies that used photographs of children's faces (Boyatzis et al., 1993; Camras & Allison, 1985; Widen & Russell, 2003), photographs of adults' faces (Durand et al., 2007; Markham & Wang, 1996; Vicari et al., 2000), or both (De Sonneville et al., 2002). At least with some stimulus sets, there is continued improvement in accuracy into early adolescence (Kolb, Wilson & Taylor, 1992). Moreover, children's pattern of brain activation when processing different intense facial expressions differs from that of adults until at least age 11 for fMRI activation to neutral versus fear (Thomas et al., 2001; see also Monk et al., 2003) and until late adolescence for ERP patterns (Batty & Taylor, 2006).

The previous studies with intense emotional expressions document that children are accurate in judging intense exemplars by about age 7, with subsequent changes in reaction time and neural specificity. However, in everyday life, we see less intense facial expressions more frequently than intense facial expressions. The ability to recognize less intense facial expressions and subtle changes in the intensity of facial expressions (e.g., to see that someone is mildly amused by a joke) facilitates smooth social interactions. Therefore, it is important to investigate children's ability to recognize facial expressions of lower intensity.

The intensity of a facial expression is determined by the amount of muscle displacement away from a neutral state (Hess, Blairy & Kleck, 1997). For example, the intensity of a happy expression can be characterized by the degree of displacement of Zygomaticus Major and Orbicularis Oculi muscles, relative to their relaxed states (Duchenne, 1990). Three recent studies of children used a morphing process to move the positions of features in a neutral face toward their positions in an intense emotional face, a change simulating the consequences of facial muscle movements. One study compared children with and without psychopathic tendencies in a program for troubled children (Blair, Colledge, Murray & Mitchell, 2001). Children with psychopathic tendencies needed significantly more intensity to recognize the sad expression, and they were more likely to mistake the fearful expression for another expression even at full intensity. However, the children spanned the age range of 9 to 17 years and the authors did not investigate the effect of age on thresholds or errors. In the second study, Herba and colleagues (2008; see also Herba Landau, Russell, Ecker & Phillips, 2006, for related results on matching expression across intensity) used 10 levels of intensity to investigate the effect of familiarity on children's (aged 4 to 15 years) perception of five facial expressions (happiness, sadness, anger, fear, and disgust) in familiar and unfamiliar adult faces. Sensitivity improved with increasing age for happy and fearful expressions, but not for disgust, sad, or angry expressions, with no facilitation by familiarity for any facial expression and in fact some evidence that familiarity degraded sensitivity. However, because there was no adult comparison group, it is not possible to determine when sensitivity reaches adult levels. A different pattern emerged in a recent study that used morphing to create six intermediate intensities between neutral and expressions of fear and anger: children aged 7 to 13 and adolescents aged 14 to 18 years were less sensitive than adults for both anger and fear (Thomas, De Bellis, Graham, & LaBar, 2007). These data suggest that the development of sensitivity to at least some facial expressions continues into adolescence. However, the authors used wide age groupings and did not analyze misidentifications. Adults tend to make systematic confusions among facial expressions. For example, they often confuse fear with surprise and anger with disgust (Ekman & Friesen, 1971; Etcoff & Magee, 1992; Yong et al., 1997). Little information is known about whether children show the same pattern of confusion among facial expressions as adults.

The purpose of our study was to build on these previous findings by including more intensity levels and a method that allowed us to measure both thresholds for each expression and confusions among expressions. We systematically manipulated the intensity of three facial expressions (happiness, sadness, and fear) by morphing photographs of intense exemplars of these expressions with photographs of neutral faces of the same models to create 20 levels of intensity. With intensity of expression as a factor in the experiment, accuracy is not an adequate measure of children's performance because they can make two types of errors. The first type of error is specific to low intensity expressions. Children as well as adults may fail to detect any expression in a face when the intensity of that expression is very low. To measure this type of error, we calculated thresholds to detect expressions in faces, i.e., to see that the expression is not neutral. The second type of error, as in studies using only intense facial expressions, is to misidentify one expression as another. To measure this type of error, we calculated the percentage of misidentifications in faces that were recognized as emotional. One concern is whether the values are affected by the particular choices of expression presented to the participants, in this case, happiness, sadness, and fear. We suspect that the threshold measure will not be affected by the particular choices because it measures the intensity at which the expression is seen as no longer neutral, even if the expression cannot be identified correctly at that low intensity level. However, the specific choices will affect the pattern of misidentifications because the forced choice procedure limits the types of errors that can occur. In the discussion we consider the effect of this limitation on the interpretation of our findings.

We chose to study happy and sad expressions because, with intense expressions, children show adult-like accuracy for them earlier than they do for other expressions (Boyatzis, Chazan & Ting, 1993; Camras & Allison, 1985; Widen & Russell, 2003), perhaps because of relatively greater exposure to happy and sad faces in everyday life. We chose fear as the third expression because it is likely to show a different developmental trajectory. With intense exemplars, adult-like sensitivity to fear develops relatively late (Camras & Allison, 1985; Durand et al., 2007; Markham & Wang, 1996; Vicari et al., 2000), possibly because of low exposure in everyday life. From an evolutionary perspective, the late development of adult-like accuracy for fear is surprising because fear signals potential environmental threat and the need to take action to avoid the threat. Consistent with this evolutionary perspective, by 7 months infants generalize habituation across different individual faces showing fearful expression (Nelson & Dolgin, 1985) and they look longer at fearful faces than happy faces. This early onset of processing of fearful faces may be related to the functioning of a specific brain circuit involving the amygdala (Adolphs, Tranel, Damasio & Damasio, 1995). In human adults, the amygdala can be activated by exposure to fearful faces through a fast, seemingly automatic response to low spatial frequency information carried through subcortical connections, as well as by slower cortical input that is likely to develop later (Vuilleumier, Armony, Driver & Dolan, 2003). Here we investigated whether the developmental trajectories for happiness, sadness, and fear are similar for less intense exemplars to those reported previously for intense expressions. The same method could be used in future studies to explore the development of sensitivity the other basic emotions (anger, surprise, disgust). We did not do so here because we were worried that including additional expressions would make the task too complex for the youngest children.

In Experiment 1, we investigated age differences in sensitivity to happy, sad, and fearful expressions in children aged 5, 7, and 10 and a comparison group of adults. We also investigated confusions among these expressions at intensity levels above threshold. In Experiment 2, we investigated children's ability to distinguish between different intensities of the same expression. We expected that, unlike the results of earlier studies using only intense expressions, young children would differ from adults in the detection and discrimination of all three facial expressions and more often misidentify expressions of moderate intensity. For each experiment, we developed a child-friendly procedure suitable for children as young as 5.

Experiment 1

In Experiment 1, we presented photographs of neutral faces and of happy, sad, and fearful faces with twenty levels of intensity to adults and children aged 7 to 10, who were instructed to sort the photographs into four categories: happiness, sadness, fear, and neutrality. In addition, because pilot work indicated that 5-year-olds were not able to respond consistently during such a long procedure, we tested a group of 5-year-olds with ten of the intensity levels.

Method

Participants

Participants were 24 5.5-year-old children (±3 months), 24 7.5-year-old children (±3 months), 24 10.5-year-old children (±3 months), and 24 adults (aged 18 to 22). Child participants were recruited from names on file of parents who had volunteered their child at birth for participation in later studies. Adult participants were undergraduate students enrolled in an introductory psychology course and received course credit for participation. All the participants had normal or corrected-to-normal vision. Half the participants in each age group were female. An additional three children (two 5-year-olds and one 7-year-old) were excluded from data analysis because of inattention to the tasks.

Stimuli

A total of 16 photographs of four models (two females [Models 3 and 10] and two males [Models 24 and 25]) posing happy, sad, fearful, and neutral expressions were selected from the NimStim Face Stimulus Set (Tottenham et al., 2009). Each photograph has a resolution of 506 × 650 pixels with RGB color. The selected models and photographs are ones for which adults agree about the posed expression (mean = 84.6%, range = 67.7% -100%) and rate the expression as high in intensity (mean = 5.3, range = 5.15-5.43, on a 7-point scale) (Palermo & Coltheart, 2004).

For the happy faces, twenty levels of intensity were created by morphing a neutral face with the happy face of the same model with proportions adjusted in 5% increments so as to create 5% happy, 10% happy... 100% happy (Figure 2.1a). A similar procedure was used for the sad (Figure 2.1b) and fearful faces (Figure 2.1c). Morphs were created using software "MorphX" (www.norrkross.com/software/morphx/MorphX.php) following the procedure described by Calder, Young, Perrett, and Etcoff (1996) and based on 160 points manually positioned on the anatomic landmarks in each face photograph.

Distortions caused by the morphing process in the eye and mouth regions[1] were fixed using Photoshop (Version 8.0). There were 260 stimuli in total (20 intensity levels × 3 expressions × 4 models plus 5 neutral expressions x 4 models). The neutral expressions were included to prevent participants from being biased to see all the faces as expressive. For each model, the 5 neutral faces were identical. Photographs were printed out in full color using Cannon CP-200 photo printer on 4 · 6-inch photo paper with lamination. The sizes of the faces were approximately 7 cm (width) by 11 cm (height).

Procedures

The procedures were approved by the institutional Research Ethics Board. After the procedures were explained, we obtained written consents from the adult participants or from a parent of the child participants, and we obtained verbal assent from the 10-year-old children.

Participants were tested individually in a quiet room illuminated by overhead fluorescent lights. Participants sat in front of a desk, on which sat four

[1] Morphing between two stimuli containing lighting reflections in different locations in an eye resulted in two light reflections in the morphed eye. We fixed this distortion by replacing the two reflections by one reflection midway between them. Morphing between a closed-mouth neutral face and an open-mouth toothy face distorted the teeth in the morphed pictures. This distortion was corrected by replacing the distorted tooth region with the tooth region from the original picture (100% intensity). Brightness and contrast of the replaced area were adjusted to match the morphed picture.

miniature houses, each with a schematic face[2] (Figure 2.2) on its roof showing a happy, sad, fearful, or neutral expression. The experimenter explained the task as follows: " *In one of these houses, people are telling a happy (sad, fearful) story. Could you tell me which one it is?*" After the participant pointed to the appropriate houses for these three expressions, the experimenter said: " *In one house, people are not telling a story, and they are not feeling anything. Could you point it out?*" After the participant correctly identified the neutral house, the experimenter showed a box with the test photographs inside, and said: "*Now we have more people here. Your job is to help them to find the right house. They can only go to one house, if they have the same feeling as people inside of that house.*" The experimenter emphasized that there could be different intensities by saying that: "*One thing you may notice is that sometimes a whole group feels sad, but some feel just a little sad while others feel very sad. In this game they all go together. Do the same thing with happy and fearful people. Don't care about how happy or fearful they are.*" (We also used synonyms of fearful, namely, scary and frightening, throughout the experiment).

The experimenter handed the photographs to the participant one by one. The participant put the photographs into the house that he/she judged appropriate through a slot in the roof. Since the slots in the roofs of the toy houses were very narrow (about 1cm wide), participants could not see the cards they had already

[2] The facial expressions on the schematic faces were accurately identified by eight adults in pilot work.

placed in each house. Half of the participants of each gender within each age group were assigned to one set of photographs containing all the stimuli of one male (NimStim model 25) and one female model (model 3), and the other half of participants were assigned to the other male (model 24) and the other female model (model 10). Therefore, except for the 5-year-olds, each participant saw 130 photos (3 emotions × 20 intensity levels × 2 models plus 5 neutral expressions × 2 models). For the 5-year-old children, pilot work indicated the procedure was too long and the number of photographs was reduced by using only half of the intensities: 10 levels of intensity with 10% intervals from 10% to 100%, for a total of 64 photos (3 emotions × 10 intensity levels × 2 models plus 2 neutral expressions × 2 models). Although we collected less information from the 5-year-olds, this decision appeared to better equate the attentional demands across age. All participants appeared to understand the task and to enjoy the game. The task took approximately 30 minutes for children and 25 minutes for adults to complete.

Data analysis

The intense exemplars of each expression (100%) were chosen based on high agreement among adults about the expression being displayed and high ratings of intensity. However, we cannot be sure that the endpoint expressions all convey the maximum possible expression, or fall equally short of maximum expression, and hence that the steps between the endpoint and neutral are equivalent. For that reason, we examined age differences for each expression in separate analyses.

We combined the data from the two sexes of participant for all analyses since preliminary analyses revealed no effect of sex or interaction of sex with any other variable.

Accuracy

Figure 2.3 shows mean accuracy at each intensity level for each expression when the data were first averaged across the two models seen by each participant and then averaged across participants in each age group. There were mainly two types of error: at low intensities, identifying an expressive face as neutral and at higher intensities, misidentifying one expression as another (e.g., classifying a sad expression as fearful). We quantified these two types of error by (1) calculating the threshold to discriminate each expression as different from neutral and (2) calculating the misidentification rates above threshold.

Thresholds

To measure children's and adults' sensitivity to facial expressions, we calculated their thresholds to differentiate each facial expression from neutral. Responses were categorized as neutral or non-neutral, with non-neutral responses including both correct identifications (e.g., 40% sadness classified as sad) and misidentifications (e.g., 40% sadness classified as fearful). We fitted a cumulative

Gaussian function to the responses of each participant for each expression by using the following formula:

$$P(identification) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(-\frac{(u-\mu)^2}{2\sigma^2}\right) du$$

where x is intensity and P is the probability of identification. We estimated two parameters: μ, the mean and σ, the standard deviation of the normal distribution $X \sim N(\mu, \sigma^2)$. The estimated value of μ was used as threshold and corresponds to $P = 0.5$. In other words, the threshold value represents the intensity level at which 50% of the time the expressive face will be recognized as neutral and 50% of the time it will be recognized as having one of the three expressions. The individual's threshold for each expression was calculated by averaging across the independently derived estimates for the two models (Figure 2.4)[3].

Misidentification rates

The thresholds measured children's ability to distinguish expressive from neutral faces but did not indicate whether they identified the correct expression. To assess age differences in misidentifications, we calculated the misidentification rates combining all intensity levels that were above threshold for each participant by dividing the frequency of misidentification (e.g., sadness being misidentified as happiness or fear) by the total number of faces above the

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[3] Thresholds based on an arbitrary rule (e.g., the lowest intensity at which began the first string of 2 correct responses) yielded similar results.

threshold (Figure 2.5)[4]. The rates for each participant were averaged across the two models. Table 2.1b indicates the mean number of faces included in the denominator at each age.

Analyses

For both the thresholds and misidentification rates, we conducted one-way ANOVAs testing the effect of age separately for each expression[5]. We also tested the effect of age on accuracy for the 100% intense expressions to allow our results to be compared directly to previous studies. Dunnett's tests with adults as the control group were performed when there was a significant main effect of age (one-tailed, testing the hypotheses that children have higher thresholds or higher misidentification rates than adults).

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[4] When misidentification rates were restricted to the 10 levels of intensity tested for all four age groups the results were similar except that the misidentification rates for sadness of the 10-year-olds were no longer significantly different from those of adults ($p = .092$).

[5] The conclusions are similar if the analyses are based on mixed model ANOVAs with Age as a between subject factor and Expression as a repeated measure. For threshold, there are significant main effects of Age, $F(3,92) = 4.36$, $p < .01$, and Expression $F(2,184) = 47.13, p < .01$, and a significant interaction between Age and Expression $F(26,184) = 3.56, p < .01$. For misidentification rate, there are significant main effects of Age $F(3,92) = 9, p < .01$, and Expression, Greenhouse-Geisser corrected $F(1.7, 153.6) = 24.96, p < .01$, and a significant interaction between Age and Expression, Greenhouse-Geisser corrected $F(5, 153.6) = 4.23, p < .01$. To investigate the interactions, we examined the simple effects of age for each expression. The results are the same as when the data for each expression are analyzed separately.

Results

Happy expression

All age groups had perfect accuracy (100%) at recognizing the highest intensity happy faces. Inspection of Figure 2.3 indicates possible age differences in the range of intensities from 30% to 40%. However, this difference did not lead to significant difference in threshold. Threshold was reached at a low intensity around 20% (Figure 2.4), and misidentifications were rare (Figure 2.5). The ANOVAs confirmed that there was no main effect of age on accuracy at 100% intensity, $F(3, 95) < 1$, on thresholds, $F(3,95) = 2.55$, $p > .05$, or on misidentification rates, $F(3,95) < 1$.

Sad expression

At the highest intensity, there was no difference in accuracy among age groups, $F(3,95) = 1.04$, $p > .10$. Inspection of Figure 2.3 suggests age differences in accuracy across a broad range of intensities from about 20% to 70%. The analyses revealed that the age differences were in misidentification rates. There was no main effect of age on thresholds, $F(3,95) = 1.26$, $p > .10$ (see Figure 2.4). However, children misidentified sad as another expression more often than adults (Table 2.1a). This was supported by a main effect of age, $F(3,95) = 2.81$, $p < .05$, $\eta^2 = .08$, on misidentification rates, with both the 5-year-olds and the 10-year-olds having significantly higher misidentification rates than adults and a trend in the same direction for 7-year-olds (Dunnett's tests, $p < .05$, *Cohen's d* = .77 for 5, $p = .051$, *Cohen's d* = .60, for 7, $p < .05$, *Cohen's d* = .63, for 10). At every age, most errors were to misidentify sad faces as fearful (Table 2.1a).

Fearful expression

Inspection of Figure 2.3 reveals a different developmental pattern for fear than for happy or sad expressions, such that 5-year-olds made more errors than other age groups even at high intensities (60% and above). There was a significant main effect of age on accuracy at the highest intensity, $F(3,95) = 10.80, p < .01$, $\eta^2 = .26$. The 5-year-olds were significantly less accurate than the adults at the highest intensity ($p < .01$, *Cohen's d* = 1.14), but the 7-year-olds and the 10-year-olds did not differ significantly from adults (*p*s > .10). There was also a significant main effect of age on threshold, $F(3,92) = 7.824, p < .01$, $\eta^2 = .20$. Dunnett's tests revealed that the 5-year-olds and the 7-year-olds had significantly higher thresholds than adults ($p < .01$, *Cohen's d* = 1.06 for 5, $p < .01$, *Cohen's d* =1.15 for 7) and that 10-year-olds did not differ significantly from adults ($p > .10$). The mean thresholds to distinguish fearful expressions from neutral ranged from 30-31% for 5- and 7-year-olds to 20 to 22% for 10-year-olds and adults (Figure 2.4).

The mean misidentification rates for fearful faces were 25.5% for the 5-year-olds and 8.7% or less for the other age groups. There was a significant main effect of age, $F(3,188) = 6.22, p < .01$, $\eta^2 = .23$. Dunnett's tests revealed that the

5-year-olds had a significantly higher misidentification rate than adults for fearful faces ($p < .01$, *Cohen's d* = 1.34), but 7-year-olds and 10-year-olds were not different from adults (*ps* >.10). At every age, the most common error was to misidentify fearful faces as sad (Table 2.1a).

Discussion

It has been well documented that children can recognize happy expressions of high intensity with the high accuracy rates seen in adults as early as age 5-6 (Boyatzis et al., 1993; Camras & Allison, 1985; Kolb et al., 1992;Widen & Russell, 2003). Our findings for intense expressions are consistent with these previous findings: 5-year-olds' accuracy was nearly perfect with exemplars of 60% and higher (see Figure 2.3) and misidentification rates were low at all ages (see Figure 2.5). We also found that children's thresholds to detect emotion in less intense happy faces were adult-like at age 5[6]. Our findings differ

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[6] Five-year-olds were tested with only 10 levels of intensity, while we tested the other age groups with 20 levels of intensity. The threshold values estimated with more levels of intensity from the older age groups may be more accurate than those for 5-year-olds estimated with fewer levels of intensity. To investigate how the difference affected the developmental patterns, we recalculated the thresholds of the 7-year-olds, the 10-year-olds, and adults based only on their responses for the 10 intensity levels used with 5-year-olds. The ANOVA results for threshold were similar overall to those reported in the text: there was no main effect of age for sadness and the main effect of age for fear resulted from higher thresholds for the 5-year-olds and the 7- year-olds than for adults. In addition, there was a main effect of age for happiness, but, as in the original analyses, no significant difference in threshold between adults and any of the younger ages. The main effect of age resulted from slightly higher thresholds

from those of a previous study by Herba et al. (2008) showing that children's threshold to accurately recognize happy expression decreases with age in children between 4 and 15 years old. One possible explanation is that in our study choices were self-paced, while in the Herba et al. (2008) study, each picture disappeared after 1 second. It is possible that Herba et al's pattern of decreasing threshold between 4 and 15 reflects increasing speed of processing facial expressions, consistent with decreasing reaction time (De Sonneville et al., 2002), while our results reflect the early development of adult-like sensitivity.

The implication of our findings is that, when they are not under time pressure, by age 5 children are as sensitive as adults to subtle expressions of happiness, such as a teacher's subtle smile when the child gets a hard problem correct. Being able to recognize such subtle signals increases the child's potential to react appropriately in social situations and to be shaped by subtle feedback from adults and peers.

Children also performed well with the sad expressions. Children in the youngest age group (5-year-olds) were as accurate as adults for intense expressions and had adult-like thresholds. These findings are consistent with previous reports that children can recognize intense sad expression as accurately as adults by age 5 (Durand et al., 2007; Vicari et al., 2000) and that children's

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at age 5 than age 10. Thus, the overall conclusions of Experiment 1 were not affected by using fewer intensities for the youngest group.

threshold to accurately recognize sad expression does not change between 4 and 15 years of age (Herba et al., 2008). However, children made more classification errors than adults when viewing sad expressions that were above threshold but below 100% intensity, even at 10 years of age: they more often misidentified such sad faces as fearful. The higher confusion rates with fear at lower intensity levels imply that children are not as sensitive as adults to typical expressions of sadness. This insensitivity may limit their ability to empathize with others and to monitor the impact of their shortcomings on parents and teachers, although it is possible that low empathizing ability limits the information they find salient in the sad facial expressions they see everyday and thereby slows the development of adult-like sensitivity. Misidentifying a sad face as fearful may also cause them to take inappropriate action.

Children performed less well with the fearful expressions. Even at the peak intensity (100%) 5-year-olds were significantly less accurate than adults in recognizing fearful faces and they more often misidentified fearful faces as sad. The results for the intense expressions are similar to the report by Durand et al., (2007) that 5-year-olds are less accurate than older children and adults in recognizing fearful expressions, and, as in the current study, as accurate as older children for intense sad and happy expressions. Our results extend those findings by showing that their threshold is also significantly higher. The 7-year-olds performed like adults for higher intensities, but they had significantly higher thresholds. By age 10, children performed as well as adults on all measures. Like the results from previous studies (Herba et al., 2008; Thomas et al., 2007) with children aged 4 to 15, our results indicate that there are changes after 7 years of age in sensitivity to subtle fearful expressions, although our data suggest that the change occurs in the earlier part of the wide age range in the previous two studies. The slow development of sensitivity to fearful expressions implies that 5- and 7-year-old children often miss or misread fearful expressions that signal potential danger in the environment.

It is possible that the developmental patterns we observed reflect the particular forced choice procedure we used and that results might be different had we given different choices or asked participants to label the emotional expressions. As reviewed by Russell (1994), when a free labeling procedure is used, adults usually are poorer at recognizing facial expressions than when they have a fixed number of choices that limit the errors that can be made. The difference is likely to be even greater in children (Markham & Adams, 1992; Widen & Russell, 2003) and perhaps differ between facial expressions. Moreover, in our experiment children had only four expressions to choose from: neutral, one positive expression and two negative expressions. The limited set of choices may have made misidentifications more likely for the negative expressions: children may have recognized that a sad face was expressive and negative but been unsure of which negative expression; there was no comparable confusion possible for the happy expression. To control for this possible confound, we ignored misidentifications in calculating the thresholds: each response was scored as neutral or expressive, with both correct identifications and misidentifications counted as expressive. However, we cannot rule out the possibility that when viewing a low intense sad or fearful face, the uncertainty of whether it is sad or fearful might bias the young child to put it in the neutral pile.

While we acknowledge that the 4-alternative forced procedure may have affected the pattern of results, we note that the same limitation applies to the interpretation of previous studies of sensitivity to facial expressions in children and adults. Other aspects of the data confirm different developmental patterns for fear and sadness. The patterns of misidentification were not symmetrical: sadness was misidentified as fear on about 10% of trials in all three child groups, while fear was misidentified as sadness at higher rates (22.9%) but only by 5-year-olds. Although it is possible that for the 5-year-olds, sadness is treated as the default negative emotion, leading to an asymmetrical pattern of confusion with fear, this asymmetrical pattern was not seen in the other age groups. Moreover, at age 5, the plot of overall accuracy against intensity for fear is quite different from that for sadness (see Figure 2.3). Thus, our conclusions about different developmental patterns for different emotions are not likely to be merely an artifact of the three emotions we chose to study and the use of a forced-choice procedure. Future studies using other sets of emotional expressions (e.g., happiness and pleasant surprise, along with two negative expressions) with the same methodology can address this issue directly.

Experiment 2

Although children's ability to recognize intense facial expressions has been investigated by many studies, little attention was been paid to their ability to discriminate between different intensities of the same facial expression, which can convey information about subtle differences in a person's feelings. In Experiment 2, we assessed this ability by asking the participants from Experiment 1 to indicate the more intense expression in pairs of faces showing the same expression. To our knowledge, this is the first study to assess sensitivity to subtle differences in emotional intensity using a direct method (see Thomas et al. [2007] for an indirect measure for fearful and angry expressions based on slopes).

Method

Participants

The participants were the same as in Experiment 1. One 7-year-old was excluded from the data analysis because of chance performance in all conditions of Experiment 2.

Stimuli

The stimuli were the same as in Experiment 1, except that they were displayed on a 19-inch HP p1179 CRT monitor with 75 Hz refresh rate at 1024 × 768 controlled by a Macintosh G4 computer via PsyScope software (Cohen, MacWhinney, Flatt & Provost, 1993). Each picture was 11.4 cm (width) × 14.8

cm (height) (approximately 10.7° × 14.1 ° in visual angle when viewed from a distance of 60 cm) with a separation of 8 cm (7.6° in visual angle) between the two pictures presented during each trial.

Procedures

Participants had a 5-minute break before beginning Experiment 2. In Experiment 2, they were asked to indicate the more intense expression in a simultaneously displayed pair of images of the same model showing two different intensities of one of the expressions. Different expressions were separated by blocks (happy, sad and fearful) with the order of expression blocks counterbalanced among participants in each age group. Participants were told the target expression before each block.

All four models were used, but the two pictures shown on any given trial were always from the same model. The pairs were drawn from the relatively high intensities (70 % - 95%) so as to be clearly above threshold[7]. In pilot work with 7-year-olds (the middle age group) and adults, we determined that with a 10% difference, the 7-year-olds were as accurate as adults with a 5% difference. Therefore, we tested adults with differences of 5%, 10%, 15%, and 20% (70

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[7] We also tested low intensity pairs (40% to 65%). The results of Experiment 1 showed that individual thresholds to detect emotion ranged from 5% to 65%, indicating that for some participants, one or both faces in the low intensity pairs may look neutral. Therefore, we did not analyze the data from the low intensity pairs.

versus 75, 80, 85, and 90), and children with differences of 10%, 15%, 20%, and 25% (70 versus 80, 85, 90, and 95). We used all levels tested for analyses for linear trends within each age group. For the ANOVA including all 4 age groups, we included only the overlapping levels of differences. Each pairing appeared once with the correct answer on the left and once with it on the right. Each participant saw 32 pairs of pictures in random order for each expression (4 levels of difference × 4 models × 2 positions of correct answer). For the 5-year-olds, the position of the correct response for each test pair was randomized and not repeated in the opposite position so as to halve the number of trials.

The experimenter explained the task as follows: "*Here we have a competition. In this competition, people send us their pictures of happy faces, sad faces and fearful faces. The happiest, saddest and most fearful ones will win the competition. Now, you are the referee of this competition.*" At the beginning of each expression block, the experimenter told the participant that: "*This round is the happy (sad, fearful) round. We will show you pairs of happy (sad, fearful) faces and let you decide which one looks happier (sadder, more fearful) than the other.*" Photographs were displayed on the screen until the experimenter entered the participant's response. The task took approximately 30 minutes for children and 25 minutes for adults to complete.

Data Analysis

For the same reasons as mentioned in Experiment 1 (e.g., the endpoint expressions may not be equally intense), we analyzed the data for Experiment 2 separately for each expression[8]. Preliminary analysis revealed no effect of sex of participant or interaction of sex with any other variable. Therefore, in the following analyses, we combined data from the two sexes.

For each participant, mean accuracy was calculated across the four models for each expression at each difference level (Figure 2.6). For each expression, a mixed model ANOVA was conducted on mean accuracy with age as a between subject factor and difference level (10%, 15%, 20%, the levels tested at all four ages) as a repeated measure. Interactions between age and difference level were investigated by looking at the simple main effect of age at each difference level. Dunnett's tests comparing each group of children to adults (one-tailed, testing the hypothesis that children have lower accuracy than adults) were used to investigate significant age differences at any difference level.

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[8] The conclusions are similar if the analyses are based on mixed model ANOVA with Age as a between subject factor, and Expression and Difference level as repeated measures. There are significant main effects of Age, $F(3,91) = 11.22, p < .01$, Expression $F(2,182) = 3.29, p < .05$, and Difference level, $F(2,182) = 38.18, p < .01$, and a significant three-way interaction among these factors $F(12,364) = 2.47, p < .01$. To investigate the interaction, we examined the effects of Age and Difference level for each expression. The results are the same as when the data for each expression are analyzed separately.

To examine whether accuracy increases with increasing difference between two intensities, we tested linear contrasts between accuracy and the 4 levels of difference for each age group.

Results

Happy expression

The ANOVA revealed significant main effects of age, $F(3,91) = 8.31, p < .01, \eta_p^2 = .22$, and difference level, $F(2, 182) = 15.39, p < .01, \eta_p^2 = .15$, and a significant interaction between age and difference level, $F(2,91) = 5.55, p < .01, \eta_p^2 = .11$. There were main effects of age at all three difference levels (ps < .01, η_p^2 = .25, .16, .09 for 10%, 15%, and 20%, respectively). Dunnett's tests revealed that 5-year-olds were less accurate than adults at the 10% ($p < .01$, *Cohen's d* = 1.55) and 15% ($p < .01$, *Cohen's d* = 1.17) difference levels, but not the 20% difference level ($p > .10$) and that 7-year-olds were less accurate than adults at the 10% ($p < .01$, *Cohen's d* = .69) and 20% ($p < .01$, *Cohen's d* = .88) difference levels. Ten-year-olds did not differ from adults at any difference level (*ps* >.10)

Sad expression

There were significant main effects of age, $F(3,91) = 6.47, p < .01, \eta_p^2 = .18$, and difference level, $F(2,182) = 22.47, p < .01$. $\eta_p^2 = .20$. There was no significant interaction between age and difference level, $F(6,182) < 1$. Therefore, we investigated the effect of age by collapsing the data across difference levels.

Dunnett's test revealed that the 5-year-olds and the 7-year-olds were less accurate than adults (*ps* $< .01$, *Cohen's d* = 1.21, 0.77, for 5 and 7, respectively), while the 10-year-olds were not different from adults ($p > .10$).

Fearful expression

The results for the fearful expressions were similar to the results for the sad expressions. There were significant main effects of age, $F(3,91) = 7.15, p < .01$, $\eta_p^2 = .19$, and difference level, $F(2, 182) = 7.36, p < .01$, $\eta_p^2 = .08$. There was no significant interaction between age and difference level, $F(6,182) = 1.02, p > .10$. When we collapsed the data across difference levels, Dunnett's test revealed that the 5-year-olds and the 7-year-olds were less accurate than adults (*ps* $< .01$, *Cohen's d* = 1.03, 1.16, for 5 and 7, respectively), while the 10-year-olds were not different from adults ($p > .10$).

Linear contrasts

Adults and the 10-year-olds showed linear increments in accuracy with increasing difference level for all three expressions (*ps* $< .01$, $\eta_p^2 = .57$ [happy], .75 [sad], .60 [fearful] for adults, $\eta_p^2 = .53$ [happy], .35[sad], .60[fearful] for the 10-year-olds). The 5-year-olds showed linear increments in accuracy with increasing difference level only for happy expressions ($p < .01$, $\eta_p^2 = .35$). The 7-year-olds showed significant linear increments in accuracy with increasing difference level for sad and fearful expressions (*p*s < .01, η_p^2 = .67 for sad, η_p^2 = .42 for fearful) and a trend for happy expressions (*p* = .077, η_p^2 = .21).

Discussion

Infants as young as 7 months are able to discriminate between two happy or two fearful faces differing in intensity (Nelson, 1987). Here we report the first study to investigate developmental changes in children's ability to discriminate between different intensities of happy, sad, and fearful expressions, all of which were above threshold. Younger children were less sensitive than adults to subtle differences in the intensity of a facial expression: the accuracy of 5- and 7-year-olds was significantly lower than that of adults for all three expressions and for sad and fearful expressions 5-year-olds' accuracy did not increase as the task was made easier by increasing the difference in intensity between the two faces. By age 10, children were adult-like on all of the measures.

The insensitivity in young children to differences in the intensity of facial expressions may hinder their ability to perceive subtle changes in facial expressions in social situations. Those subtle changes could otherwise function as cues and feedback during social interactions. Note, however, that in real-world situations, children's sensitivity to such changes in the intensity of facial expressions is likely to be aided by dynamic information, as it is in adults (Ambadar, Schooler, & Cohn, 2005). We will discuss the limitation of using static images further in the general discussion.

General Discussion

The current study used facial expressions of varying intensity to investigate children's sensitivity to happy, sad, and fearful expressions. Children's threshold for indicating that a happy face is expressive (i.e., not neutral) is adult-like by age 5, but their accuracy in discriminating different intensities of happy expressions improves after age 5, with continued improvement between age 7 and age 10. These same patterns emerged for sad faces. However, unlike happy faces, even at age 10, children are more likely than adults to misidentify a sad face (as fearful). The pattern is different for fearful faces: children have higher thresholds than adults to recognize that a fearful face is expressive through age 7 and at age 5, but not 7, are significantly more likely to misidentify it (as sad) even at high intensities. As with happy and sad faces, until age 10, they also are less accurate at determining which of two fearful expressions is more intense.

Before we attribute the statistical effects of age to developmental changes in sensitivity to facial expressions, we must consider the alternative possibility that they arise from more general changes such as improvements in memory, attention, or motivation. Developmental improvements in these factors may lead to developmental improvements in children's performance on our tasks, by, for example, making it more likely that they will attend to the face long enough to detect a subtle facial expression or notice that it differs only slightly from the neutral face seen a moment earlier. Although such alternatives can never be completely eliminated, they are unlikely to account for the patterns reported here for the following reasons. First, the story scenario and visual icons helped to make the task easily understood by all age groups tested, as evidenced by the high accuracy in recognizing intense expressions in Experiment 1 and above chance performance in Experiment 2. As well, the game scenario appeared to be successful in motivating children to perform the task, as evidenced by the low drop-rate (3 of 75 children). Second, we minimized memory demands by using unlimited viewing time for both experiments and displaying the two faces to-be-compared simultaneously in Experiment 2. Third, the structure of the tasks was the same for all three expressions but we found different developmental patterns across expressions. Therefore, the developmental changes found here are likely to arise, at least in part, from developmental changes in sensitivity to facial expressions. Of course, developmental changes in attention and memory may affect the information children extract from faces during everyday social interactions—and, in turn, lead to developmental changes in sensitivity to facial expressions.

The developmental patterns identified here may have been influenced by the use of the static faces of adults as the targets rather than the faces of children or dynamic images. It is possible that children are more sensitive to subtle facial expressions in the faces of their peers, from whom subtle feedback may be especially salient to the child for regulating ongoing social interactions, or in dynamic images of the type typically seen during social interactions. Indeed adults are more accurate in recognizing facial expressions from dynamic displays than from static images, likely because the dynamic information enhances the perception of change (Ambadar, Schooler & Cohn, 2005). Had we used dynamic displays, the difference between adults and children might have been diminished, but it could instead have been increased if adults are more adept than children at using the dynamic cues. It is unlikely that we would have found greater sensitivity had we used the faces of children rather than adults because there is no systematic difference in the results from previous studies using the faces of adults (Durand et al., 2007; Markham & Wang, 1996; Vicari et al., 2000) and of children (Boyatzis et al., 1993; Camras & Allison, 1985; Widen & Russell, 2003). We also note that children need to become adept at reading the subtle facial expressions on the faces of their parents, teachers, friends' parents, and club leaders, and our results indicate that this skill develops slowly during middle childhood and at different rates for different facial expressions. A future study could use the technique described here to investigate empirically whether there is any difference in sensitivity for peer versus adult faces, as well as whether sensitivity is higher for faces of familiar individuals.

The errors by 5-year-olds in detecting low intensity expressions of fear and sadness (Experiment 1) and in discriminating intensity differences in all three expressions (Experiment 2) might be related to limits on their visual acuity and contrast sensitivity, limits that disappear by 7 years of age (Ellemberg, Lewis, Liu, & Maurer, 1999; reviewed in Maurer & Lewis, 2001). Limits on sensitivity to high spatial frequencies (i.e., fine detail) will make it harder for 5-year-olds to see the subtle differences in the shape of the mouth and eyes that distinguish neutral from expressive faces, both in our experiment and in real-world interactions. Studies of adults indicate that discrimination of neutral faces from faces conveying happiness, sadness, or fear is optimal when high spatial frequencies are available (Goren & Wilson, 2006). High spatial frequencies are likely also important for discriminating between intensities of the same emotion and in recognizing which emotion is conveyed in low intensity exemplars. Indirect evidence for their role in correct identification is the drop-off in adults' accuracy when faces are moved to the periphery, where acuity and contrast sensitivity are known to be degraded (Goren & Wilson, 2006). Thus, limitations in acuity and contrast sensitivity may limit 5-year-olds' performance on our tasks and real world processing of facial expressions. However, they cannot explain the limitations at age 7 because by that age both acuity and spatial contrast sensitivity are adult-like (Ellemberg et al., 1999).

Developmental changes in two other basic visual abilities may contribute to improved sensitivity to subtle facial expressions: vernier acuity and contour integration, both of which continue to improve into early adolescence (Kovács, Kozma, Fehér, & Benedek, 1999; Skoczenski & Norcia, 2002). Both require fine sensitivity to the alignment between two local elements: to judge which one is offset in a particular direction (vernier acuity) or to judge which elements among many form a shape-defining contour (contour integration). Improvements in these visual abilities will enhance the ability to detect small changes in the relationship between two nearby facial features. Some critical information for expressions is conveyed in this way: for example, by the distance of the eyebrows from the eyes and each other. Although children begin to process faces holistically by 4-6 years of age (de Heering, Houthuys, & Rossion, 2007; Mondloch, Pathman, Le Grand, & Maurer, 2007; Pellicano & Rhodes, 2003; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998), it takes many years for children's face processing abilities to reach adult levels. Children younger than 10 are not adult-like in processing facial identity based on small differences in the spacing of features ("second-order relations"; Mondloch, Le Grand, & Maurer, 2002; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Dobson, Parson, & Maurer, 2004; but see McKone & Boyer, 2006; Pellicano, Peters, & Rhodes, 2006, for adult-like sensitivity on some tasks at a younger age). The late improvements in sensitivity to small differences in the relationship between neighboring facial features may contribute to the observed improvement in distinguishing low intensity emotions from neutral (Experiment 1) and in discriminating between two intensities of the same emotion (Experiment 2).

The limitations on acuity, contrast sensitivity, vernier acuity, contour integration, and sensitivity to facial feature spacing not only will affect the information children pick up in our laboratory task, but what information the child picks up from the world, where context can serve as a tutor to aid the child in deciphering the meaning of subtle visual cues to emotion. Context will often disambiguate whether an individual is feeling neutral or mildly emotional, and which emotion is being felt. In addition to visual improvements, cognitive changes may affect children's ability to learn from such contextual cues. Deciphering the context often requires taking the perspective of the person conveying the emotion, and perspective-taking ability continues to develop through adolescence (Choudhury, Blakemore & Charman, 2006). In fact, one explanation of the difficulties individuals with autism have with decoding facial expressions is their deficiency in taking other people's perspective (Baron-Cohen, 2002).

The contribution of experience to developmental changes in sensitivity to facial expressions has been supported empirically by comparing typically developing children to children who are likely to have had abnormally high or low exposure to facial expressions. Neglected children, whose rearing environment is likely characterized by fewer social interactions than normal, are less accurate at discriminating facial expressions than children reared in a normal social environment (Pollak, Cicchetti, Hornung & Reed, 2000). Physically abused children, who can be assumed to have more than the usual amount of exposure to anger, have a lower threshold to detect anger in a face, but perform like typical children in detecting happy and fearful expressions (Pollak & Sinha, 2002). While visuo-cognitive development and experience both likely contribute to the development of facial expression processing, they may not be separate factors but ones that interact with each other. When children with immature sensitivity to facial expression and immature visual-cognitive skills interact with other people, they may fail to notice subtle facial expressions (subtle sadness after a loss) or to modify their behaviour appropriately even when they see intense facial expressions (mom's surprise that the house is clean versus that the child lost a shoe again at school). Improvements in understanding contextual cues and the perspective of others will allow the child to more appropriately modify behaviour in response to a facial expression and may cause the child to attend more carefully to informative facial expressions, leading to improved sensitivity. Improvements in sensitivity to facial expressions, in turn, may make expressive information more salient and hence more likely to affect the child's responses in social interactions, leading to improved social cognitive skills.

Our results suggest that sensitivity to happy, sad, and fearful expressions develop at different rates. However, it may be problematic to make direct comparisons of the pattern of age differences for the three expressions because the endpoints (100% intensity) of each expression may not have the same amount of physical difference from neutral—in our experiment and, perhaps, in the real world. It is possible that children were adult-like with happy expressions but not fearful expressions, simply because the physical difference between the endpoint of our happy expressions and neutral might have been larger than the physical difference between the endpoint of our fearful expressions and neutral. If so, the physical difference between two adjacent intensities in happy faces (e.g., 0% versus 5%) would be larger than the physical difference between those two values in fearful faces. As a result, happy faces would be easier to detect than fearful faces. This scaling issue is inherent in studies of facial expression, even those limited to intense expressions.

Two analyses of our stimuli suggest that we succeeded in creating a stimulus set in which the endpoints were equally distinct from neutral and hence that it is reasonable to compare the developmental patterns across expressions. First, the endpoint faces were selected because adults in a previous study (Palermo & Coltheart, 2004) had rated them as comparably intense examples of the emotional expression: on a 7-point scale, adults gave the endpoint expressions a mean intensity rating, averaged across the four models, of 5.43 for the happy faces, 5.35 for the sad faces, and 5.2 for the fearful faces. Second, correlations between the luminance values in the endpoint faces and in the neutral face were similar for each of the three expressions. For each model, we converted the four pictures (100% happy, 100% sad, 100% fear, neutral) to grayscale images with 256 levels of intensity. We correlated the luminance values of corresponding pixels in the neutral face and each of the three expressive faces, using normalized cross-correlations (Gold, Sekuler & Bennett, 2004). The means of the correlation coefficients across the four models were .87 for happy compared to neutral, .84 for sad compared to neutral, and .85 for fearful compared to neutral. These values suggest that our endpoint pictures have similar physical differences to their corresponding neutral faces. However, it is possible that, in the real world, the peaks of different expressions may involve different amounts of feature displacement away from a neutral expression (e.g., more displacement for surprise than for happiness or sadness). Future studies could investigate this possibility by measuring the maximum displacement possible of the muscles activated for each expression, asking adults to rate the naturalness of simulations of those maximum displacements and/or creating a data base of expressions generated in natural situations that evoke intense feelings. Another methodological concern is that we assumed that linear morphing between a neutral face and an emotional face accurately represents the change in intensity of the corresponding facial expression. Although the same technique was used by previous studies (Blair et al., 2001; Herba et al., 2006, 2008; Hess, Blairy & Kleck, 1997; Thomas et al., 2007), it is possible that in naturally occurring facial expressions, intensity of feeling is not related linearly to facial muscle displacement. To our knowledge, there is no study directly investigating the quantified relationship between intensity of facial expression and displacement of facial features.

In summary, by using varying intensities of facial expression, we made new discoveries about the development of sensitivity to happy, sad, and fearful facial expressions. Future studies could use the techniques described here to study age differences in sensitivity to other facial expressions and how that sensitivity varies with the familiarity of the face (same versus other race; familiar versus unfamiliar; child versus adult) and with the possible misidentifications (e.g., fear with surprise). As well, the threshold technique used in the current study could be used to measure sensitivity to facial expressions in special population, such as children with autism, children with abnormal visual experience, and shy children.

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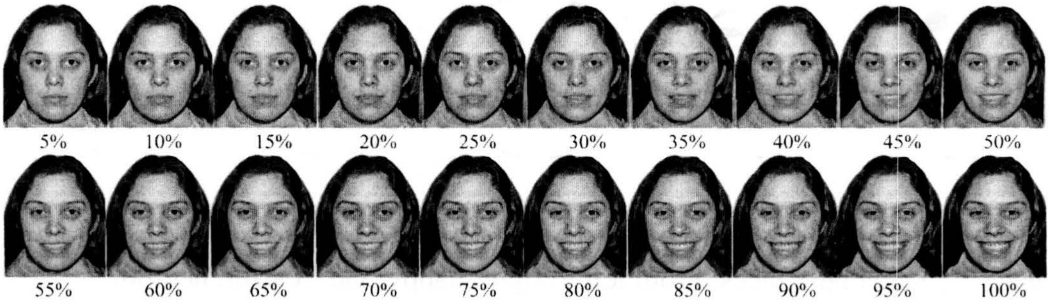
(a)



(b)

(c)

Figure 2.1 Examples of happy (a), sad (b), and fearful (c) expressions at varying intensity levels.

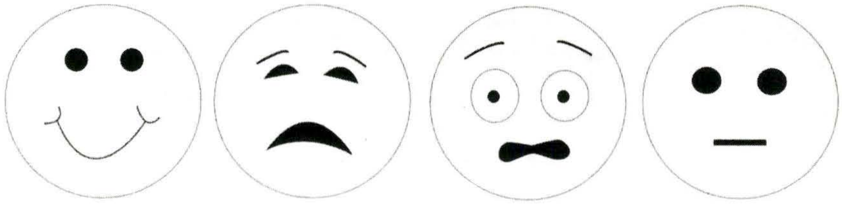


Figure 2.2 Schematic faces. From left to right: happy, sad, fearful, neutral.

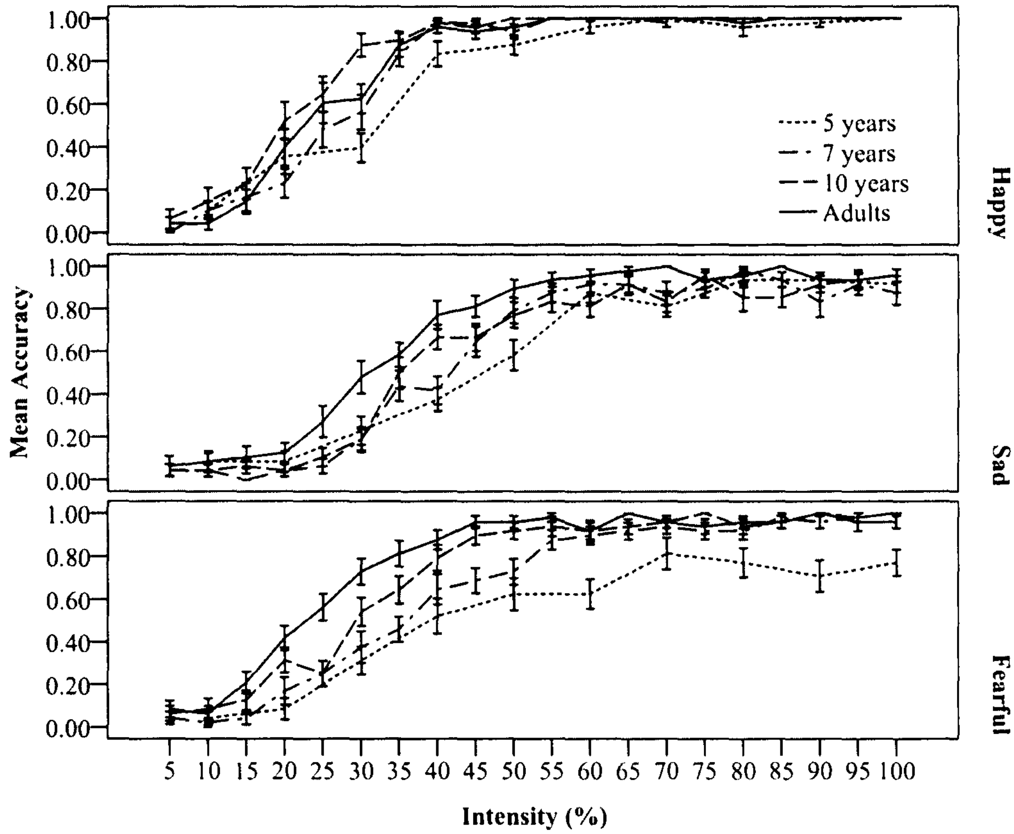


Figure 2.3 Mean accuracy (± 1 *s.e.*) for each expression at each age in Experiment 1.

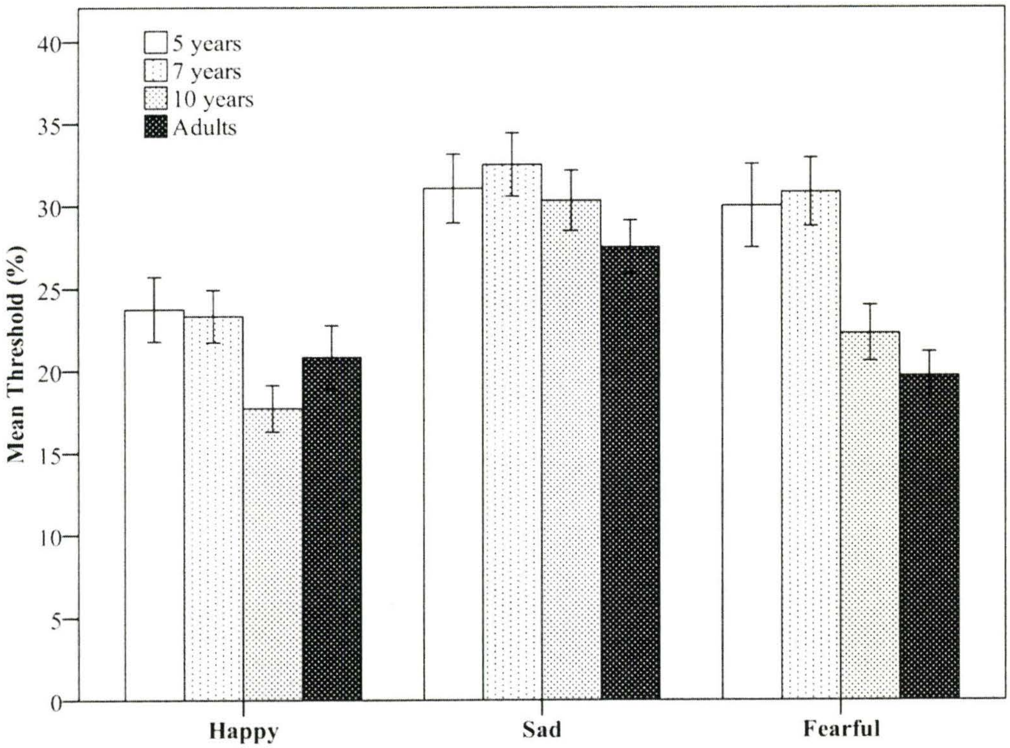


Figure 2.4 Mean threshold (± 1 *s.e.*) for each expression at each age.

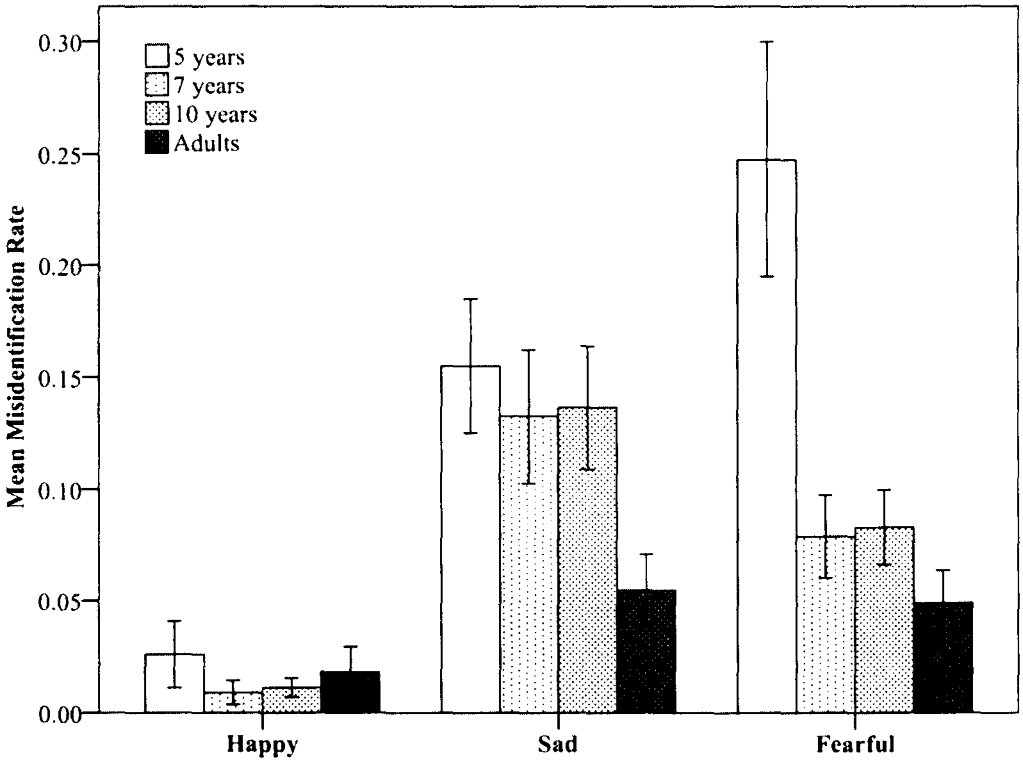


Figure 2.5 Misidentification rate (± 1 *s.e.*) for each expression at each age.

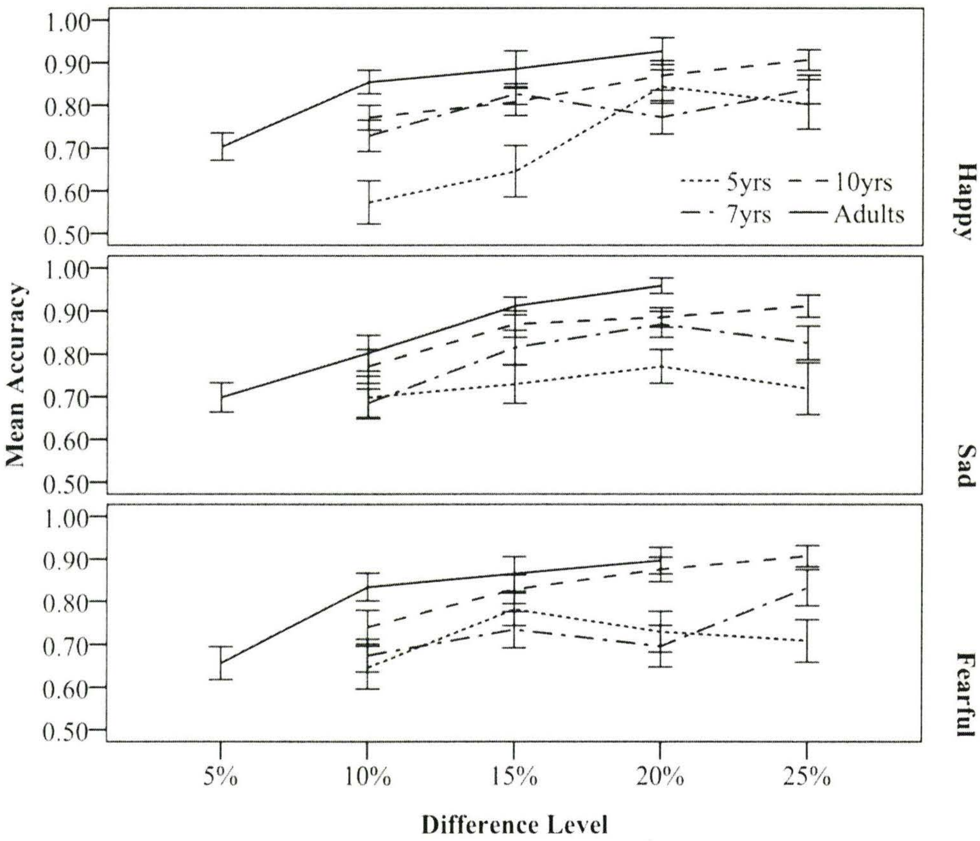


Figure 2.6 Mean accuracy (± 1 *s.e.*) for each expression at each age in Experiment 2.

Table 2.1

a) Mean misidentification Rates

	Happy			Sad			Fearful		
Misidentified as	Sad	Fearful	Total	Happy	Fearful	Total	Happy	Sad	Total
5-year-olds	0.3	2.4	2.7	3.0	12.4	15.4	2.6	22.9	25.5
7-year-olds	0.5	0.4	0.9	3.4	10.0	13.4	1.2	7.0	8.2
10-year-olds	0.6	0.5	1.1	4.0	10.6	14.6	2.8	5.9	8.7
Adults	1.3	0.8	2.1	0.3	5.0	5.3	0.9	4.1	5.0

b) Mean number (standard deviation) of faces identified as expressive for each expression averaged across models. (For each expression except neutral, 5-year-olds saw 10 faces of each model; other age groups saw 20 faces of each model)

	Happy	Sad	Fearful
5-year-olds	7.7 (1.0)	6.9 (0.9)	7.1 (1.1)
7-year-olds	15.4 (1.5)	13.5 (1.8)	13.9 (1.9)
10-year-olds	16.5 (1.5)	14.0 (1.8)	15.6 (1.8)
Adults	15.9 (1.9)	14.6 (1.6)	16.1 (1.5)

Chapter 3

Preface

The research described in this chapter has been written as a manuscript entitled "A happy story: developmental changes in children's sensitivity to facial expressions of varying intensity" and submitted to *Journal of Experimental Child Psychology*. The submitted manuscript was accepted for publication.

The purpose of the research in Chapter 3 is twofold. First, in Chapter 2, we investigated children's sensitivity to subtle facial expressions of happiness, sadness, and fear. We found patterns of developmental changes that are not obvious in studies using intense facial expressions. However, we did not examine children's sensitivity to other facial expressions that are also important signals in social interaction. In the research described in Chapter 3, we used the same methods as in Chapter 2 to investigate children's sensitivity to subtle facial expressions of surprise, disgust, and anger. Second, in the research described in Chapter 2, the forced-choice procedure limited the response alternatives. Therefore, the developmental patterns we found may be affected by the particular groupings of facial expressions. In the research described in Chapter 3, we investigated the effect of facial expression groupings by testing children's sensitivity to the same facial expressions tested in Chapter 2, namely, happiness, sadness, and fear, but in different groupings than in Chapter 2. Consistent with the previous findings in Chapter 2, children as young as age 5 were as sensitive as adults to happy expressions. Children's sensitivity to surprised, disgusted, and fearful expressions improved between age 5 and 10, and their sensitivity to sad and angry expressions was not adult-like even at age 10. The details of the age differences for sad and fear were affected by the groupings of expressions. The results indicate slow development of sensitivity to subtle expression of all basic emotions except happy.

Running Head: SENSITIVITY TO SUBTLE FACIAL EXPRESSIONS

A Happy Story: Developmental Changes in Children's Sensitivity to Facial Expressions of Varying Intensity

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Abstract

Using 20 levels of intensity, we measured children's thresholds to discriminate the six basic emotional expressions from neutral and their misidentification rates. Combined with the results of an earlier study using the same method (Gao & Maurer, 2009), the results indicate that by age 5, children are adult-like, or nearly adult-like, for happy expressions on all measures. Children's sensitivity to other expressions continues to improve between age 5 and 10 (surprise, disgust, fear) or even after age 10 (anger, sad). The results indicate that there is a slow development of sensitivity to the expression of all basic emotions except happy. This slow development may impact children's social and cognitive development by limiting their sensitivity to subtle expressions of disapproval or disappointment.

Keywords: facial expression; development; intensity; threshold; misidentification; morphing

Introduction

The ability to accurately recognize other people's facial expressions is important for social interactions but takes surprisingly long to develop. Although infants can categorize some facial expressions (e.g., 5-month-olds: happiness, Bornstein & Arterberry, 2003; 7-month-olds: surprise, Caron, Caron, & Myers, 1982; reviewed by Nelson, 1987), it is many years before children reach adults' level of accuracy and speed in recognizing facial expressions (e.g., De Sonneville et al., 2002; Durand, Gallay, Seigneuric, Robichon & Baudouin, 2007; Kolb, Wilson, & Taylor, 1992; reviewed in Herba & Phillips, 2004). Even though by early adolescence children are adult-like on behavioral measures of recognition, their corresponding brain activity is still different from that of adults until late adolescence (Batty & Taylor, 2006; Monk et al., 2003; Thomas et al., 2001).

To map this long developmental course, previous studies used photographs of prototypical expressions from different emotion categories. These prototypical expressions are usually posed by trained actors/actresses, using strictly prescribed muscle movements (e.g., Pictures of Facial Affect, Ekman & Friesen, 1976) The posed expressions usually are high in intensity. With such prototypical expressions, children show a large improvement in accuracy in tasks requiring matching or labeling between 3 to 7 years of age (Camras & Allison, 1985; Durand et al., 2007; Markham & Wang, 1996; Vicari, Reilly, Pasqualetti, Vizzotto & Caltagirone, 2000), with an improvement in processing speed between 7 and 10 years of age (De Sonneville et al., 2002). There are also different developmental trajectories for different expression categories, with positive expressions being recognized earlier and more accurately than negative expressions (Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; Widen & Russell, 2003).

Photographs of intense expressions are a useful tool to study the development of the recognition of facial expressions, but in everyday life, we see less intense expressions more frequently than intense facial expressions. Only a few studies have tested children with facial expressions at varying levels of intensity. One method is to select expressions based on adult ratings of their intensity. Gosselin and Pelissier (1996) selected expressions at three intensities based on ratings of the intensity of activation of Facial Action Coding System action units (FACS, Ekman & Friesen, 1978). Nine- to 10-year-old children were as accurate as adults in recognizing happy expressions at all three intensities but were not as good as adults in recognizing disgusted expressions of low intensity. No other age groups or expressions were tested.

A second way to control the intensity of facial expressions is to create blends between a neutral face and an expressive face using a morphing technique (Benson, 1994; Hess, Blairy, & Kleck, 1997), which simulates facial muscle movement in a linear manner. Other than our own work (Gao & Maurer, 2009), three studies have used this technique to study developmental differences. Thomas and colleagues (2007) tested with static photos representing 6 levels of fearful or angry expressions. Two other studies tested children with 4-10 levels of intensity of 5 basic expressions (all except surprise) using a morphing technique in which the child saw animated sequences moving from neutral to successively higher intensities with a fast (0.05 second/frame, Montirosso et al., in press) or a slow (1 second/frame, Herba et al., 2008) frame rate and the measure was the frame at which the expression was first recognized. The reported pattern of improvement with age varies with expression and method. For example, Thomas and colleagues (2007) found that both children (7-13 years) and adolescents (14-18) are less sensitive than adults in discriminating static photos of anger and fear from neutral expressions, while Montirosso and colleagues (in press) found that sensitivity to animated expressions is already adult-like for anger at age 7 and for fear at age 10. Unlike Gosselin and Pelissier (1996), they found no age changes in sensitivity to disgusted expressions. They also reported that sensitivity to happy expressions is already adult-like at age 7, while sensitivity to sad expressions is not adult-like until age 13. However, it is not clear whether the improvements with age with their animated technique reflect increased sensitivity to low intensity expressions or in the speed of processing that allows the expression to be recognized after less exposure/fewer frames. Herba and colleagues (2008; see also, Herba, Landau, Russell, Ecker, & Phillips, 2006, for results on matching expression across intensity) found improvements in sensitivity for happy and fearful expressions between 4 and 15 years of age for photographs of both familiar and unfamiliar adults, with no facilitatory effect of familiarity. However, it was not possible to infer when children's sensitivity reaches adults levels because there was no adult comparison group.

These previous studies document developmental changes in the accuracy of recognizing facial expressions of varying intensity. However, they fail to distinguish between two types of error. The first type is the failure to detect expression at low intensity levels, and the second type, which can occur at any intensity level, is to misidentify one expression as another. Studies using forced choice procedures without neutral as a choice (Herba, et al., 2008; Montirosso, et al., 2010; Gosselin & Pelissier, 1996) do not permit identification of the intensity at which children started to see expression in a face (that is, stopped making the first type of error more frequently than adults). Thomas and colleagues (2007) used a two alternative forced-choice procedure in which a fearful (or angry) face was shown, followed by a choice between a verbal label of neutral or fearful (angry). Although that procedure measured the first type of error, it did not measure misidentifications between fearful and angry expressions.

In a recent study, we (Gao and Maurer, 2009) investigated the development of sensitivity to the facial expressions of happiness, sadness and fear with 20 levels of intensity. We measured sensitivity with 1) threshold level of intensity to detect expression in the face, that is, to see it as non-neutral, and 2) misidentification rate above detection threshold. There were different developmental patterns for the three expressions tested. For happiness, even the 5-year-olds were as sensitive as adults on both measures. For sadness, by 5 years of age, children had adult-like thresholds to detect expression in sad faces (i.e., to see them as non-neutral), but even at 10 years of age, they were more likely to misjudge sad as fearful. For fear, children's detection thresholds were not adult-like until 10 years of age, and 5-year-old children often confused it with sadness. However, the conclusions of this study are limited by the fact that it included only three facial expressions and hence restricted the possible misidentifications among the expressions. As well, it is also important to investigate the developmental trajectory for other basic facial expressions, namely anger, disgust, and surprise, with a technique that distinguishes between the two types of error.

In the current study, we investigated developmental changes in sensitivity to facial expressions of the six basic emotions at varying intensity levels using the same methodology as in our previous study (Gao & Maurer, 2009). Two groupings of facial expressions were selected based on confusability reported in previous studies of adults (Palermo & Coltheart, 2004): 1) happiness, fear, surprise, neutral and 2) sadness, disgust, anger, neutral. Children at age 5, 7, and 10 years of age and a comparison group of adults were asked to categorize facial expressions with varying intensity in a game scenario. The intensity levels varied from 0% (neutral) to 100% (peak) for each expression. The results revealed developmental changes in sensitivity to facial expressions of the six basic emotions at different intensities as measured by the threshold to differentiate the expression from neutral and the rate of misidentification among expressions. By comparing the current findings to the findings from our previous study (Gao &

Maurer, 2009), we can also examine the effect of context, that is, the effect of the expression groupings on thresholds and misidentification rates for the expressions used in both studies, namely happy, sad, and fearful.

Methods

We tested new groups of participants from the same age groups as in our previous study using the same methods (Gao & Maurer, 2009).

Participants

The final sample consisted of 24 5.5-year-old children (±3 months), 24 7.5-year-old children (±3 months), 24 10.5-year-old children (±3 months), and 24 adults (aged 18 to 22). Half the participants in each age group were female. Child participants were recruited from names on file of parents who had volunteered their child at birth for participation in later studies. Adult participants were undergraduate students enrolled in an introductory psychology course and received course credit for participation. All the participants had normal or corrected-to-normal vision. Four additional participants (one 5-year-old, one 7-year-old, and two 10-year-olds) were excluded from data analysis because they failed visual screening (criteria: 20/25 for 5- and 7-year-olds, 20/20 for 10-year-olds and adults).

Stimuli

We selected photographs of four models (two male and two female), each posing intense facial expressions of the six basic emotions (happiness, sadness, fear, anger, disgust, and surprise) and neutral from the NimStim Face Stimulus Set (Tottenham et al., 2009; Model numbers 03, 10, 24, 25). Each photograph had a resolution of 506 × 650 pixels with RGB color. The facial expressions were generated by professional actors who were instructed to pose specific expressions, rather than to make the specific facial muscle movement prescribed in the Facial Action Coding System (FACS, Ekman & Friesen, 1978). As a result, some of the posed expressions may include facial action units that are not canonical. Nevertheless, this stimulus set has been validated by high agreement among adults on the posed expression (Palermo & Coltheart, 2004; Tottenham, et al., 2009). For the current study, we chose specific models for which adults have high agreement on the posed expressions (mean = 86.9 %, range = 62.5-100 %) and give high ratings of intensity (mean = 5.5, range = 4.4 -6.4, on a 7-point scale) for the expression of all six basic emotions (Palermo & Coltheart, 2004).

For each of the six expressions of each model, we created 20 levels of intensity ranging from 5% to 100% with 5% increment by morphing the emotional face with the neutral face (for details, see Gao & Maurer, 2009). As a result, for each model, there were 121 images (6 expressions × 20 intensities + 1 neutral face; see Figure 3.1 for examples). In total, there were 484 images across the four models. We printed out all the images in full color using a Cannon CP-200 photo printer onto 4”×6” photo paper with lamination. The sizes of the faces were approximately 7 cm (width) × 11 cm (height).

Design

Each participant finished two testing blocks with the order of blocks counterbalanced within each sex within each age group. One block consisted of pictures showing happy, surprised, and fearful expressions at all intensity levels from one male model and one female model plus four neutral faces of each model. The other block consisted of pictures showing sad, disgusted, and angry expressions at all intensity levels from one male model and one female model plus four neutral faces of each model. As a result, each block contained 128 pictures ([3 expressions × 20 intensities + 4 neutral faces] × 2 models). Each participant saw the same male model and the same female model in both blocks. Half of the participants of each sex within each age group were assigned to model 25 (male) and model 03 (female), and the other half of participants were assigned to model 24 (male) and model 10 (female). For the 5-year-old children, pilot work indicated the procedure was too long and, as in our previous study (Gao & Maurer, 2009), the number of photographs was reduced by using only half of the intensities: 10 levels of intensity with 10% intervals from 10% to 100%, for 64 pictures ([3 expressions × 10 intensities + 2 neutral face] × 2 models) in each block. Therefore, each 5-year-old participant saw 128 pictures, while each participant in the other age groups saw 256 pictures.

Procedures

The procedures were approved by the institutional Research Ethics Board. After the procedures were explained, we obtained written consents from the adult participants or from a parent of the child participants, and we obtained verbal assent from the 10-year-old children.

We used the same procedure as in previous study (for details, see Gao & Maurer, 2009). In each block, the experimenter introduced a game scenario to the participant. In this game, the participant helped people by putting their pictures into appropriate houses according to the expressions/feelings shown on the pictures. Four miniature houses were presented for each block, each with a schematic face (Figure 3.2) on its roof showing the three expressions in the block plus neutral. The experimenter introduced the game as follows: "In one of these houses, people are telling a happy (scary, surprising) story (or a story that makes people sad [angry, disgusted] in the other block). Could you tell me which one it is?" After the participant pointed correctly to the appropriate houses for the three expressions in that block, the experimenter said, "In one house, people are not telling a story and they are not feeling anything. Could you point it out?" After the participant correctly identified the neutral house, the experimenter showed a box with the test photographs inside and said, "Now we have more people here. Your job is to help them to find the right house. They can only go to one house if they have the same feeling as people inside of that house." The experimenter emphasized that there could be different intensities by saying, "One thing you may notice is that sometimes a whole group feels happy, but some feel just a little happy while others feel very happy. In this game, they all go together. Do the same for the surprised and scared people (or for the people who feel sad, angry, disgusted in the other block). Don't worry about how surprised or scared they are." The experimenter handed the photographs to the participant one by one. The participant put the photograph into the house that he/she judged appropriate through a slot in the roof. Since the slots in the roofs of the toy houses were very narrow (about 1 cm wide), participants could not see the cards they had already placed in each house. All participants appeared to understand the task and to enjoy the game. Each block took approximately 30 minutes for children and 25 minutes for adults to complete. There was a 5 minutes break between the two testing blocks.

Data Analysis

We analyzed the data in the same way as in our previous study (Gao & Maurer, 2009). The data consisted of individual accuracy scores at each intensity level for each expression, averaged across the two models seen by that participant. The means for each age group and expression are shown in Figure 3.3. However, there were two types of error: at low intensities, misidentifying an expressive face as neutral and, at high intensities, misidentifying one expression as another (e.g., classifying a sad expression as fearful). Therefore, we did not use accuracy as the main measure of children's sensitivity to facial expressions. Instead, we quantified these two types of error by 1) calculating the threshold to discriminate each expression as different from neutral and 2) calculating the misidentification rates above threshold.

Thresholds

To calculate individual thresholds to discriminate each expression from neutral, we categorized each participant's responses as neutral or non-neutral, with non-neutral responses including both correct identifications (e.g., 50% happiness identified as happy) and misidentifications (e.g., 50% happy identified as surprise). Figure 3.4 shows the mean curves for each expression and age group. We fitted a cumulative Gaussian function to the responses of each participant for each expression in each age group by using the following formula:

$$P(discrimination) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{x} \exp\left(-\frac{(u-\mu)^2}{2\sigma^2}\right) du$$

where x is intensity and P is the probability of discrimination. The two parameters, μ and σ, are the mean and the standard deviation of the normal distribution $X \sim N(\mu, \sigma^2)$. We estimated μ using a maximum likelihood procedure. In this procedure, for each participant and expression, we first calculated the likelihood values of the 400 possible combinations of the 20 values of μ (5 to 100 with a step size of 5) and the 20 values of σ (5 to 100 with a step size of 5), given the cumulative Gaussian function. We then marginalized the estimation of σ by summing the likelihood values across all the values of σ for each value of μ. After marginalization, we used the μ value corresponding to the highest likelihood value as the estimation of threshold. This value corresponds to $P = 0.5$, that is, the intensity level at which 50% of the time the expressive face will be recognized as neutral and 50% of the time it will be recognized as expressive. This procedure gave us the best estimate of μ, while minimizing the influence of σ on the estimate. We calculated each participant's threshold for each expression by averaging across the independently derived threshold estimates for the two models.

Misidentification rates

We categorized non-neutral responses into correct responses and misidentifications. We calculated misidentification rates for each participant by dividing the frequency of misidentification by the total number of non-neutral responses the participant made across all intensity levels. The misidentification rates for each participant were calculated separately for the two models and then averaged. Table 3.1 indicates the mean number of faces that were chosen as non-neutral (the denominator in the calculation of the misidentification rates) at each age for each expression.

Analyses

For all the dependent measures, we applied a non-recursive outlier elimination procedure with a cutoff of 2.4-standard deviation based on the distribution for each facial expression tested at each age (Van Selst & Jolicoeur, 1994). We removed 1.7%, 2.6%, and 3% of the scores as outliers for thresholds (3 cases for age 5, 3 cases for age 7, 1 case for age 10, and 3 cases for adults), misidentification rates (3 cases for age 5, 4 cases for age 7, 4 cases for age 10, and 4 cases for adults), and accuracy scores at peak intensity (4 cases for age 5, 2 cases for age 7, 7 cases for age 10, and 4 cases for adults), respectively.

Preliminary analysis showed no effect of assignment to models 03 and 25 or 10 and 24 on the results for either threshold or misidentification; therefore we did not include model grouping as a factor in the main analyses. For both thresholds and misidentification rates, we conducted one-way analyses of variance (ANOVAs) with Age as a between subject variable separately for each expression. We also ran the same ANOVA on accuracy for the peak intensity expressions (100%) to allow direct comparison of our results to previous studies that used only intense expressions. Significant main effects of Age were analyzed by Dunnett's tests comparing each group of children to adults (one-tailed, testing the null hypothesis that children's performance is as good as that of adults).

The main analyses were conducted separately for each expression because we could not be sure that the 100% intensity examples were equivalently near the maximum possible expression for that emotion and hence that the 5% increments were scaled equally across expressions. This is an issue in any study comparing facial expressions. To minimize the problem, we chose the 100% intensity examples to be similar based on adult accuracy and intensity ratings in published norms (see Stimuli). Analyses comparing the physical difference of each expression from neutral also suggest that the scaling was similar across expressions (see Discussion). Nevertheless, the ratings and the physical differences were not identical for the 6 expressions and hence we took the more conservative approach of analyzing separately the effect of age on each expression for each of the three measures. This approach is also justified by an Age x Expression interaction for all three measures in an mixed-model ANOVA including Age and Sex as between subject variables and Expression as a repeated measure (thresholds: $F[10.4, 273.7]$, Greenhouse-Geisser corrected = 2.9, $p <.01$, partial $\eta^2 =.1$; misidentification: $F[7.3, 182.1]$, Greenhouse-Geisser corrected = 1.2, $p <.05$, partial $\eta^2 =.1$; accuracy at peak intensity: $F[15, 365] = 3.6$, $p <.01$, partial $\eta^2 =.13$). Those analyses also indicated that females had slightly lower thresholds ($Mean_{female}$=26.1%, $Mean_{male}$=29.4%, $F[1, 79] = 8.6$, $p <.01$, partial $\eta^2 =.1$) and misidentification rates ($Mean_{female}$ = 0.12, $Mean_{male}$=0.15, $F[1, 75] = 4.9$, $p <.05$, partial $\eta^2 =.06$) than males. Sex did not interact with age or expression and did not affect accuracy at peak intensity (all *ps* >.1).

Results

Happy expressions

In all four age groups, accuracy started to increase with intensity from a very low level (around 10%) and reached ceiling at around 60% intensity (Figure 3.3a). All age groups had perfect accuracy (100%) at the peak intensity. The mean threshold was around 25% for all age groups (Table 3.2) and there was no significant effect of age, $F(3,91) = 1$. For misidentification rates, in contrast, there was a significant main effect of age, $F(3,88) = 4.6, p < .01$, partial $\eta^2 = .14$. Although the misidentification rates were low (less than 5% for all age groups, see Table 3.3), the 5-year-olds had significantly higher misidentification rates than adults ($p <.05$, Cohen's $d=.9$). Five-year-olds' misidentifications were most likely to occur in the mid-intensity range around 20% to 50% (Figure 3.3a) and usually involved misinterpreting happy faces as surprised (Table 3.3). Thus, by age 5, children are nearly as sensitive as adults to expressions of happiness with no significant difference on any measure by age 7.

Sad expressions

For sad expressions, accuracy increased between 20% and 70% (Figure 3.3b), but the four age groups diverge in this range, with both 5-year-olds and 7-year-olds deviating from adults on some measures. Even at peak intensity (100%), there was a significant effect of age on accuracy, $F(3,86) = 7, p < .01, \eta^2 = .2$, with the 7-year-olds having significantly lower accuracy (88%) than adults (100%, $p <.05$, Cohen's $d = 1.1$), while the 5- and 10-year-olds were as accurate as adults. The differences in the mid-intensity range were captured by a significant effect of age on threshold, $F(3,91) = 9.8, p <.01, \eta^2 = .25$, with both the 5- and 7-year-olds having higher thresholds than adults (ps<.05, Cohen's d=1.3, 1.2), and a significant effect of age on misidentification rate, $F(3,88) = 4$, $p<.05$, $\eta^2 = .12$, with the 7-year-olds having a higher misidentification rate than adults ($p <.05$, Cohen's d=1.0). The major type of misidentification was to classify sad faces as disgusted (Table 3.3). Thus, both 5-year-olds and 7-year-olds are more likely than older groups to classify a mid-range sad face as neutral; in addition, 7-year-olds are more likely to misidentify it as conveying a different emotion, usually disgust, even at peak intensity. It is only between age 7 and 10 that children become as sensitive as adults on all three measures.

Fearful expressions

For fearful expressions, the curves for the four age groups are quite close to each other, with accuracy increasing with intensity between 5% and 55% (Figure 3.3c). All age groups performed well at peak intensity with no main effect of age, $F(3, 86) = 2$, $p = .12$. The thresholds ranged from 20.7% (adults) to 29.6% (5-year-olds, Table 3.2). There was a significant effect of age on threshold, $F(3,89) = 3.1$, $p<.05$, $\eta^2 = .1$. The 5-year-olds showed a significantly higher threshold to detect expression in fearful faces than adults ($p<.05$, Cohen's $d=.9$) but there was no difference between adults and the two older age groups (all $ps >$ .1). All four age groups made about 10% misidentifications, mainly from a confusion of fear with surprise (Table 3.3); there was no effect of age on misidentification rates $F(3, 89) < 1$. Thus, school-aged children are as sensitive to fearful expressions as adults, except for a higher threshold at age 5.

Surprised expressions

For surprised expressions, accuracy increased slowly with intensity, and approached an asymptote only beginning around 60% (Figure 3.3d). At peak intensity, accuracy ranged from only 54% (5-year-olds) to 77% (adults). There was a significant effect of age on accuracy at peak intensity, $F(3,90) = 3.7, p < .05, \eta^2 = .11$, and threshold, $F(3,89) = 10.1, p < .01, \eta^2 = .25$, with the 5-year-olds having lower accuracy than adults at peak intensity ($p < .05$, Cohen's $d = .6$) and higher thresholds ($p < .05$, Cohen's $d = 1.5$) but no differences between adults and the two older age groups. All four age groups made a substantial number of misidentifications, which ranged between 17.6% (adults) to 41.1% (5-year-olds), mainly from the confusion of surprise with fear (Table 3.3). The effect of age on misidentification rates was significant, $F(3,92) = 4.1, p < .01, \eta^2 = .12$, with the 5- and 7-year-olds making more misidentifications than adults ($ps < .05$, Cohen's $d = 1.0, .6$) but no significant difference between 10-year-olds and adults ($p = .32$). Thus, 5-year-olds are less sensitive than adults to surprised expressions even at peak intensity; sensitivity to the expressiveness in surprised faces improves to adult levels by age 7 but children still make significantly more misidentifications; it is only between age 7 and 10 that sensitivity becomes adult-like by all three measures.

Disgusted expression

For disgusted expressions, for all four age groups, accuracy increased sharply in the low intensity range (around 10% to 30%) followed by slower increases over a broad intensity range (35% to 100%, Figure 3.3e). At peak intensity, accuracy ranged from 60% (5-year-olds) to 70% (adults) and there was no significant effect of age, $F(3, 91) = 2, p = .12$. There was a significant main effect of age on thresholds, $F(3,91) = 4.1, p < .01, \eta^2 = .12$, with the 7-year-olds having a higher threshold than adults (p<.05, Cohen's d=1.0). There was also a significant effect of age on misidentification rate, $F(3,92) = 2.8$, p<.05, $\eta^2 = .08$, with the 5-year-olds making significantly more misidentification than adults (p<.05, Cohen's d=.7). The misidentification rates ranged between 26.7% (adults) to 41.3% (5-year-olds). All age groups tended to misidentify disgusted faces as sad (Table 3.3). Thus, 5-year-olds and 7-year-olds differ from adults in more often misidentifying disgusted faces as sad (age 5) or neutral (age 7); it is only between age 7 age 10 that children become as sensitive as adults on all measures.

Angry expression

For angry expressions, accuracy increased sharply between 20% to 50% for all four age groups, and reached ceiling at around 55% (Figure 3.3f). All age groups had perfect accuracy (100%) at peak intensity. There was a significant effect of age on thresholds, $F(3, 90) = 7.3$, p <.01, $\eta^2 = .2$, with all three groups of children having higher thresholds than adults (ps < .05, Cohen's d = 1.2, 1.2, 0.8, for 5, 7, and 10 respectively). The misidentification rates for all age groups were less than 7% (Table 3.3), with no difference among age groups, $F(3,88)$ =1.4, p=.26. Thus, throughout the age period between 5 and 10, children are more likely than adults to miss the expressiveness in an angry face at lower intensities and to mistake it as neutral.

Effect of number of levels of intensity

We tested the 5-year-olds with only 10 levels of intensity, whereas we tested the other age groups with 20 levels of intensity. The thresholds and misidentification rates estimated with more levels of intensity may be more accurate than those for the 5-year-olds estimated with fewer levels of intensity. (Peak intensity was the same for all ages and hence not affected by this difference). We investigated how the difference affected the developmental patterns by recalculating the thresholds and misidentification rates of adults based on responses for the 10 levels of intensity used with the 5-year-olds. The results for the misidentification rates were identical to those reported above. The results for thresholds were similar to what is reported above except that the thresholds of the adults for happy and disgusted expressions were significantly lower (that is, better) than those of 5-year-olds in the new calculation but not the original one. We have not highlighted these differences because adults' thresholds based on more levels of intensity are likely to be more accurate. In any event, we can rule out the possibility that the immaturities we report above for 5-year-olds are from overestimating their thresholds and misidentification rates based on fewer levels of intensity than used with the other age groups.

Effects of expression grouping

The choices of answers in the forced-choice procedure may affect the patterns of developmental changes found in the current study. To investigate the effect of expression grouping, we compared the current findings to our previous study (Gao & Maurer, 2009), in which we tested children's sensitivity to happy and fearful expressions grouped with sad instead of surprise as in the current study. We also compared sensitivity to the sad expressions in the previous study (when grouped with happy and fearful) to that in the current study (when grouped with anger and disgust). Specifically, for each of the three expressions that was common to the two studies we used an ANOVA for each measure (accuracy at peak intensity, threshold, and misidentification rate) with two between subjects factor (Age and Study).

For happy expressions, there was no significant effect of Study or interaction between Study and Age on any measure (all *ps* >.09). Therefore, our sensitivity measures for happy expressions were not affected by the specific grouping of expressions. For fearful expressions, there were significant interactions between Study and Age on both misidentification rates, $F(3,181) = 6.9, p <.01$, partial $\eta^2 = .1$, and accuracy at peak intensity, $F(3,178) = 5.6, p <.01$, partial $\eta^2 = .08$. Both interactions were caused by the fact that in our previous study (Study 1) the 5-year-olds misidentified fearful expressions as sad at a higher rate than adults at all intensities (Table 3.3). For fearful expressions, there was no main effect of Study on any measure nor interaction between Study and Age on thresholds (all *ps* >.1).

For sad expressions, there were significant main effects of Study on both threshold, $F(1,3) = 14.7, p <.05$, partial $\eta^2 = .83$, and misidentification rates, $F(1,3) = 10.7, p <.05$, partial $\eta^2 = .78$. Participants in Study 1 generally had higher misidentification rates than participants in Study 2, as a result of more misidentifications of less intense sad expressions as fearful in Study 1 (>10% in the three groups of children and 5% in adults, Table 3.3). Participants in Study 2 generally had higher (worse) thresholds for sad expressions than participants in Study 1 (Table 3.2). The elevated thresholds in Study 2 may be related to the fact that only negative expressions and neutral were included, where as in Study 1, sad expressions were tested with both positive and negative expressions. However, the exact reason for the elevation in threshold for sad expression in Study 2 is not clear. For sad expressions, there was no main effect of Study on accuracy for peak intensity expressions or interaction between Study and Age on any measure (all *p*s >.05).

These analyses indicate that the available choices in the forced-choice procedure affected the patterns of developmental changes in children's sensitivity to fearful and sad expressions, mainly because children but not adults confused sad and fearful expressions in Study 1. Grouping also affected the threshold to differentiate sad expressions from neutral. However, the reason for the latter effect is not clear.

Discussion

Using facial expressions with varying intensity, we investigated children's sensitivity to facial expressions of the six basic emotions by measuring their thresholds to discriminate each expression from neutral and the rates of misidentification. Like previous studies (e.g., Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; Widen & Russell, 2003), we found different developmental trajectories for sensitivity to different facial expressions. The current findings extend previous findings by using less intense facial expressions, of the type seen more frequently in everyday life, and by differentiating children's errors into those involving a failure to see that the face is expressing an emotion and those involving errors in identifying the emotion expressed. Below we compare our findings for each expression to the literature, consider methodological limitations that might have affected the results, and then offer hypotheses about possible causes of the different developmental trajectories for different emotional expressions.

We also found a small but reliable effect of sex, which did not interact with expression or age. Females had lower (better) thresholds than males (Cohen's d = 0.56) and lower rates of misidentification (Cohen's d = 0.37). Such a female advantage is consistent with the results from a previous meta-analysis on sex difference in sensitivity to facial expression (McClure, 2000). However, the effect found here is small and there are also studies that did not find a sex difference either with intense expressions (e.g., De Sonneville, et al., 2002; Vicari, et al., 2000) or expressions of varying intensity (e.g., Gao & Maurer, 2009; Herba et al., 2006, 2008).

Happiness

However measured, sensitivity to happy expressions develops more quickly than sensitivity to any other expression. For example, infants just 1-4 days old look longer at a happy face than at a fearful face with which it is paired, perhaps as a result of experience immediately after birth (Farroni, Menon, Rigato, & Johnson, 2007). Our results are consistent with previous studies indicating that young children's accuracy in recognizing happy expressions is better than their accuracy for other expressions (Camras & Allison, 1985; Durand et al., 2007; Kolb, Wilson, & Taylor, 1992; Markham & Adams, 1992; Vicari et al., 2000; Widen & Russell, 2003) and that by age 5, children are as sensitive as adults in recognizing intense happy expressions (Durand et al., 2007). Five studies have used less intense expressions and the results differ between those using dynamically varying intensity (Herba et al., 2008; Montirosso et al., 2010) and those using static photos of different intensity (Gao & Maurer, 2009; Gosselin & Pelisser, 1996; this study). Herba and colleagues (2008) reported an improvement between 4 and 15 years of age in the minimum intensity needed to recognize a happy expression increasing dynamically in intensity at 1 second/frame. With a shorter interval between frames (0.05 second/frame), Montirosso and colleagues (2010) also found improvement with age in accuracy to recognize happy expressions increasing dynamically in intensity, but the increase was significant only between the group 4-6 years old and the group 7-9 years old, with no further change until adulthood. The improvement on dynamically displayed expression may reflect changes in children's speed in processing facial expressions, which is known to increase between age 7 (the youngest age tested) and age 10, with a further increase by adulthood (De Sonneville et al., 2002). Using static images of facial expressions of varying intensity, we found that children' s threshold for discriminating a subtle happy expression from neutral is adult-like by age 5, regardless of whether the expression is grouped with fear and sadness (Gao & Maurer, 2009) or surprise and fear (this study). Gosselin and Pelsser (1996) also found adult-like accuracy at age 9-10 (the youngest age tested) when three intensities of happy were paired with the other 5 basic emotions, but not neutral. Nevertheless, in the current study the 5-year-olds made more misidentifications than adults for the intermediate intensities when happy expressions were grouped with another expression that can be construed as positive (e.g., surprise), although the misidentification rate was still low (<5%). In addition, in our previous study (Gao & Maurer, 2009) we found that both 5-year-olds and 7-year-olds are not as good as adults at detecting small differences in the intensity of mid-intensity happy expressions. Together, the evidence suggests that by age 5, children are as sensitive as adults to subtle facial expressions of happiness (Gao & Maurer, 2009; this study), although it takes them longer than adults to perceive the expressive cues (De Sonneville et al., 2002; Herba et al., 2008; Montirosso et al., 2010), they occasionally mistake them for surprise (this study), and they are not as good as adults at noticing small increases and decreases in the intensity of the expression (Gao & Maurer, 2009). The adult-like thresholds and low misidentification rate should allow children to pick up subtle positive feedback from their peers and from adults, thereby helping them to react appropriately in social interactions. With age, they will become more sensitive to small differences in that feedback and pick it up more quickly.

Sadness

By 12 month of age, infants are able to use mothers' facial expressions to disambiguate situations and respond differently to sad expressions than they do to happy, fearful, or angry expressions (Sorce, Emde, Campos, & Klinnert, 1985). When asked to cross the deep side of a visual cliff, they are likely to do so if the mother poses happy (14 of 19 infants) or interest (11 of 15 infants) expressions, but not if she poses fearful (0 of 17) or angry (2 of 18) expressions. Unlike happy, interest, fearful or angry expressions, sad expressions do not signal whether the situation should elicit avoidance or approach. Consistent with this analysis, 6 of 18 infants crossed to the deep side when their mothers posed sadness, a value not different from baseline. Therefore, by 12 month of age, infants are not only able to discriminate sad expressions from other expressions, but may understand the meaning of sad expressions.

Previous studies of children using intense sad expressions have reported early development of the ability to recognize them as accurately as adults (Camras & Allison, 1985; Durand et al., 2007; De Sonneville et al., 2002), consistent with our findings for high intensity expressions (> ~88%); the exception is Kolb et al.

(1992), who found lower accuracy in all age groups between 6-7 and 12-13 years than in adults. Studies using less intense dynamic expressions also reported slow development, with changes in the intensity at which the expression is recognized up to 13-15 years (Herba et al., 2008; Montirosso et al., 2010). These findings may reflect increases in the speed of processing subtle sad expressions. Our results for static sad expressions indicate that, in addition, there are improvements in threshold and reductions in misidentifications, although the exact pattern depends on the grouping of expressions. When sad expressions were grouped with happy and fearful expressions, there were no differences in threshold, but children as old as age 10 (the oldest tested) misidentified sad faces as fearful more than twice as often as adults (10.6% versus 5.0%, Gao & Maurer 2009). When sad expressions were grouped with only negative expressions (e.g., disgust and anger) in the current study, 10-year-olds were adult-like, but 7-year-olds deviated on all three measures: they made more errors at peak intensity, needed more intensity than adults to discriminate sad faces from neutral (i.e., had higher thresholds), and more often misidentified the face as disgusted. Combined with previous results, the data suggest that young children are slower than adults to identify subtle expressions of sadness and are more likely to misidentify them as neutral, disgusted, or fearful. Some of these differences persist until early adolescence. Thus, children may miss or misread subtle signals of sadness and consequently may fail to show empathy to people with subtle sad expressions.

Fear

Although newborns show no evidence of discriminating intense fearful expressions from neutral (Farroni et al., 2007), by 7 months of age, infants categorize intense fearful expressions across different individual faces, look longer at such fearful faces than at happy faces, and disengage attention more slowly from intense fearful faces than from neutral or happy faces in order to look at a peripheral target (Nelson & Dolgin, 1985; Peltola, Leppänen, Mäki, & Hietanen, 2009; Peltola, Leppänen, Palokangas, & Hietanen, 2008). As summarized above, by 12 months (the youngest age tested), they also appear to understand the meaning of fearful expressions and respond appropriately to them by avoiding the deep side of the visual cliff (Sorce et al, 1985). This early onset of processing of fearful faces is consistent with the important evolutionary role of fear in signaling potential environmental threat.

Nevertheless, adult-like sensitivity to fearful expressions develops relatively late whether children are tested with intense exemplars (De Sonneville et al., 2002; Durand et al., 2007; Kolb et al., 1992) or with expressions of varying intensity (Gao & Maurer, 2009; Herba et al., 2008; Montirosso et al., 2010; Thomas et al., 2007; this study). Thus, previous studies using varying intensity reported that children aged around 7-9 years have higher threshold than adults (Gao & Maurer, 2009; Thomas et al., 2007), with continuing change up to age 15 in one study using dynamically changing intensity (Herba et al., 2008; but see Montirosso et al., 2010). The current findings indicate that the details of the developmental pattern vary with the grouping of expressions with which fear can be confused. When fear is grouped with sadness, 5-year-olds misidentify it as sad more than 5 times as often as adults (22.9% versus 4.1%) and do so even at peak intensity (Gao & Maurer, 2009). The confusion between fear and sadness is greatly reduced by age 7 (Gao & Maurer, 2009; Gagnon, Gosselin, Hudon-ven der Buhs, Larocque, & Milliard, 2010). When fear is grouped with happy and surprise, as in the current study, all age groups confuse it with surprise at fairly high rates (around 10%), but the error is no more likely in children than in adults. As in the previous study, however, 5-year-olds needed more intensity than adults to detect expression in fearful faces, that is, their thresholds were about 50% higher (29.6% versus 20.7% in this study; 30.0% versus 19.7% in the previous study). By 10 years of age, children are adult-like on all measures of sensitivity to fear in static faces of varying intensity, whether it is grouped with sadness or with surprise. The slow development of sensitivity to fearful expressions may be a result of low exposure in everyday life. Consequently, young children (age 5) may fail to identify signals of potential danger in the environment evident in other people's facial expressions and misconstrue even intense fearful expressions as sad.

Anger

Anger is another facial expression that has high evolutionary signal value, as it provides cues to retreat or prepare to defend oneself. As noted above, by 12 months (the youngest age tested), infants appear to understand this signal value, as it keeps them from crossing into the deep side of the visual cliff (Sorce et al., 1985). Previous studies using either intense expressions or expressions varying in intensity agree that the developmental trajectory after infancy is as long as that for fearful expressions (Camras & Allison, 1985; Gagnon et al., 2010; Kolb et al., 1992; Markham & Adams, 1992) or even slightly longer (Durand, et al., 2007; Montirosso et al., in press; Thomas et al., 2007). The current study indicates that the long developmental trajectory arises mainly from higher thresholds as late as age 10 (the oldest age tested), that is, from children's mistaking a low- or mid-intensity angry expression as neutral. Once they see the face as expressive, children as young as 5 are no more likely than adults to confuse it with disgust or sadness. It is unclear whether there is also an increase in the speed of processing angry expressions during childhood (cf., the improvement in processing speed and accuracy in De Sonneville et al., 2002 and Montisorro et al., 2010, with the flat functions in Herba et al., 2008). The slow development of sensitivity to angry expressions may reflect children's rare exposure to angry expressions in everyday life. In contrast, at age 9, physically abused children, who are likely to have more than the usual amount of exposure to anger, have a lower threshold to detect anger in a face but perform like typically developing children in detecting happy and fearful expressions (Pollak & Sinha, 2002). The failure to detect subtle angry expressions in typically developing children between 5 and 10 year of age may keep them from interpreting appropriately the reaction of others to angry-provoking actions and limit what they can learn from social feedback about inappropriate behaviours.

Surprise

By 6-7 months of age, infants categorize surprised expressions across different individual faces and discriminate surprised from happy (Caron, Caron, & Myers, 1982) and angry (Serrano, Iglesias, & Loeches, 1992) expressions. The later development of sensitivity to surprise is not well charted because many previous studies of children did not include surprise among the expressions tested (e.g., Herba et al., 2008; De Sonneville et al., 2002; Montirosso et al., 2010) or did not include an adult comparison group (e.g., Vicari et al, 2000; Gossellin & Larocque, 2000; Markham & Adams, 1992). In the one previous study using intense expressions and an adult comparison group, children were less accurate than adults as late as 12-13 years of age (Kolb et al, 1992). One reason for children's poor accuracy may be the fact that surprised expressions share muscle action units with fearful expressions (Ekman & Friesen, 1978; Gosselin & Simard, 1999), a commonality likely contributing to high rates of confusion between fear and surprise even in adults. Interestingly, in the current study, 5- and 7-year-olds were twice as likely as adults to misidentify surprised expressions as fearful (error rates of 20-24% versus 12.8%) but were no more likely to misidentify fearful expressions as surprised at any age (error rates of 6-10%). The 5-year-olds also confused surprised expressions with happy expressions three times more often than adults (17% versus 4.8%) and had higher thresholds to see them as non-neutral. The pattern of misidentification in 5-year-olds may be a result of the ambiguity in the valence of surprised expressions, which can be either positive (e.g., a surprise gift) or negative (e.g., the onset of an unexpected unpleasant event). In everyday life, contextual information may help children to decode the ambiguity in the valence of surprised expressions, although children's ability to use such contextual information remains largely unexplored. Alternatively, in the faces of the two female models depicting surprise, there was activation of the lip corner puller, which is typically seen in happy but not surprised faces and, perhaps as a result, at all ages the error was more common for these faces than the two male faces without this intrusion. The 5-year-olds' higher rates of misidentification of surprise as happy might have been caused by their acute sensitivity to cues to happy expressions, and their inability to ignore intrusions as effectively as adults and older children. However, 5-year-olds also made this error for the male faces more frequently than adults and older children (3.3-3.8% vs. 0 -1.4%), despite there being no intrusion from the lip corner puller. Overall, our results suggest that young children (aged 5 and 7) are likely to misread surprised expressions 2-3 times more often than adults, a misreading that may lead to inappropriate reactions.

Disgust

By 14 months (the youngest age tested), infants appear to understand the meaning of disgusted expressions: they are more likely to search in a box associated with a happy expression than a box associated with a disgusted expression (Repacholi, 1998). During childhood, sensitivity to the facial expression of disgust develops more slowly than other expressions, even when the expression is intense (Camras & Allison, 1985; Durand, et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; but see Montirosso et al, in press). Previous studies indicate that children 5 to 10 years old confuse intense expressions of disgust, not only with sadness, as adults do, but also with anger, especially at age 5-6 (Gangon et al., 2009; Gosselin & Larocque, 2000; Goseselin & Pélisser, 1996). Similarly, in the current study, all four age groups misidentified disgust as sadness at a high rate (>25%). Five-year-olds made this error more often (37.2% of disgust trials for which they chose a non-neutral response), and, unlike the other groups, also sometimes misidentified disgust expressions as angry (4.1% versus ≤1%). The high misidentification rates between disgust and sadness may have resulted from the presence of the brow lowerer facial action unit in all four models depicting disgusted expressions. Brow lowerer is normally seen in sad expressions but not in canonical disgusted expressions. However, this interpretation cannot explain the higher incidence of this error in the 5-year-olds, who showed poor sensitivity to sad expressions on all three measures.

We found that children at age 7 need more intensity than adults to detect expression in faces showing disgusted expressions, that is, they have higher thresholds. (The thresholds of 5-year-olds were also higher than those of adults when the calculations of both were based on 10 levels of intensity.) There were no age differences for the recognition of intense expressions of disgust. The fact that children at 5 and 7 are as accurate as adults in recognizing intense disgusted expressions but not less intense ones may reflect their sensitivity to disgust as a biological response (e.g., to bad food), which tends to be intense, but not to disgust as a moral response, which is not always intense, and to which they are likely not exposed often during early childhood. Adults recruit the same neural system for both forms of disgust and use the same muscles to express it (Chapman, Kim, Susskind, & Anderson, 2009). If this analysis is correct, then young children may miss the meaning of a mildly disgusted expression signaling a negative moral response to their behaviour.

Methodological issues

The developmental patterns observed here are affected by the particular groupings of facial expressions in the forced-choice procedure. Different response alternatives affected the patterns of confusion among facial expressions for two of the three expressions included in both studies (sad and fear), but not the third (happy). In our previous study (Gao & Maurer, 2009), which paired fear with sad and happy, compared to adults, 5-year-olds more frequently misidentified fear as sad, even at high intensity. In the current study, in which fear was paired with surprise and happiness, there were no age differences in misidentifications. There was a similar pattern for sadness. All age groups had higher misidentification rates for sad expressions when they were grouped with fearful and happy expressions (Gao & Maurer, 2009) than when they were grouped with disgusted and angry expressions (current study), mainly because of confusion of sadness with fear in the previous study. Different choices of facial expression also affected the thresholds to discriminate sad expressions from neutral. When sad expressions were grouped with only negative expressions (e.g., disgust and anger), all age groups had higher thresholds to detect expression in sad faces compared to the previous study, in which sad faces were grouped with both positive (e.g., happy) and negative (e.g., fearful) expressions. The reason for the elevation in thresholds for sad in the current study is not clear. These differences highlight the importance of testing children with groupings that involve the expected errors seen in adults (e.g., surprise and fear) but also with groupings of expressions that are not expected to be confused (e.g., surprise and happy). Although a procedure involving all seven choices (6 basic emotions plus neutral) would get around the grouping issue, such a procedure is not appropriate for children: it would require the child to attend to 7 choices on each trial. A free labeling procedure in which children provide the verbal label for the expression shown in each picture is another alternative, but it is considered to be a difficult task for children, even with a small number of trials with intense expressions (Markham & Adams, 1992; Widen & Russell, 2003).

Besides the use of a forced-choice procedure, another factor that could affect the developmental patterns we observed is the end point of each expression at what we called 100% intensity. It is possible that children were as sensitive as adults to our subtle happy expressions simply because the end point happy expressions we used are further away from neutral than other expressions, resulting in larger steps between two adjacent intensity levels for happy expressions than for other expressions. However, this explanation seems unlikely for three reasons. First, an analysis of the physical differences between each expression used and neutral indicates that the differences are not physically larger for the happy continuum. In this analysis, we converted each picture to a grayscale image with 256 levels of intensity. We measured the similarity between each expressive face and its corresponding neutral face by calculating normalized cross-correlations (Gold, Sekuler, & Bennett, 2004) based on the luminance values of the pixels and then averaged the results across the four models. As shown in Figure 3.5, for all six expression categories, as intensity increases, the physical difference between the expressive face and the neutral face increases linearly, as shown by the linearly decreasing correlation. The end points of the six expression categories have similar physical differences from the neutral face (range of correlation = 0.83[anger] – 0.87[happiness]). In fact, the slightly higher correlation between neutral and 100% happy indicates that the end point of the happy continuum is physically closer to neutral than the end points of other expressions. Second, we selected the endpoint faces based on ratings from adults in a previous study (Palermo & Coltheart, 2004). Those ratings indicate that adults perceive the endpoints we used as not differing substantially in intensity. Specifically, adults had similar mean intensity ratings for the six expressions (on a 7 point scale, averaged across the four models, 6.1 for angry faces, 5.6 for disgusted faces, 5.4 for happy and fearful faces, 5.2 for sad and surprised faces).

Although there are small differences among the perceived intensity of the selected expressions, such differences cannot account for the different developmental patterns found in the current study. For example, the endpoint angry faces were rated as the most intense of the expressions, but the angry continuum was the only expression for which thresholds were still not adult-like at age 10. In contrast, although the rated intensity of the endpoint happy faces is not the highest in the set, children showed early maturation in detecting expression in the happy faces. Third, the analyses did not involve comparison of thresholds across expressions but rather comparison of performance with each continuum across age, that is, comparison of thresholds for each expression between children and adults and conclusions about the developmental trajectories, not the absolute thresholds. Therefore, the small differences in physical intensity and perceived intensity of the endpoint faces for the six expression categories are not likely to account for the different developmental patterns for different expressions found in the current study.

A final limitation is that, unlike the current testing conditions, in everyday life, facial expressions are dynamic, within specific contexts, and often accompanied by other cues to expressed emotion (e.g., voice, body posture). Had we provided these types of information in the current study, the differences between adults and children might have been smaller, but they could instead have been increased if adults are more adept than children at using the additional cues.

The benefit from these additional cues may also differ across expressions. Children's ability to use such information remains largely unexplored.

Differences between emotions

For the reasons outlined in the previous section, our main conclusions concern the development of sensitivity to each emotional expression considered on its own. Nevertheless, it is instructive to compare the developmental patterns across expressions. Although we can never eliminate the possibility that the developmental changes in sensitivity to facial expressions in the current study reflect general improvements in memory, attention, and motivation, these factors are not likely to account for the patterns found here, given the child-friendly procedure and unlimited viewing time we used in the study and the fact that children as young as 5 had adult-like thresholds for happy expressions, as they did in our previous study (Gao & Maurer, 2009).

A comparison across expressions tested in the current study and our previous one (Gao & Maurer, 2009) confirms the early development of sensitivity to happy expressions reported in the literature (Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000; Widen & Russell, 2003) and also suggests that sensitivity to negative expressions develops at different rates for different expressions and different measures. Thresholds become adult-like earlier for surprise (age 7) than for fear, sadness, and disgust (age 10, at least with some groupings), with the latest maturity for anger (after age 10). However, misidentifications show a different pattern: adult-like levels quite early for anger (by age 5) and especially late for sad (after age 10, at least with some groupings). The different developmental patterns may reflect the amount of exposure to different facial expressions in a child's environment: frequent for happy expressions, intermediate for surprise, and least for anger. Studies of special populations support the hypothesis that exposure influences the development of sensitivity. Neglected children, who are likely to have less exposure to facial expressions than normal developing children, are less accurate at discriminating facial expressions than normal developing children (Pollak, Cicchetti, Hornung, & Reed, 2000). Physically abused children, whose rearing environment is likely to have more angry expression than usual, have a lower threshold to detect anger in a face than normal developing children (Pollak & Sinha, 2002). Children's early sensitivity to subtle happy expressions found in the current studies may be a result of their exposure to happy expressions at a wide range of intensities in the environment. However, exposure alone does not readily account for the patterns among the other expressions (e.g., adult-like thresholds earlier for subtle expressions of surprise than disgust). These differences may instead, or in addition, be related to differences among expressions in salience and signal value of the expressions children view and express themselves. The environmental factors may also interact with children's changing visuo-cognitive skills in shaping children's sensitivity to subtle facial expressions. Those visuo-cognitive skills include the skills that allow children to extract visual information from faces, such as acuity and contrast sensitivity (adult-like by 7, Ellemberg, Lewis, Liu, & Maurer, 1999), vernier acuity (adult-like by early adolescence, Skoczenski & Norcia, 2002), contour integration (adult-like by early adolescence, Kovács, Kozma, Fehér, & Benedek, 1999), and sensitivity to facial feature spacing (continues to develop after age 10, Mondloch, Dobson, Parsons, & Maurer, 2004; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grend, & Maurer, 2002; but see McKone & Boyer, 2004, and Pellicano, Rhodes, & Peters, 2006, for adult-like sensitivity on some tasks at a younger age). Improvements in cognitive skills such as perspective taking will also help children to decipher the context and hence the meaning of subtle facial expressions (Choudhury, Blakemore, & Charman, 2006).

In conclusion, by using facial expressions at varying intensities, we investigated developmental changes in children's sensitivity to facial expressions of the six basic emotions with multiple measures. The results indicated that children are as sensitive as adults to subtle happy expressions by age 5, while they show a longer developmental course for negative facial expressions. Future studies could use the stimuli and technique described here to study changes in the neural mechanisms underlying the perception of facial expressions. The stimuli and technique developed in the current study could also be used to study special populations, such as children with autism, neglected or abused children, and children with abnormal visual experience. Future studies could also adapt the current technique to study the effect of familiarity (familiar vs. unfamiliar faces), race (own race vs. other race faces), age (children's faces vs. adults' faces) or dynamic emotion on children's sensitivity to facial expressions.

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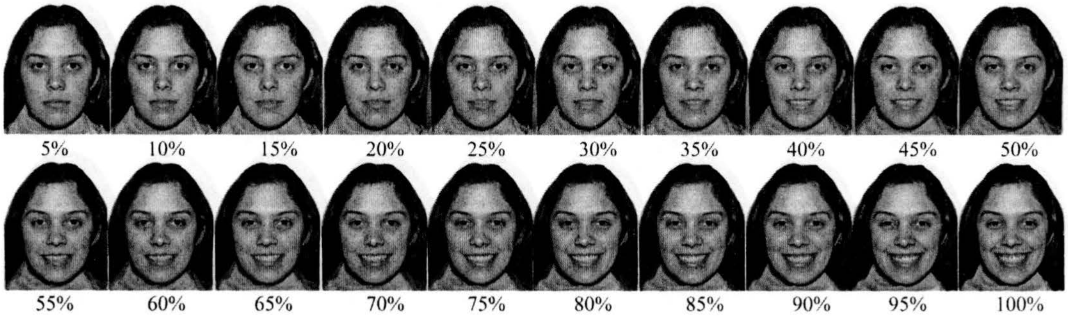
(a)



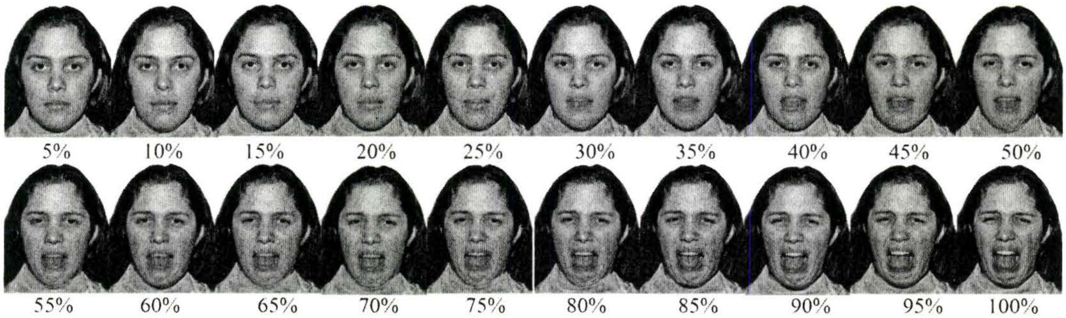
(b)

(c)

Figure 3.1 Examples of happy (a), sad (b), fearful (c), surprised (d), disgusted (e), and angry (f) expressions at varying intensity levels.

(d)

(e)



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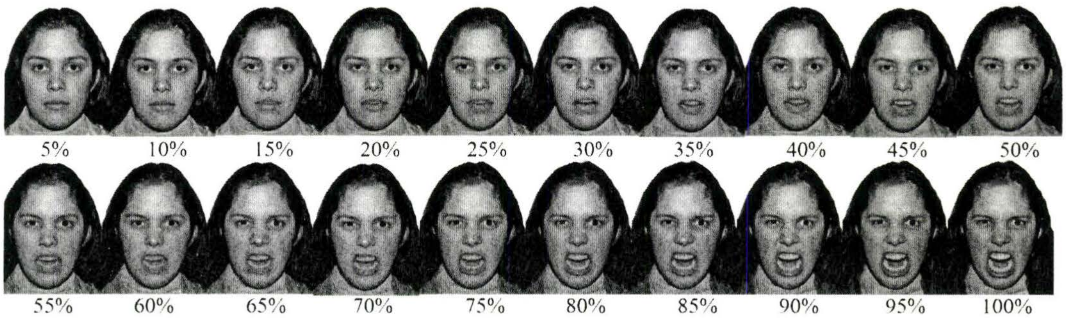

Figure 3.1 Examples of happy (a), sad (b), fearful (c), surprised (d), disgusted (e), and angry (f) expressions at varying intensity levels.

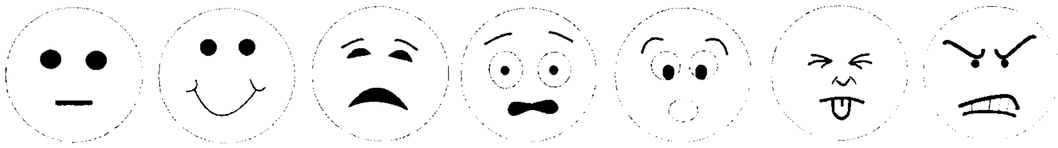

Figure 3.2 Schematic faces marking the response categories. From left to right: neutral, happy, sad, fearful, surprised, disgusted, and angry.

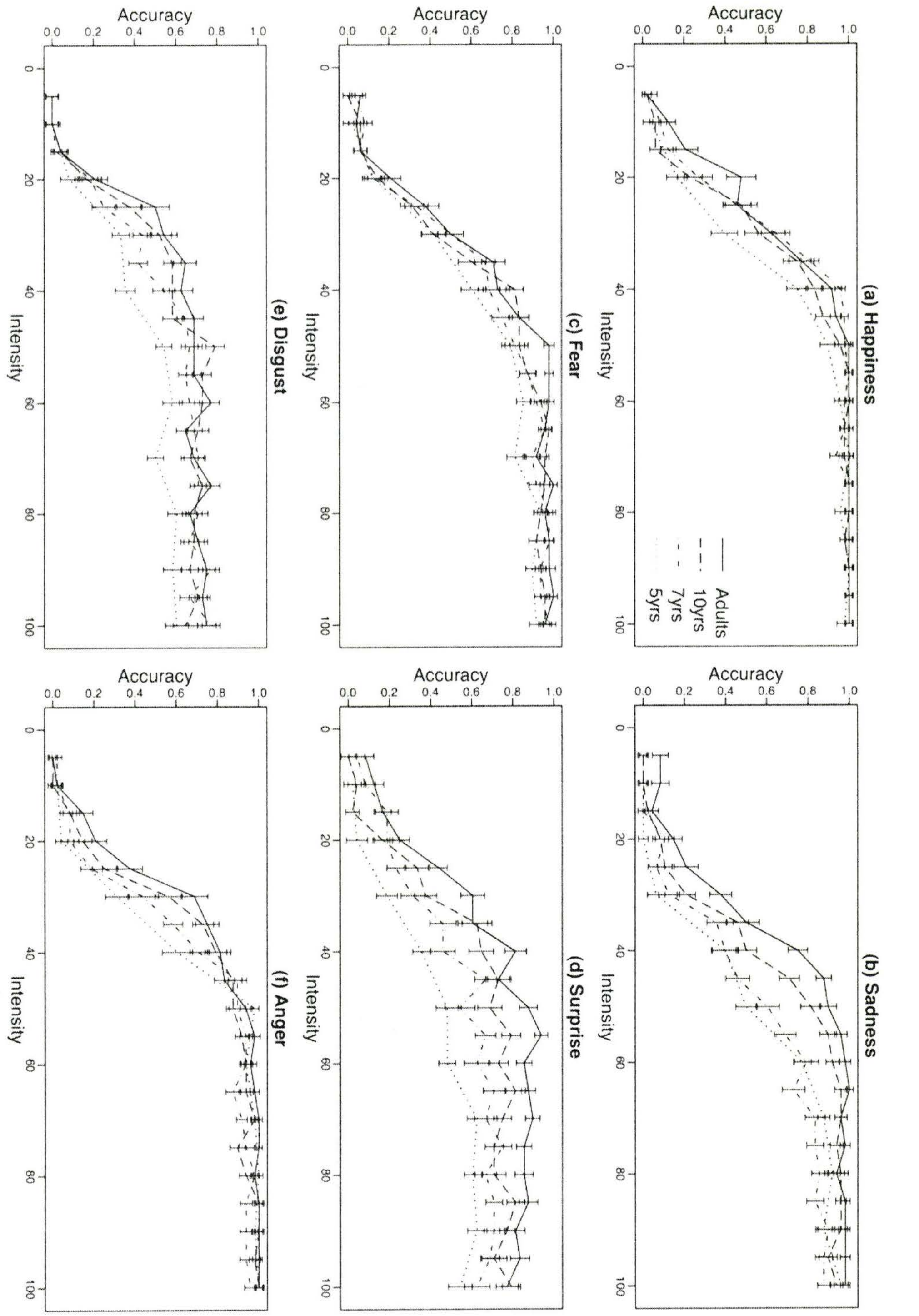

Figure 3.3 Mean accuracy (± 1 *SE*) for each expression at each age as a function of intensity.

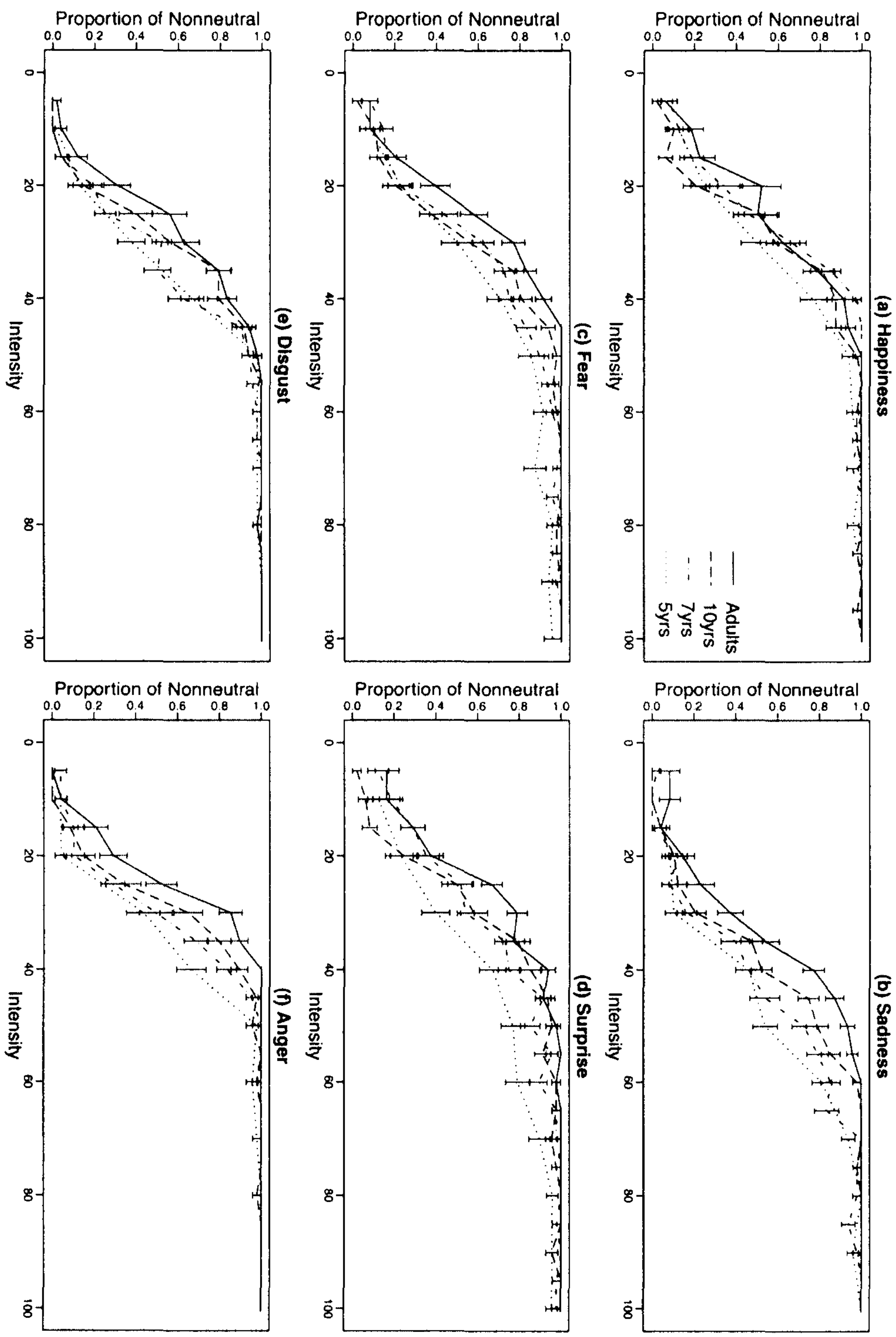

Figure 3.4 Mean proportion of non-neutral expressions for each expression at each age as a function of intensity.

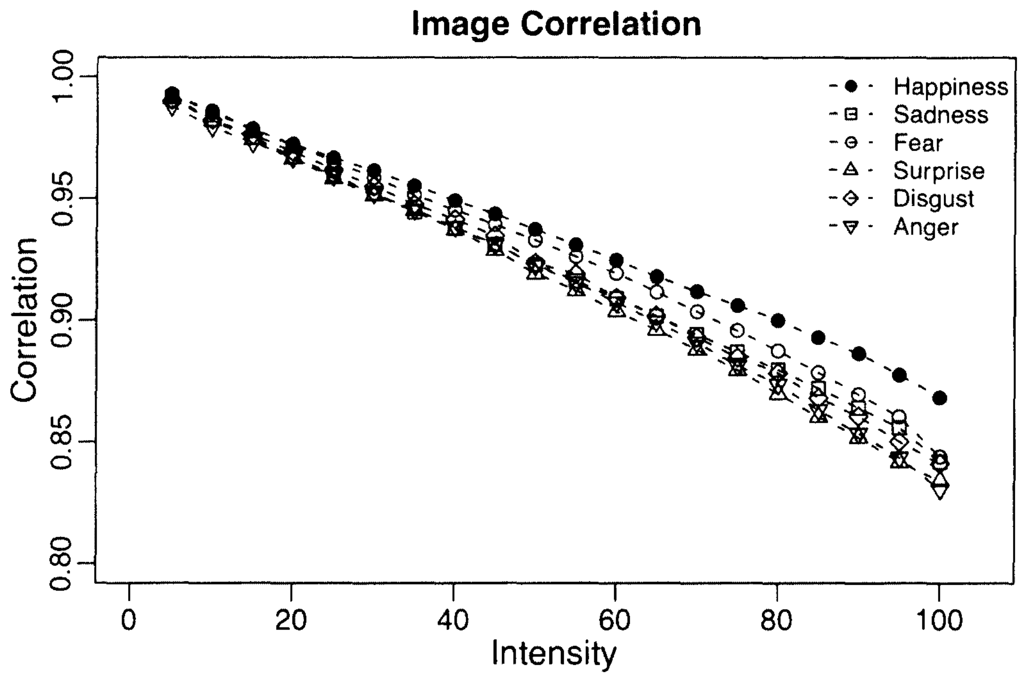

Figure 3.5 Mean correlation between each expression at each intensity and neutral based on image pixel information. Figure shows the mean across the four models.

Table 3.1

Mean number of faces identified as expressive for each expression averaged across models.

	Happiness	Sadness	Fear	Surprise	Disgust	Anger
5-year-olds	7.5 (75%)	5.9 (59%)	7.0 (70%)	6.8 (68%)	7.1 (71%)	7.1 (71%)
7-year-olds	15.6 (78%)	11.9 (60%)	14.7 (74%)	15.0 (75%)	13.9 (70%)	14.6 (73%)
10-year-olds	15.0 (75%)	13.1 (66%)	14.9 (75%)	14.9 (75%)	14.6 (73%)	14.9 (75%)
Adults	15.8 (79%)	14.0 (70%)	15.9 (80%)	16.0 (80%)	15.2 (76%)	15.8 (79%)

Percentages are in parentheses. For each expression, 5-year-olds saw 10 faces of each model, whereas other age groups saw 20 faces of each model. The numbers shown are the denominators used in the calculation of rates of misidentification.

Table 3.2
Mean thresholds.

	Current study						Gao & Maurer, 2009		
	Happiness	Sadness	Fear	Surprise	Disgust	Anger	Happiness	Sadness	Fear
5-year-olds	26.0 (10.4)	42.7 (11.0)	29.6 (13.4)	35.2 (15.7)	27.8 (6.7)	28.0 (6.3)	23.8 (9.6)	31.0 (10.2)	30.0 (12.4)
7-year-olds	22.1 (7.9)	41.9 (10.1)	26.1 (8.3)	24.0 (8.4)	31.1 (7.4)	28.0 (5.6)	23.3 (7.8)	32.5 (9.4)	30.8 (10.2)
10-year-olds	25.1 (8.7)	35.0 (5.7)	26.1 (7.2)	24.7 (6.1)	27.2 (7.3)	25.5 (7.0)	17.7 (6.9)	30.3 (9.0)	22.3 (8.4)
Adults	20.8 (10.5)	31.1 (6.5)	20.7 (5.7)	20.2 (5.32)	23.9 (7.3)	20.9 (5.0)	20.8 (9.5)	27.5 (7.9)	19.7 (7.2)

Standard deviations are in parentheses.

Table 3.3
Mean misidentification rates (%).

	Current study								
	Happiness			Surprise			Fear		
Misidentified as	Surprise	Fear	Total	Fear	Happiness	Total	Surprise	Happiness	Total
5-year-olds	3.1	1.6	4.7	24.1	17.0	41.1	6.6	1.8	8.4
7-year-olds	0.6	0.9	1.5	20.4	12.3	32.7	6.1	0.9	7.0
10-year-olds	0.3	0.6	0.9	15.8	8.9	24.7	7.0	0.4	7.4
Adults	0.4	0.3	0.7	12.8	4.8	17.6	10.1	0.5	10.6
	Sadness			Disgust			Anger		
Misidentified as	Disgust	Anger	Total	Sadness	Anger	Total	Disgust	Sadness	Total
5-year-olds	4.6	1.9	6.5	37.2	4.1	41.3	1.8	0.7	2.5
7-year-olds	10.5	0.5	11.0	26.0	0.8	26.8	5.5	0.5	6.0
10-year-olds	4.3	0.3	4.6	26.6	1.0	27.6	5.1	0.9	6.0
Adults	2.1	0	2.1	26.4	0.3	26.7	5.6	0.7	6.3
	Gao & Maurer, 2009								
	Happiness			Sadness			Fear		
Misidentified as	Sadness	Fear	Total	Happiness	Fear	Total	Happiness	Sadness	Total
5-year-olds	0.3	2.4	2.7	3.0	12.4	15.4	2.6	22.9	25.5
7-year-olds	0.5	0.4	0.9	3.4	10.0	13.4	1.2	7.0	8.2
10-year-olds	0.6	0.5	1.1	4.0	10.6	14.6	2.8	5.9	8.7
Adults	1.3	0.8	2.1	0.3	5.0	5.3	0.9	4.1	5.0

Chapter 4

Preface

The research described in this chapter is published in the *Journal of Experimental Child Psychology* (2010, volume 105, page 98-115), and has been reprinted with permission from Elsevier.

In Chapters 2 and 3, we investigated children's ability to sort facial expressions into different categories. In this chapter, we investigated children' ability to perceive a relationship among different expression categories. Previous studies modeled adults' perception of the relationship among facial expression with a circular arrangement with two underlying dimensions, namely, pleasure and arousal (the circumplex model of affect, Russell, 1980). With intense facial expressions, young children were found to have two-dimensional structure similar to that found in adults. However, this two-dimensional structure only represents affect quality and hence intensity is not explicitly represented in the model. The research described in the chapter is the first to investigate children's and adults' perceptual structure of facial expressions of the six basic emotions using systematically controlled intensities that were compared to each other. We collected similarity judgment between facial expressions from 7-year-olds, 14-year-olds and adults using age-appropriate paradigms. We found the perceptual structure of facial expressions of adults is more complex than the ones found in previous studies that used only intense expressions. This structure is optimally explained by a four-dimensional multidimensional scaling solution with the dimensions representing pleasure, potency, arousal, and intensity. The 14-year-olds showed an adult-like pattern on all measures except that their similarity judgments were more influenced by physical differences than were those of adults. The 7-year-olds showed systematic structure, which differed from that of adults in both the meaning of some dimensions and the proximity among some of the expression categories. These results suggest that an adult-like representation of facial expressions develops slowly during childhood.

Running Head: PERCEPTUAL STRUCTURE OF FACIAL EXPRESSIONS

Similarities and Differences in the Perceptual Structure of Facial Expressions of Children and Adults

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Abstract

We explored the perceptual structure of facial expressions of six basic emotions, varying systematically in intensity, in adults and children aged 7 and 14 years. Multi-dimensional scaling suggested three- or four-dimensional structures were optimal for all groups. Two groups of adults demonstrated almost identical structure, which had dimensions representing pleasure, potency, arousal, and intensity, despite that one group was tested with a child-friendly odd-man-out paradigm while the other group was tested with a conventional similarity-rating paradigm. When tested with the odd-man-out paradigm, the 7-year-olds showed systematic structure, which differed from that of adults in both the meaning of some dimensions and the proximities among some of the expression categories. When tested with similarity judgments, the 14-year-olds showed an adult-like pattern on all measures except that their similarity judgments were more influenced by physical differences than were those of adults. We conclude that an adult-like representation of facial expressions develops slowly during childhood.

Keywords: facial expression; development; multi-dimensional scaling; cluster analysis; perceptual structure; intensity.

Introduction

Human adults perceive facial expressions categorically (Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992; Young, Rowland, Calder, Etcoff, Seth, & Perrett, 1997). Nevertheless, they also perceive a relationship among different facial expressions. For example, most people would agree that a happy face is more similar to a surprised face than to a sad face. The relationship among facial expressions has been modeled with a small number of underlying dimensions. Using ratings on pleasantness-unpleasantness and on attention-rejection, Schlosberg (1952) mapped facial expressions into a two dimensional space. Expressions formed a circular arrangement along the two predefined dimensions. Later studies used multidimensional scaling (MDS, Shepard, 1962) to map the perceptual structure of facial expressions without predefining the dimensions (Alelson & Sermat, 1962; Bimler & Kirkland, 1997, 2001; Nummenmaa, 1990; Russell & Bullock 1985, 1986; Shah & Lewis, 2003). MDS is a statistical procedure that represents similarities between objects as spatial proximities in a multi-dimensional space. MDS can detect hidden structure underlying complex constructs that are not obvious in the raw similarity judgments (Kruskal & Wish, 1978). To minimize the influence of language, no verbal labels were used and MDS was based on similarity judgments about facial expressions (e.g., Alelson & Sermat, 1962; Russell & Bullock 1985, 1986), or reaction times to discriminate among them (e.g., Shah & Lewis, 2003). The MDS solutions suggest that adults represent facial expressions in a circular arrangement with two underlying dimensions, namely, pleasure and arousal (Alvarado, 1996; Bimler & Kirkland, 1997, 2001; Russell & Bullock, 1985, 1986; Shah & Lewis, 2003). These results fit well with a broader model that the structure of affective states can be represented by a circular pattern in a two-dimensional space with pleasantness and arousal as the underlying dimensions (the circumplex model of affect, Russell, 1980). Besides facial expression, this model is also supported by studies with emotion words (Russell, 1980), emotional experiences (reviewed by Remington, Fabrigar, & Visser, 2000), emotional voices (Green & Cliff, 1975), and emotion-eliciting music (Bigand, Vieillard, Madurell, Marozeau, & Dacquet, 2005).

Developmental studies reveal that young children show a perceptual structure of facial expressions that is similar to that of adults. Russell and Bullock (1985) used a sorting method to collect similarity judgments among intense facial expressions from preschoolers, and mapped the underlying perceptual structure using MDS. The structure was similar to that of adults and can be characterized by a circular arrangement along the two dimensions of pleasure and arousal, although the children's structures were less clustered. With a smaller stimulus set (10 instead of 20 stimuli), Russell and Bullock (1986) again found the same two-dimensional structures in children as young as 2 years as seen in adults. These findings are somewhat surprising given that other studies suggest that it takes a remarkably long time for children to acquire adult levels of sensitivity to facial expressions (reviewed by Herba & Phillips, 2004). For example, children's accuracy in recognizing facial expressions from still photographs does not reach adult levels until early adolescence for some facial expressions (e.g., Fear and Disgust: Durand, Gallay, Seigneuric, Robichon & Baudouin, 2007; Sadness: Gao & Maurer, 2009; Kolb, Wilson & Taylor, 1992). Studies using brain-imaging techniques also reveal a prolonged developmental course: even 14-15-year-olds' event-related potentials (ERPs) for the six basic emotional expressions differ from those of adults (Batty & Taylor, 2006) and in 11-year-olds, the amygdala activation revealed by functional magnetic resonance imaging (fMRI) is stronger for neutral than fearful faces, the opposite pattern from that shown by adults (Thomas et al., 2001; but see Guyer et al., 2008). Since 2-year-olds do not yet know the verbal labels for the six basic expressions, the early-emerging structure is not an artifact of language structure. Instead, the early structure seen at age two may seem similar to that of adults but reflect a less differentiated concept of emotion or children's perception of physical differences among the facial images rather than their perception of the emotions conveyed by the facial expressions (Russell & Bullock, 1986).

In the current study, we extended these findings by mapping children's and adults' perceptual structure of facial expressions using facial expressions of the six basic emotions with systematically controlled physical intensity. The reason to control the physical intensity of facial expressions is twofold. First, differences in physical intensity provide an objective measure of the physical difference between facial images and thus can facilitate an assessment of whether children's perceptual structure is based purely on physical difference. Second, while most previous studies only mapped the perceptual structure of intense facial expressions, by using facial expressions at varying intensities, we are able to investigate how intensity is represented in the perceptual structure of facial expressions.

The intensity of a facial expression is determined by the amount of muscle displacement away from a neutral state (Hess, Blairy, & Kleck, 1997). For example, the intensity of a happy expression can be characterized by the degree of displacement of the Zygomaticus Major and Orbicularis Oculi muscles, relative to their relaxed states (Duchenne, 1990). To create facial expressions with systematically controlled levels of intensity, previous studies morphed a neutral face with an emotional face to create a continuum of images representing increasing levels of intensity with linear physical changes. Increasing physical intensity increases adults' ratings of emotional intensity (Takehara, Ochiai, Watanabe, & Suzuki, 2007) and improves their accuracy in identifying facial expressions (Hess, Blairy, & Kleck, 1997) and in discriminating expression intensity (Gao & Maurer, 2009). Although the morphing algorithm creates linear physical changes between different intensities, the perceived change in intensity may not be linear. There has been no direct investigation on the relationship between perceived intensity and physical intensity of facial expressions. Indirect evidence suggests that when the physical difference is kept constant (e.g., 20% change) adults perceive a change between high intensity levels (e.g., 70% vs.

90%) as smaller than a change between low intensity levels (e.g., 30% vs. 50%; Bimler & Kirkland, 2001).

The circumplex model represents the structure of affect *quality* and hence the *intensity* of affect is not explicitly represented in this model. Plutchik (1980) proposed an intensity dimension running in a direction orthogonal to the circular structure. This model was supported by adults' similarity judgments and intensity ratings on emotion words. Also using emotion words, later researchers (Reisenzein, 1994) demonstrated that intensity could be determined by the proportion of pleasantness and arousal, with the centre of the two dimensional space representing zero intensity with medium arousal. Studies using facial expressions at different intensities suggest a fractal property of the underlying structures representing adults' perception of facial expressions (Takehara, Ochiai, & Suzuki, 2002; Takehara et al., 2007; Takehara & Suzuki, 2001). In such structures, low intensity expressions form a similar circumplex arrangement as their high intensity counterparts but at a smaller scale. Although Takehara and colleagues mapped the structure within each intensity level and compared the structures between intensity levels, they did not ask subjects to compare expressions with different intensity levels nor construct a single structure including different intensity levels. Furthermore, they suggested that the structure of the lower intensity expressions would fall within the circumference of the structure of the higher intensity expressions with neutral expression being the centre of the structure. However, they did not include neutral expressions in the test stimuli and this prediction is not consistent with previous findings that neutral expressions are located on the periphery of the circumplex structure (Shah & Lewis, 2003). In the only study to date in which intensity was varied with children, the stimuli were dynamic and body cues were included and were restricted to two intensity levels of happy and angry expressions. The perceptual structure of children under these conditions is similar to that of adults by 6-8 years of age (Vieillard & Guidetti, 2009). However, it is not clear whether the children benefited from the use of dynamic stimuli and/or including body information, or the ease of the task given the limited number of expressions tested.

In two experiments, we used static photographs to examine the perceptual structure of facial expressions of all six basic emotions and neutral expression in more depth by presenting four levels of intensity to each participant. We tested a group of 7-year-olds and a group of 14-year-olds with age appropriate methods, and compared their structures to that of adults.

Experiment 1

In Experiment 1, we mapped the perceptual structures of the six basic facial expressions with four levels of intensity in a group of 7-year-olds and a group of adults using a child-friendly "odd-man-out" paradigm (Alvarado, 1992). This procedure is more appropriate for testing children than the similarity-rating paradigm since the viewer simply picks out the most different expression on each trial, unlike the more conventional similarity-rating paradigm that requires the consistent use of a similarity-rating scale across hundreds of trials. We chose to compare adults to 7-year-olds because at age 7, sensitivity to some expressions is adult-like (e.g., happiness, anger) while sensitivity to other expressions (e.g., fear, sadness) is not (Durand et al., 2007; Gao & Maurer, 2009; Kolb et al., 1992). As well, 7-year-olds are mature enough to systematically compare the three faces presented on each trial and to complete the large number of trials needed to compare four intensity levels for six expressions, plus neutral.

Methods

Participants

Participants were sixteen 7.5-year-old children (± 3 months) and 16 adults (aged 18 to 24). The adult sample consisted of 10 Caucasians, and 6 South Asians, most of whom grew up in Canada[1]. The children were all Caucasians. The majority of the participants were from mid-class families. Child participants were recruited from names on file of parents who had volunteered their child at birth for participation in later studies. Adult participants were undergraduate students enrolled in an introductory psychology course and received course credit for

[1] The composition of participants represents the racial composition of students in McMaster University and the racial composition of children in the nearby communities. The greater diversity in the adult sample than in the child sample would be expected to increase the variance in the adult data and hence limit the detectable differences between children and adult. The same limitation applies to the samples of participants in Experiment 2. Nevertheless, there were systematic differences between the children and adults, and the correlation of the mean dissimilarity scores between the Caucasian adults and the non-Caucasian adults was high in both experiments ($r = 0.832$ in Experiment 1 and $r = 0.926$ in Experiment 2).

participation. All participants had normal or corrected-to-normal vision and half the participants in each age group were female.

Stimuli

We selected photographs of two models (one male and one female), each posing intense facial expressions of six basic emotions (happiness, sadness, fear, anger, disgust, and surprise) and neutral from the NimStim Face Stimulus Set (Tottenham et al., 2009; Model number: 03, Latino-American; 25, European-American). Each photograph had a resolution of 506 × 650 pixels with RGB color. The photographs were chosen because of high agreement among adults on the posed expressions (mean = 86.9 %, range = 62.5–100 %) and high ratings of intensity (mean = 5.5, range = 4.4–6.4, on a 7-point scale, Palermo & Coltheart, 2004).

For each of the six expressions of each model, we created intensities of 30%, 50%, 70%, and 90% by morphing the emotional face with the neutral face (for details, see Gao & Maurer, 2009). As a result, for each model, there were 25 stimuli (6 expressions × 4 intensities + 1 neutral face). Stimuli were displayed on a 19" HP p1179 CRT monitor (with 75 Hz refresh rate at 1024 × 768) controlled by a PowerbookG4 computer via custom software. Each picture was 11° (width, 11.6 cm) ×15° (height, 14.8 cm) of visual angle when viewed from a distance of 60 cm.

Procedures

The procedures were approved by the McMaster Research Ethics Board. After the procedures were explained, we obtained written consents from the adult participants or from a parent of the child participants, and we obtained verbal assent from the children. Participants were tested individually in a quiet room with overhead fluorescent lights. Parents sat in a waiting area or behind the child out of sight.

During each trial, the participant saw a triad of faces and was asked to indicate which face expressed the most different feeling from the others. The experimenter told the children that they were going to be playing a game where a set of male or female triplets (the concept of triplets was explained if not understood) were competing against each other by making faces. In order for a triplet to win, he or she had to make the "most different" face that represented a feeling expressed in real life. In this game, the child was the judge and could pick the winner in each round by indicating which person was feeling the "most different". The children were actively encouraged to focus on the aspect of "feeling" when making judgments. Adults received the same explanatory script. Half of the participants of each sex in each group completed the procedure with the female model and half with the male model.

Before the presentation of experimental stimuli, there were five practice trials with photographs of non-face objects (e.g., cars, airplanes) followed by five practice trials with triads of emotional faces randomly sampled from the other model that the participant would not be seeing in the testing session. All participants responded systematically during the practice trials and appeared to understand the task.

For the test trials, one unique set of 200 triads was chosen for each participant from all possible combinations (2300 in total) of three items from the 25 photographs. The composition of triads was derived from a balanced incomplete block design of 25 items (Burton & Nerlove, 1976). Since one triad can be decomposed into three pairs (e.g., ABC to AB, AC, and BC), the 200 triads represent 600 pairings. The stimuli for each participant were chosen so that each possible pairing of the 25 pictures (300 in total) appeared twice in the experiment. The three pictures in each triad appeared in an isosceles triangular formation with each picture randomly assigned to one vertex and the three vertices numbered 1, 2, and 3. Adults keyed in the vertex number of the odd face; children responded verbally or by pointing and the experimenter keyed in the responses. Mandatory breaks were scheduled after every 50 trials.

Analysis

Constructing dissimilarity matrices

If the participant chose A as the odd-man-out of triad ABC, then we assigned the pairs AB and AC a dissimilarity score of 1, and the pair BC a dissimilarity score of 0. We used the mean dissimilarity score of each pair across its two presentations for each participant as the dissimilarity score. We calculated a complete dissimilarity matrix for each participant, representing the dissimilarity score for every possible pairing of expressions.

Split half correlation

No participant was tested with all possible triads, and hence the validity of MDS depends on there being consistency among members of each group to which the MDS is applied. We evaluated intra-group consistency for the children and for the adults by randomly splitting each group into two half-groups (henceforth denoted as C1 and C2 [children], and A1 and A2 [adults]). We calculated an average dissimilarity matrix for each half-group and then examined the correlation between the two adult matrices and between the two child matrices.

Using bootstrapping (1000 iterations), we calculated the means and 95% confidence intervals (CI) between the half groups of adults and of children: mean r(A1, A2) = 0.863, 95% CI = 0.751–0.943; mean r(C1, C2) = 0.819, 95% CI = 0.677–0.928. The high correlations for both adults and children indicate considerable within group consistency when making the odd-man-out judgments. In addition, we also calculated the correlation between one half group of children and one half group of adults using the same bootstrapping routine: mean r(A1, C1) = 0.698, 95% CI = 0.585–0.778. This correlation is significantly lower than the correlation between the two halves within groups of the same age (ps < .05). The lower between-group correlation compared to the within-group correlations suggests that the judgments differed between the children and the adults, despite consistency within each group.

Multidimensional scaling

We submitted the dissimilarity matrices averaged across participants within each age group to the CMDS procedure in SPSS 16.0, with model as Euclidean distance, measurement level as ordinal, and matrix shape as symmetric. For each group, we computed multidimensional scaling solutions from two to six dimensions. Goodness-of-fit of each solution was measured by Kruskal's Stress 1 formula (Kruskal & Wish, 1978), with a lower stress value representing a better fit. As shown in Figure 4.1, for every solution adults and the 7-year-olds had similar Stress values, a result suggesting that the solutions fit both groups equally well. Stress values decrease with increasing number of dimensions, but with increasing dimensions, the solution is less interpretable. A common practice is to choose the number of dimensions corresponding to the "elbow" of the stress plot (Giguère, 2006). Based on this rule, Figure 4.1 suggests a three- or four-dimensional solution. We chose the four-dimensional solutions since they provided better fit than the three-dimensional solutions.

With four-dimensional solutions, the stress values for both adults and 7-year-olds were 0.07. According to Kruskal and Wish's (1978) suggestion, the fits were "Good" ($.05 \leq$ Stress $\leq .10$).

Hierarchical Clustering

To better understand the proximity of the facial expressions in the MDS solutions than is possible with simple visual inspection, we submitted pair-wise distances from the four-dimensional solutions of each group to hierarchical clustering analysis (Sireci & Geisinger, 1992; Vieillard & Guidetti, 2009) using the method of between groups linkage in SPSS 16.0. Facial expressions in the same cluster can be interpreted as being perceptually similar to each other.

Results

Dimensionality

Figure 4.2 shows the four-dimensional MDS solutions for adults (A) and for 7-year-olds (B). Visual inspection of the solutions suggests that the first dimension for both groups represents pleasure since happy expressions lie on one end of this dimension while the high intensity negative expressions including sadness, disgust and anger lie on the other end of this dimension. For adults, dimension two may represent potency of the model since it has angry expressions on one end (strong) and fearful expressions on the other end (weak) (Fontaine, Scherer, Roesch & Ellsworth, 2007; Osgood, May, & Miron, 1975; Russell & Bullock, 1985, 1986). In children, dimension two seems to represent intensity since neutral and low intensity expressions are on one end, while the higher intensity expressions spread away from neutral towards the other end of this dimension. The third dimension seems to represent intensity in adults in a way similar to the second dimension of the 7-year-olds. The fourth dimension in adults seems to represent arousal since it has angry and fearful expressions on one end (high arousal) and other expressions spreading towards the other end. The third dimension for children may also represent arousal, although unlike adults, children maximally differentiate fearful expressions from surprised expressions on the third dimension. The meaning of the fourth dimension in children is not clear. It seems to represent intensity for most of the expression categories, but not for the happy category. Since dimension two already represents intensity and the dimensions are mathematically orthogonal to each other, it is difficult to name the fourth dimension for children.

Intensity

In the MDS structures of both children and adults, the neutral expression is located in the periphery of the space. Within each expression category, expressions with higher intensity are further away from neutral than their low intensity counterparts. A pattern observable in both structures is that the physical distance between two expressions does not map linearly into perceived distance. For example, in both children and adults, the perceived distance between 30% anger and 50% anger is greater than the perceived distance between 70% anger and 90% anger, although the physical distances between these two pairs of facial images are the same (20%). To further investigate the relationship between the perceived distance and physical distance, we calculated the perceived distance of a 20% change in intensity for three intensity ranges (30%–50%, 50%–70%, 70%–

90%) averaged across the six expression categories. Figure 4.3 shows that in these three intensity ranges, although physical differences are always the same, the perceived distance is much larger between two low intensity expressions (30%–50%) than between two moderate intensity expressions (50%–70%), which is in turn somewhat larger than between two high intensity expressions (70%–90%). The pattern for the 7-year-olds is almost identical to that for adults.

Hierarchical clustering

As shown in Figure 4.4, in adults (A), the facial expressions were clustered into four groupings: [happiness and neutral], [fear and surprise], [sadness and disgust], and [anger]. In adults, the lowest intensity sadness and disgust were located close to neutral, perhaps because at such a low intensity, these expressions are perceived as neutral. In the 7-year-olds (B), we found only two of the four groupings seen in adults: [sadness and disgust] and [anger]. The other expressions were clustered differently than in adults: [happiness], [neutral and low intensity expressions sadness, fear, and surprise], [surprise], and [fear].

Unlike adults, the neutral category was not clustered with happiness, and surprise and fear were not clustered together. The 7-year-olds also grouped more expressions with the neutral category than adults did, including not only the lowest, but also the medium intensity (50%) of fearful and sad expressions.

Discussion

The odd-man-out method yielded systematic results from both 7-year-olds and adults: in both groups the judgments correlated highly within the group, the stress values indicated a good fit to the data with three or four dimensions, similar expressions clustered together to some extent, and the dimensions included ones previously identified in the literature, namely arousal, pleasure, and, at least for adults, potency (Fontaine, et al., 2007; Osgood et al., 1975; Russell & Bullock, 1985, 1986). Thus, it is reasonable to use the data to draw conclusions about similarities and differences between 7-year-olds and adults in the perceptual representation of facial expressions.

Adults generated a typical circular arrangement of facial expressions with the intense facial expressions but the structure was complicated by intermediate intensities that filled the centre of the emotional space. The solutions yielded the typical dimensions of arousal and pleasure (Russell, 1980), plus an orthogonal dimension that appears to represent the intensity of the expressions. An additional dimension, which appears to represent the potency of the expresser, was apparent in the adults' solution: it separated expressions related to feelings of power, dominance, and impulses to act (e.g., anger) from expressions related to feelings of weakness, submission, and refraining from action (e.g., fear). Such a dimension has been identified previously in adults with emotion words (Fontaine et al., 2007) and in the MDS solutions for adults asked to sort 20 facial expressions (Russell & Bullock, 1985) or just 10 facial expressions (Russell & Bullock, 1986) including the basic emotions plus less common ones such as boredom and contentment. In earlier studies, this dimension was described as representing "assertiveness, boldness, moving toward, and asserting control at one end" versus "moving away, reacting, overwhelmed, and taken aback" (Russell & Bullock, 1985, 1986).

The perceptual structure of 7-year-olds overlapped partially with that of adults: as for adults, pleasure, arousal, and intensity appeared to be underlying dimensions. For both groups, sad and disgust expressions formed a cluster, and angry expressions clustered separately from the others. The perceptual distances were not mapped linearly onto physical difference in either the 7-year-olds or the adults. Instead, for both groups, the distance between two low intensity expressions was perceived as larger than the distance between two high intensity expressions with the same amount of physical difference. These findings suggest that children's perception of similarities among facial expressions is not based purely on physical differences among facial images and that it reflects, at least in part, the perception on an expressed emotion. The patterns are consistent with previous evidence for categorical perception of emotions in adults (Bimler & Kirkland, 2001; Calder et al., 1996; Etcoff & Magee, 1992; Young et al., 1997) such that intense expressions are perceived as similar despite variations in intensity; only near the boundary of the category with neutral (i.e., at low intensities) does intensity exert a large influence on perceived similarity. However, physical differences may have a larger influence on children's perceptual structure of expressions that that of adults because the dimension representing intensity of facial expression appeared earlier in children's structure (dimension two) than in adults' structure (dimension three).

There were also significant differences between the perceptual structures of 7-year-olds and adults. Unlike adults, the 7-year-olds did not show a dimension representing potency in their structure. This finding suggests that the potency dimension emerges later than the pleasure, arousal, and intensity dimensions.

The clustering analysis also revealed that the 7-year-olds perceived the relation between surprised and fearful expressions differently from adults: unlike adults, fearful and surprised expressions formed separate clusters, and children's third dimension, which appeared to represent arousal as in adults, included fear and anger as expected at one end, but unexpectedly not surprise. Adults' organization mirrors the perceptual similarity between surprise and fearful expressions and their overlapping signaling of possible threat (Smith, Cottrell, Gosselin & Schyns, 2005). The perceptual structure of the 7-year-olds does not represent this perceptual or emotional overlap. In adults, fearful expressions are processed by both a cortical pathway involved generally in emotion processing and a subcortical pathway involving the amygdala that does not play a role in the processing of surprise (Rotshtein, Vuilleumier, Winston, Driver & Dolan, 2007). Amygdala responses are larger for fearful than neutral expressions in adults, but in children the pattern is reversed, even in children as old as 11 years (Thomas et al., 2001). Moreover, inhibitory responses from the prefrontal cortex, which contribute to emotion processing by inhibiting subcortical responses (Phillips, Drevets, Rauch & Lane, 2003), continue to develop into adolescence (Stuss, 1992). Perhaps as a result of the neural differences, children's sensitivity to fearful expressions is especially slow to develop (Gao & Maurer, 2009). In addition, children may be confused about the valence of surprised facial expressions since surprise can be either positive (unexpected joy) or negative (unexpected threat).

The 7-year-olds also perceived neutral expressions differently from adults. For adults, neutral is perceived as more similar to happy expressions than to other facial expressions. However, in children, neutral is perceived as more similar to low intensity negative facial expressions. Young children have difficulty labeling neutral faces, often calling them sad (Durand et al., 2007; Vieillard & Guidetti, 2009). They may detect these faces as ambiguous and hence negative, as suggested by the greater amygdala activation to neutral than fearful faces as late as age 11 (Thomas et al., 2001). Similarly, children may perceive low intensity expressions like those used in the current study as signaling uncertain and negative feelings. The exception is happy expressions, for which all intensities were clustered together, perhaps reflecting the early emergence of adult-like sensitivity to subtle expressions of happiness (Gao & Maurer, 2009; see Vieillard & Guidetti, 2009 for similar evidence in a study involving angry, happy and neutral expressions).

In summary, using facial expressions of varying intensity and a child friendly procedure, we found that, at age 7, children show a systematic structure of facial expressions that overlaps only partially with that of adults. The differences in the way they represent surprise, fear, and neutral expressions likely affect their interpretation of facial expressions in everyday interactions: they may, for example, be more likely than adults to misinterpret the valence of surprise or misconstrue a neutral expression as mildly negative.

Experiment 2

With the same stimuli as used in Experiment 1, we mapped the perceptual structure of facial expressions in a group of 14-year-olds and a group of adults using a conventional *similarity-rating* paradigm in which the observer judges the similarity of pairs of facial expressions using a standard rating scale. We chose to use the similarity-rating paradigm since it allows the derivation of individual structures instead of only the group structure that can be derived with the "odd-man-out" paradigm. However, it requires the observer to use a rating scale consistently across a large number of trials—something we judged likely to be possible at age 14 but not age 7. In addition, we chose to compare 14-year-olds to adults because at age 14, children are as sensitive as adults in behavioral measures of the perception of facial expressions (Kolb et al., 1992; see review by Herba & Phillips, 2004), but their brain responses to facial expressions are not adult-like (Batty & Taylor, 2006; Monk et al., 2003). To evaluate any possible difference in the perceptual structure of facial expressions that are derived from similarity-ratings rather than the odd-man-out procedure, we also compared the results from the adults in Experiment 2 to those found for adults in Experiment 1.

Methods

Participants

Participants were sixteen 14-year-old children (± 3 months) and 16 adults (aged 18 to 24). The adult sample consisted of 9 Caucasians, 6 South Asians, and 1 African American, most of whom grew up in Canada. The children were all Caucasians. All participants had normal or corrected-to-normal vision and half the participants in each age group were female.

Stimuli

The stimuli were the same as in Experiment 1.

Procedures

Participants were shown a model displaying a pair of facial expressions and were asked to rate how similar they were using a 7-point scale, displayed below each pair of faces, with 1 representing "very similar" and 7 representing "very different". They were instructed to give ratings based on the "feeling" that was being portrayed by the individual in the photographs. Participants were actively encouraged to use the entire range of the rating scale and keyed in their own responses.

Participants were introduced to the task by being shown a pair of faces from the other model, which the participant would not be seeing in the testing session. They saw the model with two different facial expressions and were asked to rate how similar they were on a 7-point scale. They then completed a 28-trial practice session with all possible combinations of two expressions (happiness and sadness) from the model they had just seen but would not be seeing in the testing session, each at all four levels of intensity. The purpose of the practice session was to familiarize the participants with the use of the scale and to give them a sense of the range of intensity. In the testing session, there were 300 trials, representing all possible combinations of the 25 stimuli. The expression pairs were displayed in a different random order for each participant. The positions (left/right) of pictures in each pair were random. Half of the participants of each sex in each group completed the procedure with the female model and half with the male model.

Analysis

We used the original ratings as the dissimilarity scores and collected a complete dissimilarity matrix for each participant, representing the dissimilarity score for every possible pairing of expressions.

Multidimensional scaling

We submitted the dissimilarity matrices averaged across participants within each group to the CMDS procedure in SPSS 16.0 as we did in Experiment 1. As shown in Figure 4.1, for every solution both groups had similar Stress values, and the Stress values are similar to those found in Experiment 1. Therefore, we chose the four-dimensional solutions as optimal. With four-dimensional solutions, the stress value was 0.06 for adults and 0.07 for the 14-year-olds. According to Kruskal and Wish's (1978) suggestion, the fits were "Good"(.05 ≤ Stress ≤. 10).

Individual weightings

Before we compared the structures of the two groups, we calculated the individual weightings on different dimensions of the group solutions using INDSCAL procedure in SPSS 16.0 to assess the homogeneity within each group. Figure 4.5 shows individual weightings for the adults and the 14-year-olds on each dimension of the four-dimensional solutions. All of the 14-year-olds showed equal weightings across all four dimensions. This pattern is similar to most of the adults except that a subgroup of adults (5 participants) show slightly skewed weightings towards dimension one. In further analysis we calculated group solutions based on similarity scores averaged across participants within each group.

Hierarchical Clustering

We also submitted pair-wise distances from the four-dimensional solution of each group to hierarchical clustering analysis using the same method as in Experiment 1.

Results

Dimensionality

Although tested with a different method, the group of adults in Experiment 2 demonstrated a MDS structure similar to that of the group of adults in Experiment 1, with nearly identical stress values (see Figure 4.1) and similar dimensions (Figure 4.6). As for the adults tested with the odd-man-out procedure in Experiment 1, dimension one to dimension four can be explained as representing pleasure, potency, arousal, and intensity. One difference between the two groups of adults is that the order of the third and the fourth dimensions changed. For the group of adults tested with similarity-rating paradigm in Experiment 2, dimension three is better explained as arousal and dimension four is better explained as intensity than the other way around.

For the 14-year-olds, dimension one represents pleasure, as seen in other groups, with happy expressions at one end and higher intensities of the negative expressions (anger, disgust, sad, fear) at the other end. Dimension two may represent potency as seen in the two groups of adults. However, although the 14-year-olds differentiate fearful expressions from angry expressions on dimension two, unlike in adults, fearful expressions are not at one end of the dimension. Dimension three may represent arousal since fearful expressions and angry expressions spread towards one end of the dimension, leaving others at the other end. Dimension four seems to represent intensity as seen in the other groups.

Intensity

As shown in Figure 4.3, adults show the same pattern of relationship between perceived distance and physical distance as found in the two groups in Experiment 1: greater perceived difference for low intensity expressions (30 versus 50%) than for high intensity expressions (70 versus 90%). However, we did not see such a pattern in the group of 14-year-olds. Instead, the 14-year-olds show similar perceived differences when judging two expressions differing in intensity by 20% regardless of the intensity range.

Hierarchical clustering

As shown in Figure 4.7A, in adults, the facial expressions were clustered in a similar way to that found in the group of adults tested with the odd-man-out procedure in Experiment 1: [happiness and neutral], [fear and surprise], [sadness and disgust], and [anger]. The pattern of clustering in 14-year-olds (Figure 4.7B) tested in Experiment 2 was similar except for some of the lowest intensity expressions: [happiness and neutral with lowest intensity sadness], [fear and surprise], [sadness and disgust], and [anger]. The adults in Experiment 2 included the lowest intensity expressions from more expression categories in the neutral cluster than the 14-year-olds or the group of adults in Experiment 1. Specifically, neutral grouped with the lowest intensity of angry, sad, fear, and surprise for adults in Experiment 2; with the lowest intensity of sad for 14-year-olds; and with the lowest intensity of disgust and sad for adults in Experiment 1. The inconsistent clustering suggests that the lowest intensity expressions used here sit on the perceptual boundary between neutral and expressive so that they are categorized as neutral sometimes and as expressions at other times.

Discussion

Although tested with different methods, the adults in Experiments 1 and 2 yielded very similar perceptual structures of facial expressions, including similar dimensions and clustering. The similar results mean that it is reasonable to compare the solutions from the 7-year-olds with the odd-man out procedure in Experiment 1 to those of adults and 14-year-olds tested with similarity judgments in Experiment 2 and to those of adults reported in the literature.

The results for 14-year-olds are very similar to those for adults: both groups' dimensions appear to include pleasure, arousal, potency, and intensity, although for 14-year-olds fearful expressions are not at the expected end of the potency dimension. Both groups also showed similar clusters of expressions, namely, [happiness, neutral, and some low intensity expressions], [fear and surprise], [sadness and disgust], and [anger]. In addition, the analyses of individual weightings indicated that the group solution characterized well the perceptual structure for individual members of both age groups.

However, the 14-year-olds differed from the adults and even the 7-year-olds in Experiment 1 in the pattern of relationship between physical and perceived differences. Unlike the other groups, the 14-year-olds perceived a specified physical difference (a 20% change in intensity) as representing the same magnitude of perceptual difference, regardless of whether the change occurred to a low or high intensity expression (see Figure 4.3). The adults in both experiments, as well as the 7-year-olds in Experiment 1, perceived the difference as larger when it occurred to low intensity expressions (Figure 4.3), perhaps because they perceived those low intensities as near the category boundary with neutral. It is puzzling that this effect is apparent in 7-year-olds and adults but not at the intermediate age of 14. One possibility is that when two intensities of the same expression in the same model are presented side-by-side in the similarity-rating paradigm, participants are more prone to make their judgments based on physical differences and not the underlying feeling. This would be less likely to occur when those two stimuli are compared to a third expression in a triad of the odd-man-out paradigm. It is possible that adults are better able than 14-year-olds to keep judging the "feeling" expressed by the faces, even when two intensities to the same expression are presented as a pair.

In summary, the results of Experiment 2 indicate that the perceptual structure for representing facial expressions of the six basic emotions is essentially adult-like by 14 years of age, despite the fact that their event-related potentials evoked by those expressions are still not adult-like (Batty & Taylor, 2006; Monk et al., 2003). Although by age 7, some aspects of the perceptual structure are already adult-like, between 7 and 14 years of age, the representation of low intensity expressions and neutral is altered, fear begins to be perceived as more similar to surprise, and the dimension of potency is added. Of course, we can draw no conclusions about exactly when between 7 and 14 the changes occur, except to note that other evidence suggests that it is likely to occur over a number of years: accuracy in recognizing facial expressions (Durand, et al., 2007; Kolb, et al., 1992; Vicari, Reilly, Pasqualetti, Vizzotto, & Caltagirone, 2000), reaction time in processing facial expressions (De Sonneville, Verschoor, Njiokiktjien, Op het Veld, Toorenaar, & Vranken, 2002), and sensitivity to subtle expressions (Gao & Maurer, 2009, and unpublished data) all improve gradually after 7 years of age.

General discussion

In the current study, we mapped the perceptual structure of facial expressions in adults and in children aged 7 and 14 years with facial expressions of six basic emotions at varying intensity levels. For all four groups tested, a three- or four-dimensional structure explained the data optimally. The two groups of adults demonstrated almost identical structure despite the fact that one group was tested with a conventional similarity-rating paradigm (Experiment 2) while the other was tested with a child-friendly odd-man-out paradigm (Experiment 1). The 7-year-olds showed a systematic structure, which differs from that of adults in both the meanings of some dimensions and the proximities among some of the expression categories. The 14-year-olds showed an adult-like pattern on all measures except that they were more influenced by physical differences in their similarity judgments than adults, probably due to the similarity-rating paradigm used.

The structures we found here are more complex than the ones found in previous studies which used only intense expressions and which typically found data matching the circumplex model (Russell, 1980). The circumplex model reduces complex data sets to two meaningful underlying dimensions, typically labeled pleasure-displeasure and high-low arousal (Alvarado, 1996; Bimler & Kirkland, 1997, 2001; Russell & Bullock, 1985, 1986; Shah & Lewis, 2003). However, this model has difficulty in representing adults' perception of the difference between fear and anger. Although fear and anger are not conceptually or perceptually similar to each other, they fall next to each other in the circumplex model. On the pleasant dimension, both fear and anger are on the unpleasant side whereas on the arousal dimension, both fear and anger are on the high arousal side. Some researchers suggest that at least three dimensions are needed (Fontaine, et al., 2007). Besides pleasure and arousal, potency is suggested as the third dimension (Fontaine, et al., 2007; Osgood, et al., 1975). On the potency dimension, high values relate to feelings of power, dominance, and impulses to act whereas low values relate to feelings of weakness, submission, and refraining from action. Anger and fear fall on different sides of the potency dimension. Although most studies mapping the perceptual structure of facial expressions have focused on two-dimensional models, some studies tried to incorporate a third dimension. However, studies based on predefined dimensions usually found the third dimension to be correlated to the first two dimensions (Schlosberg, 1954) while studies based on MDS have usually found the third dimension hard to interpret (Abelson & Sermat, 1962; Shah & Lewis, 2003; Bimler & Kirkland, 1997). Russell and Bullock (1985) suggested a third dimension representing potency, control and dominance, in their interpretation of the MDS solutions of both adults and 4-year-olds. However, they suggested treating this dimension with caution because only 10 stimuli were used to test the 4-year-olds. In the current study using more stimuli and four levels of intensity, we found that in the structures of both groups of adults and of the 14-year-olds, there is a dimension clearly differentiating anger from fear, a pattern suggesting a potency dimension. However, we did not see such a dimension in the structure of the 7-year-olds.

Previous studies have not directly assessed how intensity is represented in the perceptual structure of expressions because only intense expressions were used or because intensities were not compared to each other. The current findings suggest that intensity is represented as one dimension, which is orthogonal to the other dimensions of pleasure, arousal, and potency, and present by 7 years of age. Consistent with the existence of an intensity dimension, the neutral expression seems to be located on the periphery of the perceptual structure of facial expressions, with low intensity expressions close to neutral and higher intensity expressions farther away, although not spaced linearly by physical intensity. Our results are consistent with the findings from one previous study showing that the neutral expression is located in the periphery of the structure (Shah & Lewis, 2003), and do not support the theoretical prediction that neutral is in the center of the structure (Takehara et al., 2007).

The differences in clustering between the 7-year-olds and adults' perceptual structures of facial expressions may reflect biases in children's experience with different expressions, as well as more general developmental changes in visuo-cognitive abilities. Unlike adults, children did not group surprise with fear and they grouped neutral with low intensity negative expressions rather than with happiness. These differences may be related to children's everyday experiences with facial expressions. For example, children's positive interactions with adults and peers may be usually accompanied by intense happy expressions and rarely by neutral expressions. For that reason, children may consider a neutral expression to be unfriendly or hostile. They may react to low intensity expressions in the same way because their infrequent experience with them makes them ambiguous. Immaturities in the visual system will also limit their sensitivity to subtle expressions both in everyday life and our experiment (e.g., vernier acuity: Skoczenski & Norcia, 2002; contour integration: Kovács, Kozma, Fehér, & Benedek, 1999; configural face processing: Mondloch, Le Grand, & Maurer, 2002). The immaturity of children's cognitive abilities (e.g., perspective-taking: Choudhury, Blakemore & Charman, 2006) may also limit their ability to interpret information from some facial expressions. For example, it may make it harder for them to disambiguate whether a surprised expression is positive (unexpected happiness) or negative (unwanted danger). On the other hand, we may have overestimated the difference between children and adults by using static pictures of facial expressions.

In conclusion, using facial expressions of varying intensity, we found that children at age 7 have a perceptual structure of facial expressions that differs systematically from the one in adults. Although children's perceptual structure is not purely based on physical difference among facial images, they are influenced by physical difference more than adults even at 14 years of age. By age 14, children's perceptual structure is otherwise adult-like. Further study is needed to investigate when an adult-like structure first emerges in children after 7 years of age.

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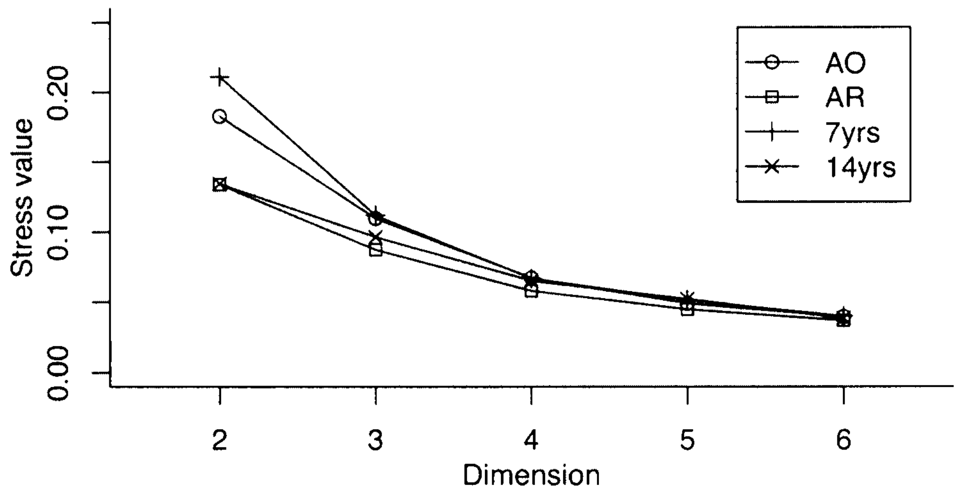

Figure 4.1 Stress values of two to six dimensional solutions for each group. Shown are the values for adults tested with odd-man-out paradigm in Experiment 1 (AO), adults tested with the similarity-rating paradigm in Experiment 2 (AR), 7-year-olds tested with the odd-man-out procedure in Experiment 1 (7yrs), and 14-year-olds tested with the similarity-rating procedure in Experiment 2 (14yrs).

(A)

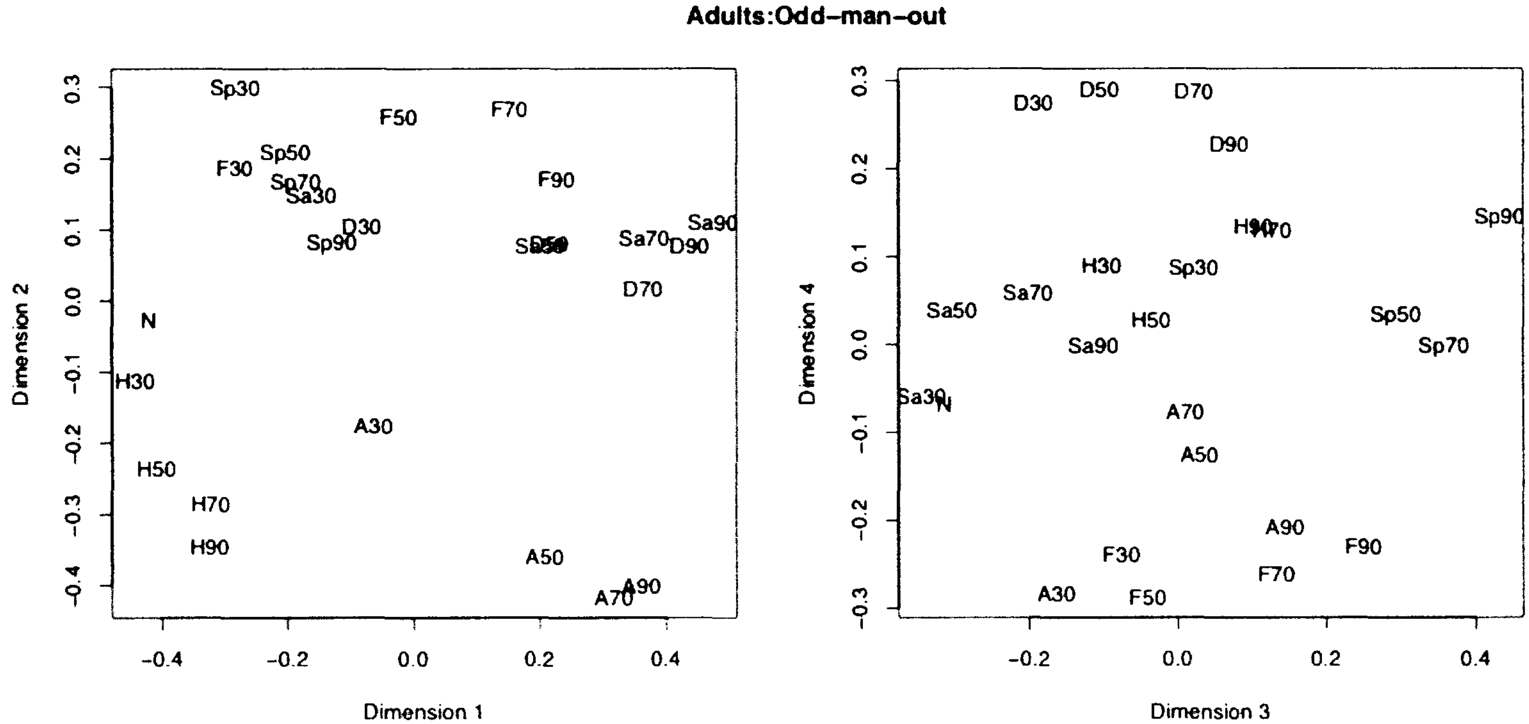

Figure 4.2 Four-dimensional solutions for (A) adults and (B) 7-year-olds in Experiment 1. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

(B)

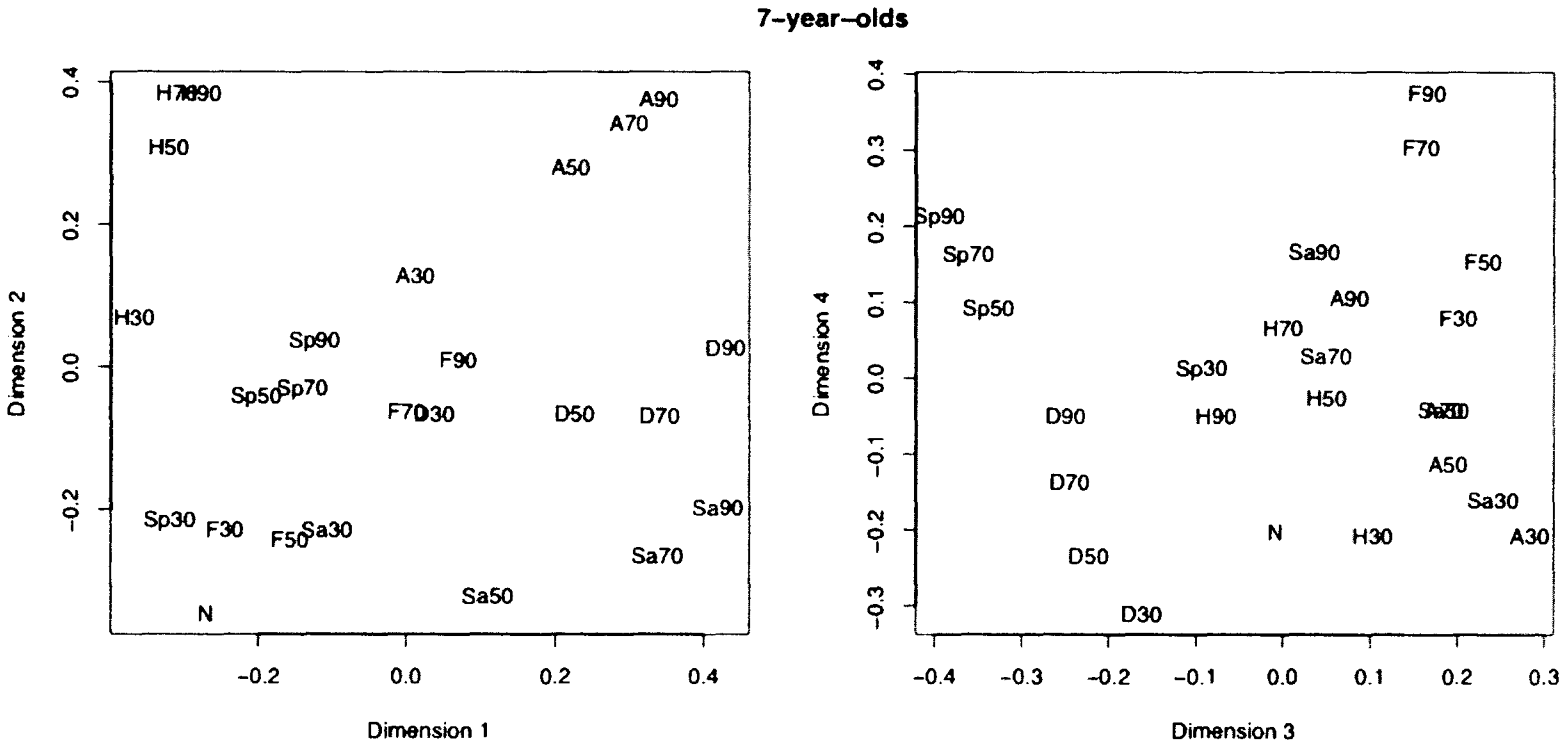

Figure 4.2 Four-dimensional solutions for (A) adults and (B) 7-year-olds in Experiment 1. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

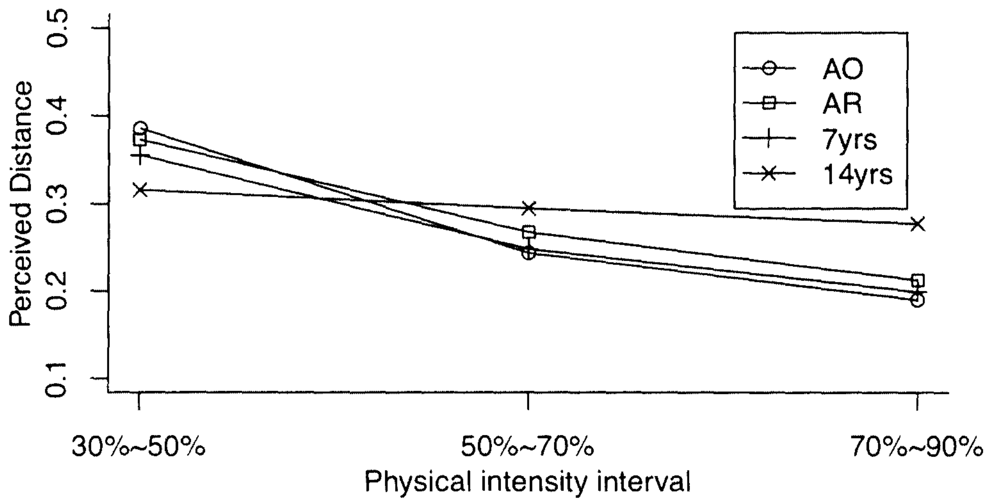

Figure 4.3 Relation between perceived distance and physical distance at different intensity intervals. Shown are the values for adults tested with odd-man-out paradigm in Experiment 1 (AO), adults tested with similarity-rating paradigm in Experiment 2 (AR), 7-year-olds tested with the odd-man-out procedure in Experiment 1 (7yrs), and 14-year-olds tested with the similarity-rating procedure in Experiment 2 (14yrs).

(A)

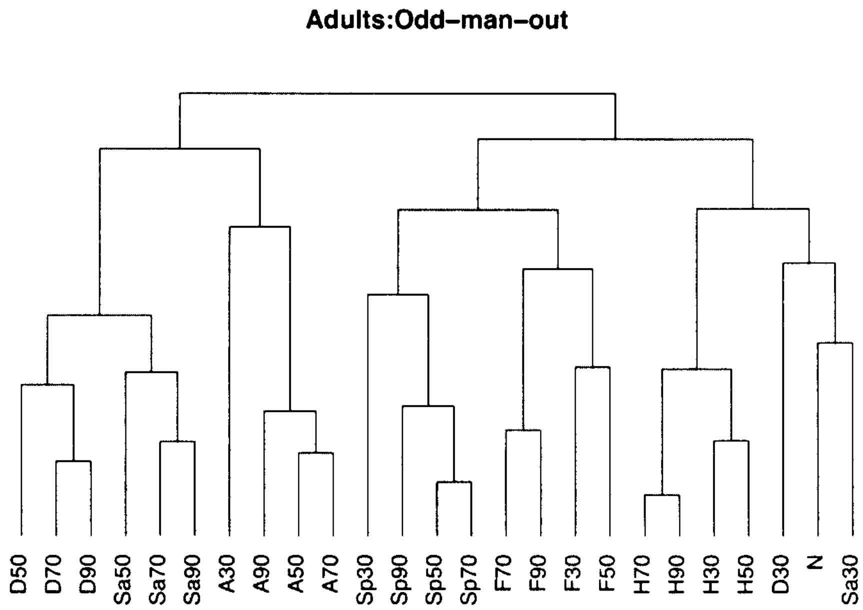

Figure 4.4 Dendrograms of Hierarchical clustering analysis in Experiment 1 for (A) adults and (B) 7-year-olds. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity. The dendrograms should be read from the bottom toward the top. Facial expressions that are perceived as similar merge into the same groups earlier than facial expressions that are perceived as different when moving toward the top.

(B)

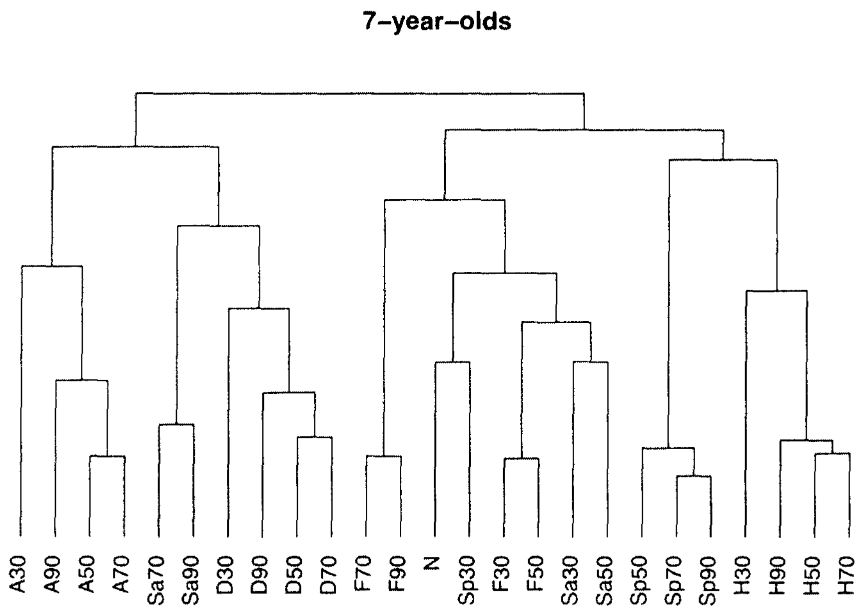

Figure 4.4 Dendrograms of Hierarchical clustering analysis in Experiment 1 for (A) adults and (B) 7-year-olds. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity. The dendrograms should be read from the bottom toward the top. Facial expressions that are perceived as similar merge into the same groups earlier than facial expressions that are perceived as different when moving toward the top.

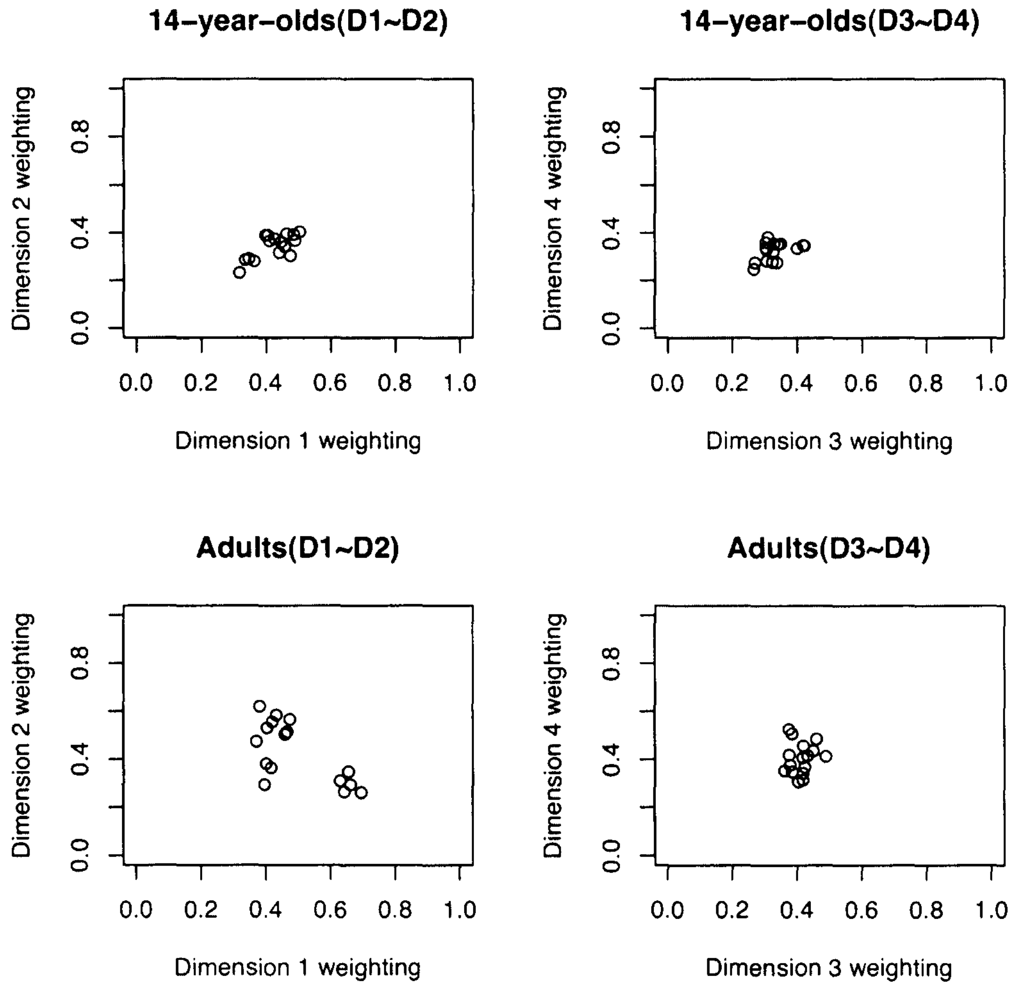

Figure 4.5 Individual weightings for 14-year-olds and adults on the four-dimensional solutions in Experiment 2. Each circle represents the weighting for an individual participant.

(A)

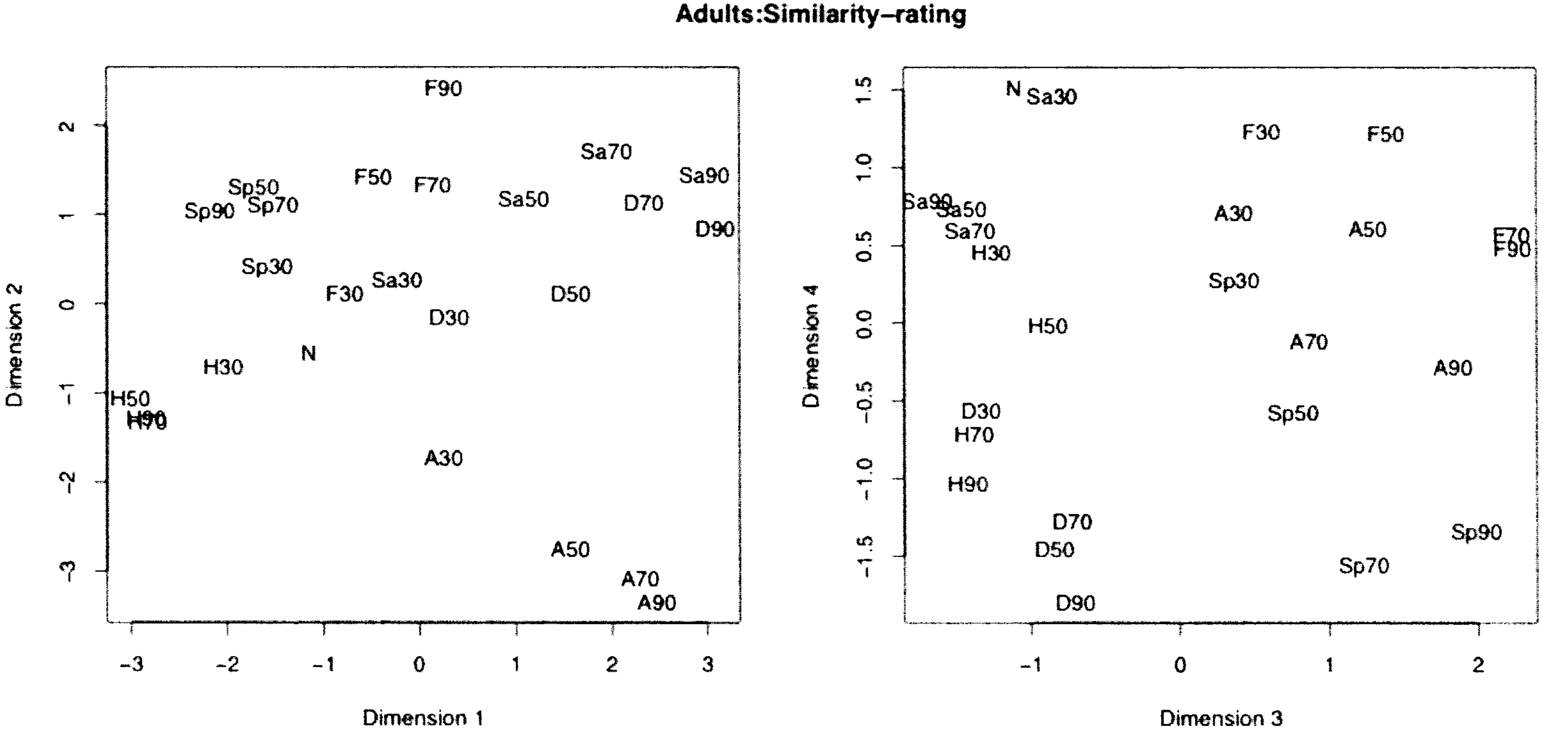

Figure 4.6 Four-dimensional solutions for (A) adults and (B) 14-year-olds in Experiment 2. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

(B)

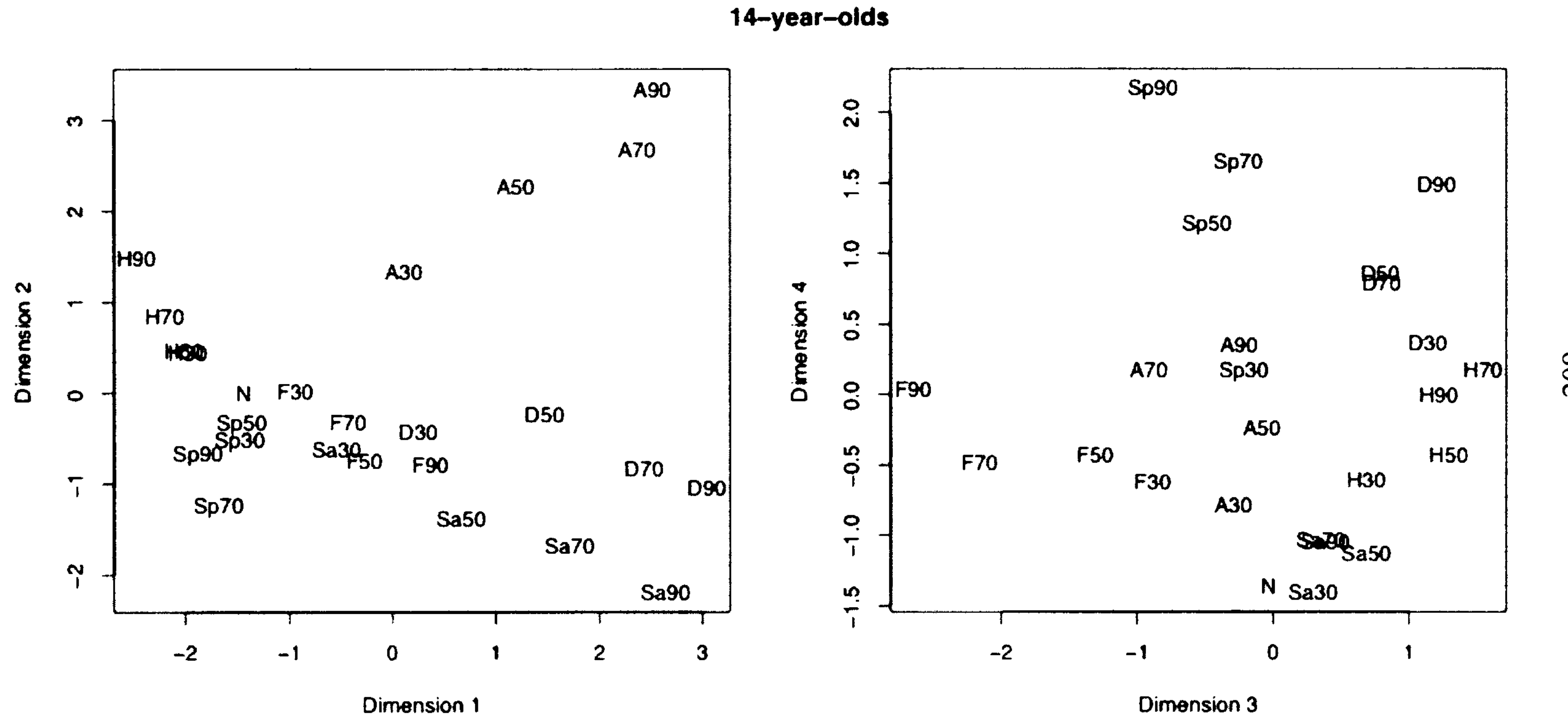

Figure 4.6 Four-dimensional solutions for (A) adults and (B) 14-year-olds in Experiment 2. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

(A)

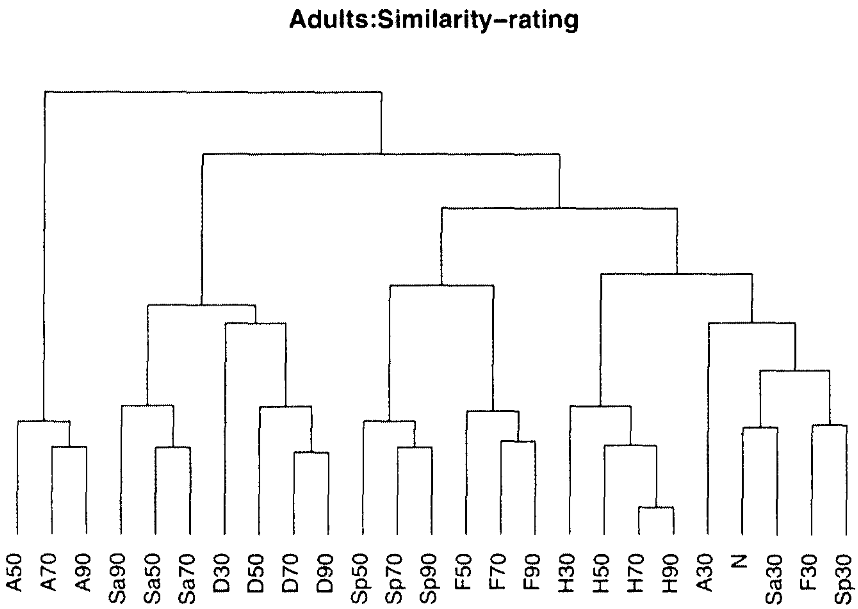

Figure 4.7 Dendrograms of Hierarchical clustering analysis in Experiment 2 for (A) adults and (B) 14-year-olds. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

(B)

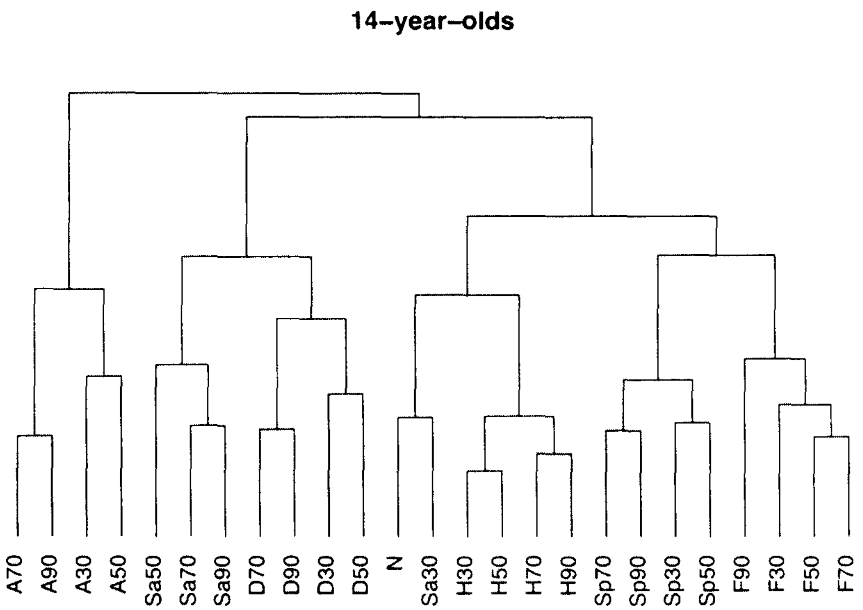

Figure 4.7 Dendrograms of Hierarchical clustering analysis in Experiment 2 for (A) adults and (B) 14-year-olds. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

Chapter 5

Preface

The research described in Chapter 5 has been written as a manuscript and submitted to *Vision Research.* The version included in this thesis incorporates minor revisions suggested by my supervisory committee after the manuscript was submitted.

In the research described in the previous chapters, I found a slow development of children's ability to categorize facial expressions, and of their perception of the relationship among facial expressions. One possible explanation underlying this slow development is that children may not use information in faces as optimally as adults in processing facial expressions. In the research described in Chapter 5, I investigated how children use spatial frequency information to recognize facial identify and facial expressions. Using a narrow band noise masking paradigm, I found that the center of the critical spatial frequency band that adult use to recognize facial expressions is significantly higher than the center of the critical spatial frequency band that adult use to recognize facial identity. This pattern held true at different viewing distances. Children at age 10 and 14 relied on similar spatial frequency bands as adults to recognize facial identify and facial expressions. However, unlike adults, the centers of children's critical spatial frequency bands for recognizing facial identity and facial expressions did not differ from each other. The patterns suggest that adults use finer details for recognizing facial expressions than for identifying faces, and that this tuning takes many years to develop. The current findings add another piece of evidence for the slow development of children's sensitivity to facial expressions of the six basic emotions.

Running Head: SPATIAL FREQUENCY TUNING IN FACE PERCEPTION

The comparison of spatial frequency tuning for the recognition of facial identity and facial expressions in adults and children

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Abstract

We measured contrast thresholds for the identification of faces and facial expressions as a function of the center spatial frequency of narrow-band additive noise. In 5 adults, the critical band was higher for expressions than for identities (Experiment 1), and both shifted to slightly lower values as distance increased (Experiment 2), a pattern indicating only partial scale invariance. Children aged 10 and 14 years showed similar tuning for facial identity but flatter functions for facial expression (Experiment 3). The patterns suggest that adults use finer details for recognizing facial expressions than for identifying faces, a tuning that takes many years to develop.

Keywords: facial identity; facial expression; spatial frequency; development

Introduction

Facial identity and facial expression represent invariant and changeable aspects of faces, respectively. Human adults are fast and accurate in extracting these two types of information from faces. Several researchers have proposed that the recognition of facial identity and facial expression involve two separable systems (Bruce and Young, 1986; Haxby, Hoffman, & Gobbini, 2000). That proposal is supported by evidence from behavioural measures (Young, McWeeny, Hay, & Ellis, 1986), neuropsychological studies (Etcoff, 1984; Young, Newcombe, de Haan, Small, & Hay, 1993; Tranel, Damasio, & Damasio, 1988; Hornak, Rolls, & Wade, 1996), functional imaging (George, et al., 1993; Sergent, Ohta, MacDonald, & Zuck, 1994; Winston, Henson, Fine-Goulden, & Dolan, 2004), and single cell-recordings (Hasselmo, Rolls, & Baylis, 1989). However, no previous study has investigated whether we use the same or different spatial frequency information to recognize facial identity and facial expression.

Research on the recognition of facial identity has revealed that adults use a limited range of mid spatial frequencies, with spatial frequency defined as the number of sinusoidal transitions across the face, measured in cycles per face width (c/fw), rather than the number of variations across the retina, which is measured in cycles per degree. Unlike cycles per degree, cycles per face width remain constant as the face is viewed from different distances. Although it is generally agreed that the mid spatial frequency bands contain the critical information for face identification, the estimates of the critical center frequency vary from study to study, probably because of different ways of manipulating the available spatial frequency information. Pixelizing was one of the earliest approaches used to manipulate spatial frequency information in faces. In this approach, a grid was put on a face image and the gray level within each block (pixel) was set to the mean gray level of the block. Studies using this approach reported that accuracy for recognition of facial identity dropped when the image quality dropped below 16 (Harmon, 1973), 18 (Bachmann, 1991), 21 (Costen, Parker, & Craw, 1994), and 23 (Costen, Parker, & Craw, 1996) pixels per face (8-11.5 c/fw). However, pixelizing introduces additional high spatial frequencies into the image, which may affect the estimates of the critical spatial frequency bands for face identification. As a better way to manipulate spatial frequency information than pixelizing, filtering is a commonly used approach, because it allows the selective removal of certain spatial frequencies without adding extra spatial frequencies to the image. Using low-pass filtered faces, in which higher spatial frequencies were removed, Fiorentini, Maffei and Sandini (1983) found that adults were less accurate in recognizing facial identity when the cutoff frequency dropped from 8 to 5 c/fw. Using low-pass and high-pass filtered faces, Costen and colleagues (1994, 1996) found that the most useful information for face identification is carried by a spatial frequency band between 8 and 16 c/fw. In contrast, using band-pass filtered faces, which only contain information in a narrow range of spatial frequencies, Hayes, Morrone and Burr (1986) found that the most critical information is located around 20 c/fw. An alternative approach to selectively removing certain bands of spatial frequency by filtering is to add noise in the target spatial frequency band, a procedure called noise masking. Using narrow band additive white Gaussian noise, Näsänen (1999) found that adults asked to recognize the identity of faces are most sensitive to spatial frequency information centered around 8-11 c/fw. Similar to noise masking, Fourier phase randomization selectively disrupts information in a certain spatial frequency band by scrambling the phase information in that band. This method has the advantage of leaving the amplitude spectrum of the face constant because no noise is added to the image. Using Fourier phase randomization, Näsänen (1999, Experiment 2) reported similar results (8-11 c/fw) to those found with noise masking (Näsänen, 1999, Experiment 1, 8-11 c/fw) for the critical spatial frequency band used by adults in face identification. Also using Fourier phase randomization, Ojanpää and Näsänen (2003) reported similar results (8-11 c/fw) when a visual search paradigm was used.

The use of spatial frequency information in face identification is assumed to be scale invariant. Hayes and colleagues (1986) found that the most informative spatial frequency band is located around 20 c/fw when adults were tested at 2.1 m or 8.5 m. However, Näsänen (1999, Experiment 4) and Ojanpää and Näsänen (2003) reported a slight shift of the critical spatial frequency band when adults were tested at different distances. When the testing distance was increased from 60 cm to 240 cm in the first study, the center of the critical spatial frequency band shifted from 11 c/fw to 6.9 c/fw. When the testing distance was increased from 57 cm to 171 cm in the second study, the center of the critical spatial frequency band shifted from 8-11 c/fw to 5.6-8 c/fw. One explanation of the shift is the attenuation of high spatial frequencies by the optics of the eye (Näsänen, 1999; Ojanpää & Näsänen, 2003). Nevertheless, when compared to the shift in retinal spatial frequency with increased viewing distance (e.g., from 60 cm to 240 cm in the Näsänen's [1999] study), the shift in object-based spatial frequency is relatively small. Therefore, the critical spatial frequency in recognizing facial identity appears to be partially scale invariant.

The far fewer studies on the recognition of facial expressions generally agree that the mid spatial frequency band is also critical. Using low-pass and high-pass noise masking, Schwartz, Bayer and Pelli (1998) found that the critical spatial frequency band for recognizing facial expressions is located around 8 c/fw. Using hybrid faces, which contained a face with information below 8 c/fw superimposed on a face with information above 24 c/fw, Schyns and Oliva (1999) reported a low spatial frequency bias in categorizing facial expressions. The same low frequency bias was also found when the participants categorized facial identity in hybrid faces. Using filtered synthetic faces representing different facial expressions, Goren and Wilson (2006) found that when the spatial frequency band shifted from mid (10 c/fw) to low (3.3 c/fw) spatial frequency, discrimination thresholds increased for most of the expressions, especially for sadness, but not for anger. No change in threshold was found when the spatial frequency band shifted from mid to high (30 c/fw) spatial frequency. The difference in critical spatial frequency among expressions is also suggested by Smith and Schyns (2009)'s finding that different facial expressions are represented by different diagnostic spatial frequency spectra. In this study, the critical spatial frequency band for recognizing each expression revealed by the Bubbles technique (Gosselin & Schyns, 2001) was related, to some extent, to observers' sensitivity to that expression at different viewing distance. Expressions that have lower critical spatial frequencies (happy, surprise, disgust) were better recognized in smaller images simulating a longer distance than expressions that have higher critical spatial frequencies (neutral, sad).

There has not been a direct comparison of the critical spatial frequency bands for the recognition of facial identity and the recognition of facial expression in which the same methods were used to manipulate spatial frequency. Although previous studies agree that the mid spatial frequency band is critical for both facial identity and facial expression, the amount of variation across methods and studies makes it impossible to ascertain whether the critical bands are completely or only partially overlapping. That was the purpose of Experiment 1. We used noise masking to measure the critical spatial frequency band for the recognition of facial identity and of facial expressions, in each case with variable information from the other dimension. Specifically, we measured contrast thresholds for recognizing facial identity with varying expression and for recognizing facial expression with varying identity as a function of the spatial frequency of narrow-band additive white Gaussian noise. To increase the generality of the findings, we used four different identities and four facial expressions capturing the major variation in adults' perceptual structure of facial expressions (Gao, Maurer & Nishimura, 2010), namely, happiness, sadness, fear, and anger. In Experiment 2, we used the same paradigm to investigate the effect of viewing distance. In Experiment 3, we used a subset of conditions to explore developmental changes in the critical spatial frequency band used in recognizing facial identity and expression.

General methods

Apparatus

The stimuli were generated on an Apple Mac Pro computer and displayed on a 21-inch CRT monitor (Dell P1130) with a resolution of 1600 × 1200, a refresh rate of 85Hz (non-interlaced), and 256 grayscale levels. The average luminance of the stimuli and background was 20.4 cd/m^2. The experiments were controlled by custom software based on the Matlab (version 7.1) programming environment using Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Participants viewed the stimuli binocularly in a dimly lit room with their heads stabilized on a chinrest.

Face images

We used two female models (model number: 03, 10) and two male models (model number: 24, 25) from the Nimstim stimulus set (Tottenham et al., 2009).

For each model, we selected the images depicting happy, sad, angry, fearful, and neutral expressions. The selected models received high agreement on the expression posed and high ratings of intensity from adults in a previous study (Palermo & Coltheart, 2004). The neutral faces and the original expressive faces were used only for generating the testing stimuli. For each expression, we created intensities of 50% and 90% by morphing the emotional face with the neutral face (for details, see Gao & Maurer, 2009), and only these two images were used during the test. The 90% expressions were near the maximum intensity produced by human adults and will be referred to as high intensity. The 50% expressions were lower but still quite a bit above threshold for each expression, as revealed in previous research with this stimulus set (Gao & Maurer, 2009). For ease, we will refer to them as low intensity. This procedure created 32 test stimuli (4 models × 4 expressions × 2 intensities).

Image processing was carried out using Matlab (version 7.1). The stimuli were converted to grayscale images and the amplitude spectrum of each face image was replaced by the average amplitude spectrum of the 32 face images. An oval-shaped Gaussian window was applied to each image to remove hair cure from the face (see Figure 5.1). Each face has a width of 11cm, or from a testing distance of 60 cm, 10.5 visual degrees.

Spatial frequency manipulation

On each trial, a white Gaussian noise mask, which was the same size as the face image was superimposed. The noise mask was filtered by a Gaussian filter at one of seven center frequencies (4, 5.6, 8, 11, 16, 23, 32 c/fw) with a bandwidth of 1.58 octaves (full width half height). The noise mask alone had a mean grayscale value of 0. When the noise mask was combined with the face image, the mean luminance value of the masked image was the same as the original face image. Image Root-mean-square (*RMS*) contrast was computed by first computing local contrast:

$$c_i = \frac{l_i - L}{L} \tag{1}$$

where c_i is the contrast at pixel location i. L is average luminance and l_i is the luminance of the ith pixel.

These values were then used to compute *RMS* contrast:

$$c_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} c_i^2} \tag{2}$$

where n is the number of pixels in the image. The *RMS* contrast of the face image was varied according to a staircase procedure, while the *RMS* contrast of the noise was kept constant at 0.04 (the *RMS* contrast of the noise was reduced to 0.02 in Experiment 3). At a *RMS* contrast of 0.04, the standard deviation of the grayscale values of the noise mask was 5.47. Since there were only 256 gray levels, any gray scale values in the masked image larger than 255 or smaller than 0 were truncated to be within the range of 0 and 255.

Procedure

The protocol was approved by the McMaster Research Ethics Board. We obtained written consents from the adult participants or from a parent of the child participants, and we obtained verbal assent from the child participants.

Training

Participants began with training to recognize the identity of all the target faces that would be used in the following testing session. Each training task had three stages. In the first stage, participants passively viewed the eight versions of each target face identity (with 4 expressions × 2 intensities) twice, for 2 seconds each time, preceded by a label identifying the face (female 1, female 2, male 1, male 2). In the second stage, participants indicated the identity of each face image by pressing a predefined key. Each version of the target face images was shown once for 500 ms (the presentation time was extended to 1000 ms in Experiment 3). Auditory feedback was given after each key press with a high pitch tone indicating a correct response and a low pitch tone indicating an incorrect response. The third stage was identical to the second stage except that no feedback was given after each response. Participants needed to reach 100% accuracy in the third stage to proceed to the testing session. No training was given for the facial expression discrimination task.

Testing

Each trial started with a 500 ms presentation of a fixation cross in the center of the screen followed by a 500 ms presentation of a face image (the presentation time was extended to 1000 ms in Experiment 3). Participants used the keyboard to indicate their answers and received the same auditory feedback as used in the training session. The next trial began as soon as the feedback ended. On the first trial of each staircase, the face image had a *RMS* contrast of 0.2 (a *RMS* contrast of 0.3 was used for the first trials in Experiment 3). After three (two for Experiment 2 and Experiment 3) consecutive correct responses, the *RMS* contrast of the face image was decreased by a factor of 1.26. After each incorrect response, the *RMS* contrast of the face image was increased by the same factor. The staircase procedure terminated at 80 trials or 10 reversals, whichever came first. The threshold value was calculated as the geometric mean of the *RMS* contrast values of the last 6 reversals, representing an accuracy of 0.79 (0.71 for Experiment 2 and Experiment 3).

Experiment 1

In Experiment 1, we examined the importance of different bands of spatial frequency for recognizing facial identity and facial expression by adding to the face images, white Gaussian noise that masked 7 narrow spatial frequency bands with different center frequencies. In the facial identity task, the observers learned and discriminated a pair of male faces and a pair of female faces, in each case with varying facial expressions. In the facial expression task, the same observers discriminated two pairs of facial expressions (happiness vs. sadness and anger vs. fear) posed by the same four models. Each expression pair was tested at both high intensity (90%) and low intensity (50%). We chose these two pairings of facial expression because they differ maximally on the two major dimensions in adults' perceptual structure for facial expressions, namely, the pleasure dimension and the potency dimension (Gao, Maurer & Nishimura, 2010). Happiness and sadness represent two ends of the pleasure dimension, while anger and fear represent two ends of the potency dimension. By including high and low intensities, we were also able to examine the effect of physical difference on the critical spatial frequency band for the discrimination of facial expressions since the physical difference between two low intense expressions is smaller than the physical difference between two high intense expressions. We also compared the performance of the five observers to the performance of a white noise ideal observer with all the pixel information in the images working under the assumption that the noise was distributed randomly across spatial frequencies.

Participants

Participants were five adult observers (XG, SM, JW, MV, and OK, age range: 20 – 28) from McMaster University. XG and MV are experienced psychophysical observers. SM, JW, and OK were naïve to the purpose of the current study and had very limited previous experience in psychophysical experiments. All participants had normal or corrected-to-normal vision. They completed testing over two weeks.

Design

Facial identity discrimination

Participants discriminated between the two male models in one block and between the two female models in the other block; order of blocks was randomized across observers. For each model there were 8 different images consisting of 4 expressions at 2 intensities. In each block, two staircase runs were conducted for each of the 8 noise masking conditions (no noise and 7 centre frequencies). In total, each participant generated 32 thresholds (2 testing blocks [male; female] × 8 noise conditions × 2 runs). The order of testing within each block was constrained so that the first and the ninth staircase were always the no noise condition and the other conditions appeared in a random order once before and once after the ninth staircase. The mean threshold of the two runs was used as the threshold for each condition.

Facial expression discrimination

The facial expression task consisted of 4 blocks: 90% happiness vs. 90% sadness, 50% happiness vs. 50% sadness, 90% anger vs. 90% fear, and 50% anger vs. 50% fear. Since we used the same four models for both identity and expression discrimination, we always ran the identity task before the expression task to control the amount of exposure to the four identities. Within each block, the order of masking conditions was controlled in the same way as for the identity discrimination task. In total, each participant generated 64 thresholds (4 testing blocks × 8 noise conditions × 2 runs). The four blocks of expression discrimination were tested in a pseudo random order so that the low intense pairings always followed their corresponding high intense pairings, with the starting expression pair (happy/sad or angry/fear) randomized across observers. The mean threshold for the two runs was used as the threshold for each condition.

Ideal observer analysis

On each trial, the white noise ideal observer calculated the ratio between the posterior probabilities that the current stimulus was from stimulus group A or from stimulus group B using the following formula (Tjan, Braje, Legge, & Kersten, 1995; Gold, Bennett, & Sekuler, 1999):

$$p = \frac{\sum_{j=1}^{Na} \exp\left[-\frac{1}{2\sigma^2}\sum_{i=1}^{n}\left(S_i - Ta_{ij}\right)^2\right]}{\sum_{j=1}^{Nb} \exp\left[-\frac{1}{2\sigma^2}\sum_{i=1}^{n}\left(S_i - Tb_{ij}\right)^2\right]} \tag{3}$$

where

S_i = the grayscale values of the ith pixel of the current stimulus,

Ta_{ij} = the value at pixel i in the jth template of stimulus group A,

Na = the number of templates in stimulus group A,

Tb_{ij} = the value at pixel i in the jth template of stimulus group B,

Nb = the number of templates in stimulus group B,

n = the number of pixels in each image (650 × 650),

σ = the standard deviation of the noise grayscale values.

On a given trial, the ideal observer chose answer A if P was greater than 1, and answer B if P was less than 1. The ideal observer ran all the conditions (except the no noise condition) with the same settings as human observers. For each condition the threshold was the mean threshold of two runs.

Results and discussion

As shown in Figure 5.2, the white noise ideal observer performed better than human observers except when the noise mask was centered at 4 c/fw, in which case the performance of the ideal observer did not differ from human observers. Unlike human observers, whose tuning curves have an obvious peak in the mid spatial frequency range, there is no obvious peak in the tuning curves of the ideal observer. Instead, the tuning curves of the ideal observer are relatively flat with a slight decline as the center spatial frequency increases. Such results, like previous studies (Gold et al., 1999; Näsänen, 1999), suggest that human observers do not rely on low-level image information to discriminate either facial identity or facial expression.

The tuning functions for the two facial identity discrimination tasks, one involving two male faces and the other, two female faces, are quite similar and consistent among most of the participants. The peaks of the tuning functions are all at 11 c/fw, a pattern suggesting that human observers are most sensitive to information carried in this spatial frequency band when discriminating facial identity. This value is consistent with previous findings that human adults rely on mid spatial frequencies (8-16 c/fw) to recognize facial identity (Costen et al., 1994, 1996; Fiorentini, et al., 1983; Gold et al., 1999; Näsänen, 1999; Ojanpää & Näsänen, 2003; for review, see Ruiz-Soler & Beltran, 2006).

The patterns for facial expression are different from those for facial identity, although they were consistent across the two discriminations (happiness vs. sadness and anger vs. fear) and two intensities (90% and 50%). In most cases, the peak of the tuning functions in the facial expression discrimination tasks is at 16 c/fw.

To quantify the tuning functions, we fit Gaussian functions to the group mean[1] for each task using the following formula:

$$y = A \times \exp\left(\frac{-(x-\mu)^2}{2\sigma^2}\right) \tag{4}$$

[1] We also fit Gaussian functions to the tuning curves of each individual. The results are similar and are shown in the supplementary material.

where x is spatial frequency in log units, y is the contrast threshold value, A is the height of the peak, μ is the position of the peak, and σ represents the width of the curve. We estimated the position of the peak (μ) for each task using a bootstrapping procedure based on 1000 iterations. The results are shown in Table 5.1.

These estimates indicate that the peak sensitivity is around 11c/fw for facial identity, a value significantly lower than the peak, around 13 c/fw, for facial expression for all conditions except one (happiness vs. sadness at 50%). This exception may have resulted from the non-systematic pattern of OK in this condition. As revealed by curve fitting for individual data, the fit of the Gaussian function was much worse for data from OK (r^2 = 0.18) in this condition than for data from the other observers (r^2 = 0.78-0.90). We re-ran the bootstrapping procedure for this condition with OK's data excluded. The new estimate of the peak position was 13.37 c/fw (95% confidence interval: 12.70-14.20), which is significantly higher than the peaks for the facial identity tasks.

The results for Experiment 1 indicate that the optimal spatial frequency band for adults to recognize facial identity or facial expression is in the mid frequency range, consistent with previous estimates (e.g., for identity: Costen et al., 1994, 1996; Fiorentini, et al., 1983; Gold et al., 1999; Näsänen, 1999; Ojanpää & Näsänen, 2003; for expression: Goren & Wilson, 2006; Schwartz et al., 1998; Schyns & Oliva, 1999). However, by measuring the critical band for both tasks in the same observers, the current study revealed that adult human observers' peak sensitivity for discriminating happiness vs. sadness and fear vs. anger is at a spatial frequency band that is higher than for recognizing facial identity, whether the facial expression is high or low in intensity. Such findings suggest that adults use finer details to recognize facial expressions than to recognize identity, although in both cases very high spatial frequency information is not optimal. The current finding that the critical spatial frequency bands that adults use to recognize facial identity and expression are located close to one another but with different centers adds a new piece of evidence to the proposal (Bruce and Young, 1986; Haxby et al., 2000) that in adults, the systems for processing facial identity and facial expression are at least partially separate.

Experiment 2

Previous studies of the recognition of facial identity have reported that the critical spatial frequency band is largely constant across distance, that is, it is based on the amount of information in each unit of the face (cycles per face width), rather than in each unit of the retina (cycles per degree) (Hayes et al., 1986; Näsänen, 1999; Ojanpää & Näsänen, 2003). Such an object-based system is useful for recognizing faces across varying distance. However, the empirical results for facial identity have been inconsistent: when distance was varied 3-4 fold, one study found no change in the optimal spatial frequency (Hayes et al., 1986), whereas two others found a shift toward a slightly lower spatial frequency band when distance was increased (Näsänen, 1999; Ojanpää & Näsänen, 2003).

There has been no report on the effect of distance on the critical spatial frequency band for the recognition of facial expressions.

In Experiment 2, we investigated the critical spatial frequency band for the recognition of facial identity and of facial expressions at three testing distances using the same noise masking paradigm as in Experiment 1. Because in Experiment 1, the tuning functions were similar for discriminating the two females and the two males and similar for the four facial expression tasks, we used two four-alternative forced choice tasks in Experiment 2: one with the four identities and one with the four expressions at the high intensity (90%).

Participants

Participants were the same five observers as in Experiment 1. They began Experiment 2 after completing Experiment 1 and completed it over a number of days within a two week period.

Design and procedure

Facial identity discrimination

In the identity block, participants discriminated among the four models (two female, two male) used in Experiment 1. For each model, there were 8 different images consisting of 4 expressions at 2 intensities (50% and 90%). Participants were tested in sequence at three viewing distances: 60 cm, 120 cm, and 180 cm. For each testing distance, two staircase runs were conducted at each of the 8 noise masking conditions to yield 48 thresholds (3 viewing distances × 8 noise conditions × 2 runs). The order of the conditions was controlled in the same way as in Experiment 1. The mean threshold of the two runs was used as the threshold for each condition.

Facial expression discrimination

In the expression block, participants discriminated among four expressions: happiness, sadness, fear, and anger, all at 90% intensity. Each expression was displayed in the faces of the same four models used in Experiment 1. The other details of the procedure were the same as in the identity discrimination task. We collected 48 thresholds (3 viewing distances × 8 noise conditions × 2 runs) from each participant. The expression block was always run after the identity block.

Results and discussion

As shown in Figure 5.3, at a viewing distance of 60 cm, we replicated the findings from Experiment 1: peak sensitivity at 11 c/fw for facial identity discrimination and 16 c/fw for facial expression discrimination. As the testing distance increased from 60 cm to 120 cm and 180 cm, the peak sensitivity for both facial identity discrimination and facial expression discrimination shifted gradually towards lower spatial frequencies. For facial identity, the peak sensitivity shifted from 11 c/fw at 60 cm to 8 c/fw at 180 cm. For facial expression, the peak sensitivity shifted from 16 c/fw at 60 cm to 11 cw at 180 cm.

We also ran the same bootstrapping procedure as in Experiment 1 to quantify the tuning functions in Experiment 2.[2]

The estimates indicate that, at a viewing distance of 60 cm, peak sensitivity for facial expression discrimination occurs at a higher spatial frequency than for facial identity discrimination. This pattern also is evident at the two other testing distances. Thus, regardless of distance, adult observers use slightly higher spatial frequency information (i.e., finer details) to distinguish facial expressions than they do to differentiate identity. The estimates also indicate that the peak sensitivity for both facial identity discrimination and facial expression discrimination moved to lower spatial frequencies as viewing distance increased from 60 cm to 120 and 180 cm. Nevertheless, the critical spatial frequency band did not change as much as would be expected if it were based on retinal image size: the size of the optimal spatial frequency band for facial identity in retinal coordinates at 60 cm was 1.1 cycle/degree, which corresponds to 3.8 c/fw at 180 cm; for facial expression, the corresponding figures are 1.2 cycle/degree at 60 cm and 4.2 c/fw at 180 cm. The observed shifts observed are much smaller than those predicted based on the retinal image, and therefore the results suggest that, the critical spatial frequency information used for both facial identity discrimination and for facial expression discrimination is largely object-based.

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[2] We also fit Guassian functions to the tuning curves of each individual. The results are similar to those reported in the text and are shown in the supplemental materials.

Such object-based scaling of the critical spatial frequency information is useful in real life because faces are seen at different distances, resulting in different retinal image sizes, but the critical information distinguishing them and their facial expressions is largely constant at an object-based scale. The small deviation from perfect scale invariance is consistent with findings from previous studies (Näsänen, 1999; Ojanpää & Näsänen, 2003) that with increasing viewing distance, the peak sensitivity for facial identity moved to a slightly lower object-based spatial frequency and extends those findings to the discrimination of facial expression. The optical attenuation of high spatial frequencies at greater distances is a possible explanation for the change (Näsänen, 1999; Ojanpää & Näsänen, 2003). The results of one study are discrepant from this general pattern: using band pass filtered images, Hayes et al., (1986) found a higher than typical optimal spatial frequency band (20 c/fw) for distinguishing four facial identities at both 2.1 m and 8.5 m. The higher value may have arisen because, unlike other studies, the faces included hair cues that might be more easily distinguished with information from a higher band of spatial frequencies than is optimal for discriminating internal features and face shape and/or because the faces were presented at a much lower luminance (8 cd/m^2 versus 20.4 cd/m^2 in the current study). The similar results at the two viewing distances might have arisen because the "near" distance (2.1 m) in Hayes et al. (1996) was equivalent to the farthest distance in other studies (1.8 m [current study], 2.4 m [Näsänen, 1999], 1.7m [Ojanpää & Näsänen, 2003]) and the drop in optimal spatial frequency with viewing distance may decrease with variations beyond 2 meter. In fact, as indicated in Table 5.2, most of the drop-off in the current study was between .6 and 1.2 meter, with little further decrease at 1.8 meters. Thus, beyond 1-2 meters, the critical spatial frequency band for facial identity and facial expression may be completely object-based and perfectly scale invariant. However, our data indicate that for faces at distances less than 1 meter, the critical band moves to (slightly) higher spatial frequencies as the face moves closer to the observer for judgments of both identity and expression.

Experiment 3

Experiment 1 and 2 showed that adults depend on a fairly narrow band of mid spatial frequencies to recognize facial identity and facial expression and that the critical band is lower for identity than expression. Little is know about how children use spatial frequency information in face perception. Contrast sensitivity is adult-like by age 7 (Ellemberg, Lewis, Liu, & Maurer, 1999; but see Benedek, Benedek, Kéri, & Janáky, 2003, for continued change until age 11-12). However, at age 10, children still have higher thresholds than adults for recognizing some of the basic emotional expressions (Gao & Maurer, 2009) and even at age 14, they judge the similarity of facial expressions less categorically than adults (Gao, Maurer, & Nishimura, 2010). Children's accuracy in discriminating facial identity continues to improve after age 10-14, at least for faces differing only subtly in the spacing of features (Mondloch, Dobson, Parsons, & Maurer, 2004; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grand, & Maurer, 2002).

Some of this late improvement might be related to using a different, and less optimal, band of spatial frequencies for discrimination than used by adults, or to lower sensitivity within the critical band. The only previous study with children (Deruelle & Fagot, 2005) compared children aged 5-8 years to adults using a hybrid face paradigm similar to Schyns and Oliva (1999) in which a face filtered to have spatial frequencies only below 12 c/fw was superimposed on a face filtered to have frequencies only above 36 c/fw. The two superimposed faces with different filtering differed in identity or in expression (smile or grimace). Adults judged facial identity from the low-pass face and showed no bias when asked to judge whether the facial expression was a smile or a grimace, perhaps because neither choice matched their critical frequency band (cf. Experiment 1). Children also judged facial identity from the low-pass face but, unlike adults, judged facial expression from the high-pass face. It is difficult to interpret these results because only two fairly large spatial frequency bands were contrasted, because the likely optimal mid spatial frequency band was not included, and because the faces were presented for a sufficiently long duration (400 ms for children and 100 ms for adults compared to 50 ms in the original study by Schyns and Oliva, 1999) that the participants may have been able to process both faces in the hybrid image and use more analytic higher-level strategies to make the decision.

In Experiment 3, we compared children at age 10 and 14 years to adults on the critical spatial frequency band for facial identity and facial expression. Specifically, we adapted the methods used in Experiment 1 and 2 to be suitable for children by reducing the number of conditions, reducing the contrast of the noise, and presenting the faces for a longer duration (see general methods for the details of the changes). Instead of using a broad range of spatial frequency bands as in Experiment 1 and 2, we used only four spatial frequencies bracketing the critical band for adults, namely, 5.6, 11, 16, and 32 c/fw. Each participant completed a block of judgments of facial identity involving either the two females or the two males and a block of judgments of facial expressions involving the highly intense (90%) happy and sad expressions.

Participants

Participants were 16 10.5-year-olds (± 3 months), 16 14-year-olds (± 3 months), and 16 adults who had not participated in Experiments 1 and 2 (18 – 28 years of age, mean =19.6). Child participants were recruited from names on file of parents who had volunteered their children at birth for participation in later studies. Adults were undergraduate students participating for course credit. Half of the participants in each age group were female. All of the participants had normal or corrected-to-normal vision. An additional five participants were excluded from data analysis because they failed visual screening (two 10-year-olds) or failed to reach the criterion in the training session (two 14-year-olds and one adults).

Design

Facial identity discrimination

Half of the participants in each age group of each sex discriminated between the two male models, while the other half discriminated between the two female models. For each model there were 8 different images consisting of 4 expressions at 2 intensities. One staircase was run at each of the 4 noise masking conditions (5.6, 11, 16, 32 c/fw) to collect 4 thresholds for each participant.

Facial expression discrimination

Participants discriminated between 90% happiness and 90% sadness. As in Experiments 1 and 2, each expression was displayed on the faces of four different models. One staircase was run at each of the 4 noise masking conditions to collect 4 thresholds for each participant.

Half of the participants in each age group of each sex were tested in the facial identity task first, while the other half of participants were tested in the facial expression task first. The order of the spatial frequency conditions within each task was controlled by a Latin square design. Participants were tested at a viewing distance of 60 cm.

Results and discussion

As shown in Figure 5.4, the contrast threshold to recognize facial identity and facial expressions decreases with age, $F(2,45) = 15.2$, $p < .01$. Consistent with Experiments 1 and 2, in adults, the peaks of the tuning curves for recognizing identity and expression are located at 11 and 16 c/fw, respectively. In the 10- and 14-year-olds, the peaks of the tuning curves for recognizing identity are located at 11 c/fw. However, in the 10- and 14-year-olds, there is no obvious peak for the tuning curves of recognizing expression. To quantify the tuning functions, we ran the same bootstrapping procedure as in Experiments 1 and 2.

The estimates replicate Experiments 1 and 2 in indicating that adults' peak sensitivity for recognizing facial expression is at a higher spatial frequency than for recognizing facial identity. Peak sensitivity for recognizing facial identity and facial expression is similar to that of adults in children at age 10 and 14. However, for both the 10- and 14-year-olds, the estimated peaks for identity and expression are not statistically different from each other. Therefore, unlike adults, whose peak sensitivity for recognizing facial identity and facial expression are located around different center spatial frequencies, children's peak sensitivity for recognizing facial identity and facial expression are located around the same center frequency.

The current findings suggest that 10-year-olds need a great deal more contrast than adults to recognize facial identity and facial expressions and that even at age 14, children still need more contrast than adults. This developmental difference may apply to the recognition of object characteristics in general and arise from differences in general attentional or high-level visual abilities (e.g., contour integration continues to improve until age 14, Kovács, Kozma, Fehér, & Benedek, 1999). It is also possible that children are not using the critical spatial frequency information as efficiently as adults, because the current findings suggest that children at age 10 and 14 are not as selective as adults in using specific spatial frequency information for recognizing constant (identity) versus changeable (expression) aspects of faces. Whatever the explanation, the consequence is that children as old as 14 will have more trouble than adults in recognizing faces in poor light.

The current findings are consistent with a previous report (Deruelle & Fagot, 2005) that 5- and 8-year-olds rely on low spatial frequency (<12 c/fw) information to recognize facial identity. In contrast, Deruelle and Fagot (2005) found that 5- and 8-year-olds rely on high spatial frequency (>32 c/fw) to recognize facial expression, while we found that 10- and 14-year-olds are most sensitive to the spatial frequency band centered around 12 c/fw to recognize facial expression. The difference in results may simply reflect developmental changes between 8 and 10 years. However, it is possible that the difference arises from the different methods used in these two studies. The previous study (Deruelle & Fagot, 2005) left out a large part of the mid spatial frequencies (12-20 c/fw), which previous studies, like this one, have shown to carry critical information for face perception (Costen et al., 1994, 1996; Hayes et al., 1986; Gold et al., 1999). It would be useful for a future study using methods like those in the current study to investigate the nature of developmental changes in the use of spatial frequency information in recognizing facial expressions before 10 years of age.

General discussion

In all three experiments, masking of mid spatial frequencies had the most impact on adults' recognition of both facial expressions and facial identity. This pattern is consistent with most previous studies (Costen et al., 1994, 1996; Fiorentini, et al., 1983; Gold et al., 1999; Goren & Wilson, 2006; Näsänen, 1999; Ojanpää & Näsänen, 2003; Schwartz et al., 1998; Schyns & Oliva, 1999). The tuning was also largely scale invariant: as distance tripled in Experiment 2 from 60 to 180 cm, the critical spatial frequency band shifted only slightly lower for both tasks. These patterns are consistent with previous findings that adults process both identity and facial expression holistically (Maurer, Le Grand, & Mondloch, 2002; Calder, Young, Kean, & Dean, 2000) rather than merely as a collection of independently processed features that would be most easily discriminated with higher spatial frequencies. Such holistic processing would be expected to be tied to object size (e.g., face width) rather than to retinal size.

Despite the similarities in the results for facial identity and facial expression, there was a significant difference that replicated across the three groups of adults tested at 60 cm in Experiments 1, 2, and 3, and that persisted at

120 and 180 cm in Experiment 2: in every case, the critical spatial frequency band peaked at a higher spatial frequency for facial expression than for facial identity. The non-overlapping peaks provide a new piece of evidence for the, at least partial, separation of the neural systems underlying the processing of facial identity and facial expression (Bruce & Young, 1986; Haxby et al., 2000). The difference indicates that more details are needed to recognize facial expression than to recognize facial identity. As a result, identity may be (slightly) easier to recognize than expression under conditions that degrade the transmission of higher spatial frequencies in a face image such as great distance and poor lighting.

As suggested by many researchers (de Gardelle & Kouider, 2010; Rotshtein, Vuilleumier, Winston, Driver, & Dolan, 2007), the recognition of facial expressions involves two pathways: a fast subcortical pathway relying on low spatial frequency information that does not require awareness and a slower cortical pathway relying on higher spatial frequency information, and requiring awareness. It is likely that the current results reflect the activity of the cortical pathway, since the participants were performing a recognition task with high visual awareness.

Experiment 3 indicates that children at age 10 and 14 also rely on mid spatial frequencies to recognize facial identity and facial expression. These findings are consistent with evidence that children begin to process faces holistically by 4-6 years of age (de Heering, Houthuys, & Rossion, 2007; Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007; Pellicano &

Rhodes, 2003; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). However, children's ability to recognize facial identity and facial expression continues to develop after age 10 (Gao & Maurer, 2009; Mondloch, Dobson, Parsons, & Maurer, 2004; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grend, & Maurer, 2002). Such a long developmental course is consistent with the results of the current study. We found that even at age 14, children need more contrast than adults to recognize both facial identity and facial expression, and the spatial frequency tuning is not as specific as in adults. The developmental difference may not be face-specific but arise from general differences in attentional and/or high-level visual abilities (e.g., Kovács et al., 1999; Mondloch, Maurer, & Ahola, 2006). Indeed, some of the difference may arise from the greater variability in children's responses across trials and in the larger differences among children of the same age that is reflected in the larger confidence intervals for the estimates of peak sensitivity (see Table 5.3). Whether that variability is caused by noisy tuning of the visual system or more general immaturities in attention, it has the consequence that children are not as consistent as adults in using the optimal information for each face task. Nevertheless, the variability is not the only cause of the overlap of children's tuning functions for recognizing facial identification and facial expressions. The shape of children's tuning function for identity is adult-like at both age 7 and 14 (see Figure 5.4). However, unlike in adults, the shape of children's tuning function for expression does not showing an obvious peak at either age. Therefore, the slow development of spatial frequency tuning for facial expression is also likely to contribute to children's overlapping tuning for facial identify and facial expression. That interpretation is consistent with evidence that adolescents' brain areas involved in the processing of facial identity and facial expression are not yet as specialized as in adults (Golarai, Liberman, Yoon, & Grill-Spector, 2010; Lobaugh, Gibson, & Taylor, 2006).

The current results suggest that in everyday interactions, under poor lighting (low contrast), children may be especially poor at recognizing facial identity and facial expression compared to adults. However, we used static images of faces in the current study. It is possible that in real life, dynamic information in faces may help children to recognize facial identity and facial expressions and eliminate the deficit compared to adults. In the current study, we also used only adults' faces. Although children see adults' faces in their everyday lives, they may see more faces of age mates or find them more salient. Indeed, there is some evidence for an own age advantage in the recognition of facial identity (Anastasi & Rhodes, 2005) that may reflect differential spatial frequency tuning. Future studies could use methods similar to the current study to investigate the development of spatial frequency tuning with children's and dynamic faces, as well as test children at other ages not included in the current study.

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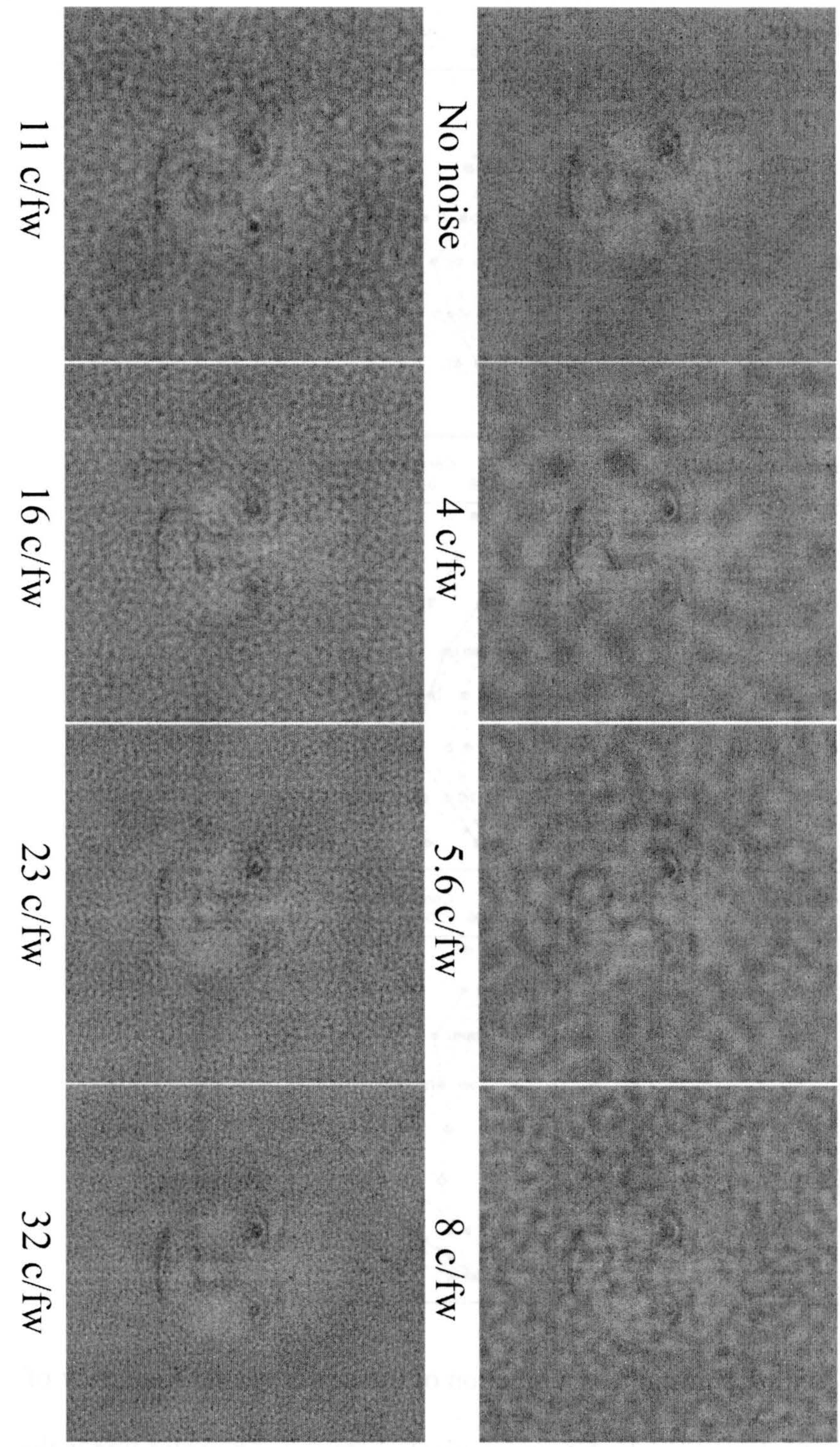

Figure 5.1 Examples of faces without additive noise and with additive white Gaussian noise filtered at different center spatial frequency bands.

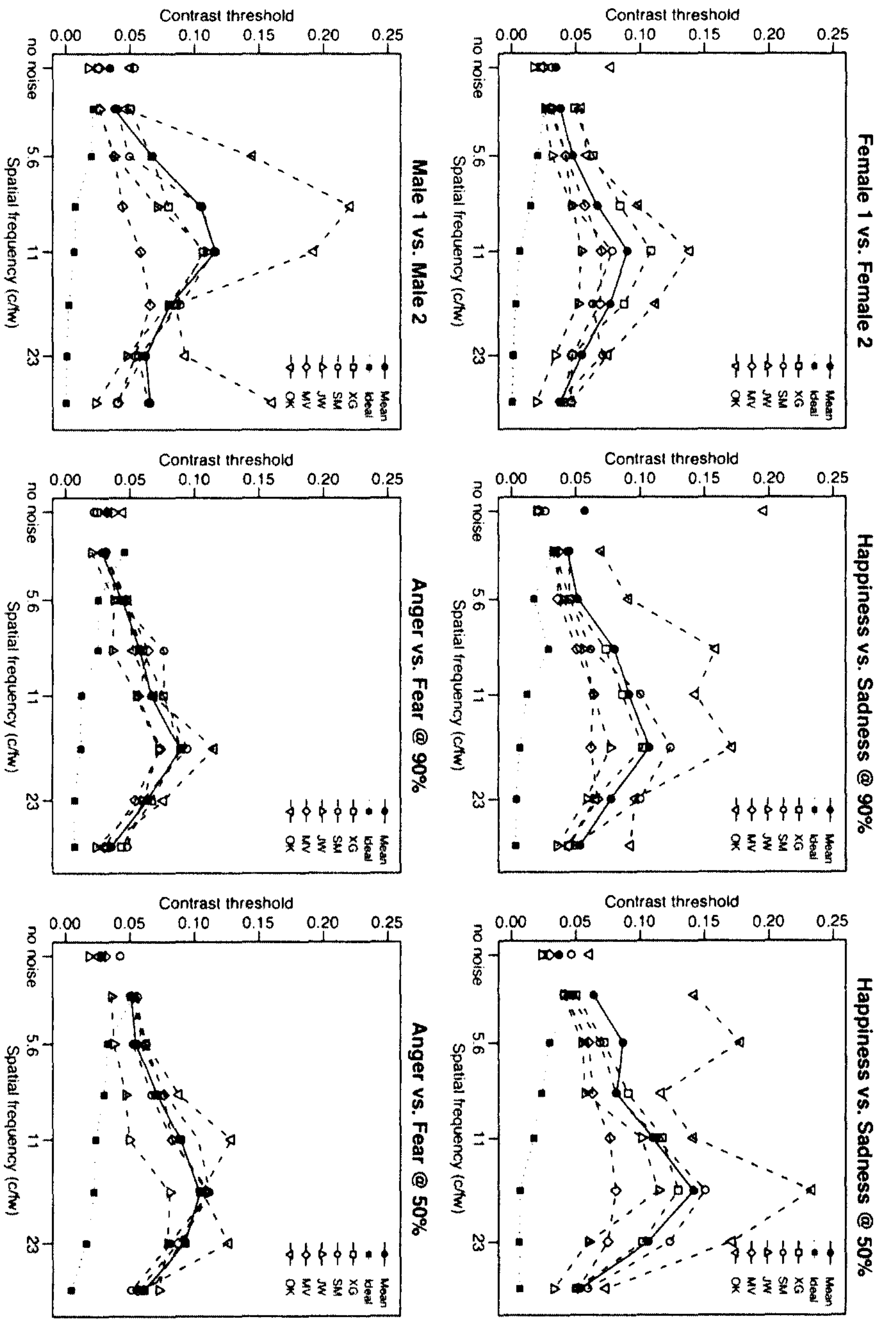

Figure 5.2 *RMS* contrast threshold as a function of the center spatial frequency of the masking noise for human and white noise ideal observers. The solid line is the mean of the five observers.

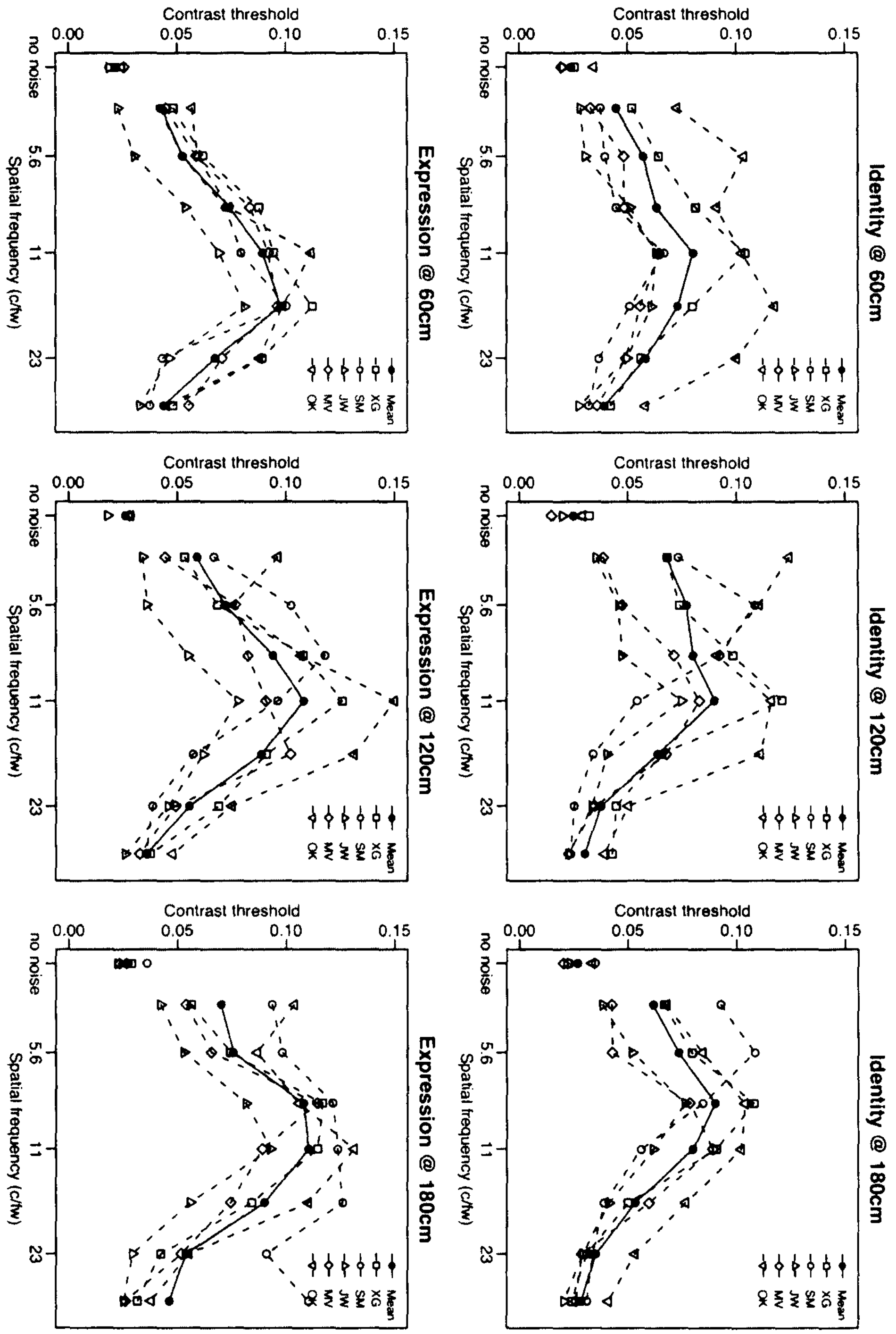

Figure 5.3 *RMS* contrast threshold as a function of center spatial frequency of noise masks for each individual and the mean across the five observers.

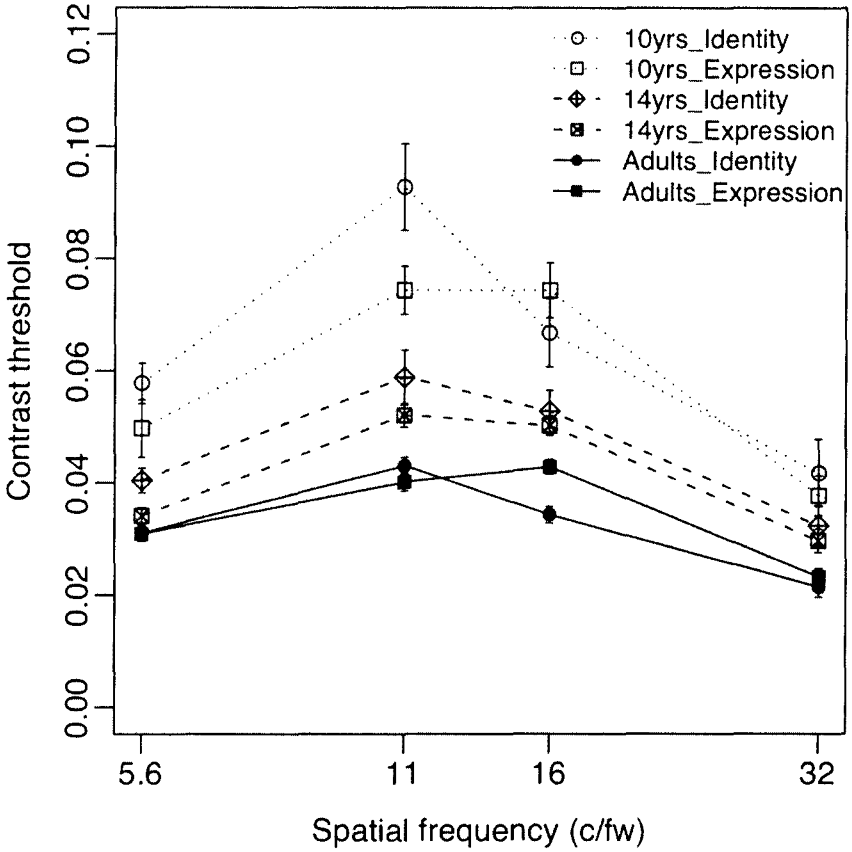

Figure 5.4 Contrast threshold as a function of noise spatial frequency for each age group on each task. Error bars represent 1 S.E..

Table 5.1
Bootstrapping estimates of peak positions.

Task	Peak (μ c/fw)	95% confidence interval of μ	
		Lower band	Upper band
Identity			
Female 1 vs. Female 2	11.93	11.16	12.99
Male 1 vs. Male 2	11.58	10.96	12.68
Expression			
Happy vs. Sad @ 90%	13.40	12.47	14.48
Happy vs. Sad @ 50%	12.82	11.56	13.90
Anger vs. Fear @ 90%	13.52	12.82	14.14
Anger vs. Fear @ 50%	14.86	13.72	18.25

Table 5.2
Bootstrapping estimates of peak positions.

Task/Distance (cm)	Peak (μ c/fw)	95% confidence interval of μ	
		Lower band	Upper band
Identity			
60	11.41	10.85	12.17
120	7.95	6.18	9.82
180	7.85	5.68	9.31
Expression			
60	12.50	11.93	12.93
120	10.09	8.76	11.10
180	9.63	9.07	10.53

Table 5.3

Bootstrapping estimate of peak sensitivity spatial frequency.

Age/Task	Peak (μ c/fw)	95% confidence interval of μ	
		Lower band	Upper band
10 years			
Identity	11.15	9.91	12.84
Expression	12.13	10.83	13.41
14 years			
Identity	11.87	10.99	13.0
Expression	12.57	11.74	13.69
Adults			
Identity	10.77	9.74	11.86
Expression	11.99	11.18	12.82

Supplementary material

Table

Estimations of individual peak spatial frequency sensitivity (c/fw) and goodness of fit (r^2).

	Peak spatial frequency sensitivity (r^2) for each observer				
	XG	SM	JW	MV	OK
Experiment 1					
Female 1 vs. Female 2	10.7 (.90)	13.8 (.76)	11.4 (.96)	13.0 (.91)	11.8 (.91)
Male 1 vs. Male 2	10.9 (.93)	11.8 (.78)	11.7 (.95)	14.5 (.94)	11.0 (.26)
Happy vs. Sad @ 90%	13.1 (.93)	14.7 (.84)	13.2 (.90)	15.1 (.83)	12.1 (.81)
Happy vs. Sad @ 50%	13.0 (.90)	14.6 (.85)	12.7 (.79)	13.6 (.90)	10.6 (.18)
Anger vs. Fear @ 90%	13.7 (.94)	13.3 (.90)	14.2 (.79)	12.0 (.83)	14.3 (.75)
Anger vs. Fear @ 50%	13.9 (.87)	13.7 (.67)	30.8 (.86)	13.7 (.79)	13.9 (.77)
Experiment 2					
Identity @ 60 cm	10.6 (.91)	11.0 (.70)	12.7 (.93)	11.9 (.88)	11.1 (.64)
Identity @ 120 cm	9.1 (.79)	6.0 (.91)	9.8 (.73)	10.3 (.95)	5.7 (.72)
Identity @ 180 cm	7.8 (.94)	3.5 (.91)	8.8 (.92)	9.9 (.87)	8.9 (.97)
Expression @ 60 cm	12.9 (.89)	11.6 (.76)	13.2 (.93)	12.6 (.97)	12.5 (.79)
Expression @ 120 cm	10.7 (.95)	7.8 (.92)	11.6 (.88)	10.6 (.86)	10.5 (.69)
Expression @ 180 cm	9.5 (.96)	12.3 (.51)	9.5 (.91)	9.4 (.89)	8.6 (.74)

Chapter 6

General Discussion

Sensitivity to facial expressions emerges early in life. However, it takes a remarkably long time before children achieve adult levels of sensitivity. This thesis characterized developmental changes in sensitivity to the six basic emotional facial expressions in children between 5 to 14 years of age with three approaches: 1) influence of intensity on children's sensitivity to facial expressions, 2) similarities and differences in the perceptual structure of facial expressions of children and adults, and 3) spatial frequency tuning for the recognition of facial expressions and facial identity in children and adults.

Sensitivity to facial expressions with varying intensities

In the research reported in Chapters 2 and 3, I found that children's sensitivity to happy expressions develops more quickly than sensitivity to any other expression of the six basic emotions. Children's sensitivity to surprised, disgusted, and fearful expressions continues to improve between age 5 and 10, and their sensitivity to sad and angry expressions continues to improve even after age 10 (Table 6.1). Here I will first summarize developmental changes found in the current studies for each expression and then discuss possible reasons for the slow development.

Happy expressions

By age 5, children are as sensitive as adults to subtle facial expressions of happiness. However, unlike adults, they occasionally mistake them for surprise, and even at age 7 they are not as good as adults at noticing small increases and decreases in the intensity of happy expressions. The adult-like thresholds and low misidentification rate will allow children to pick up subtle positive feedback from their peers and from adults, thereby helping them to react appropriately in social interactions. The results for the task requiring direct comparison of two intensities imply that, with age, children will become more sensitive to small differences in that feedback.

Sad expressions

Children aged 5 and 7 are more likely than adults to misidentify subtle expressions of sadness as neutral, disgusted or fearful. Even at age 10, children misidentify sad faces as fearful more often than adults. As a consequence, children may miss or misread subtle signals of sadness and consequently may fail to show empathy to people with subtle sad expressions.

Fearful expressions

Five-year-olds need more intensity than adults to detect expression in fearful faces and are more likely to misidentify them as sad. Although children also confuse fear with surprise at fairly high rates, this confusion is no more likely in children than in adults. By 10 years of age, children are adult-like on all measures of sensitivity to fear in static faces of varying intensity. These patterns suggest that young children (age 5) may fail to identify signals of potential danger in the environment evident in other people's facial expressions and misconstrue fearful expressions as sad or surprised.

Angry expressions

Even at age 10, children have higher thresholds than adults to discriminate angry expressions from neutral. Once they see the face as expressive, children as young as age 5 are no more likely than adults to misidentify the angry expression. The failure to detect subtle angry expressions in children between 5 and 10 years of age may keep them from interpreting appropriately the reaction of others to angry-provoking actions and limit what they can learn from social feedback about inappropriate behaviours.

Surprised expressions

Children at age 5 and 7 are more likely than adults to confuse surprised expressions as fearful, although this pattern of confusion is also seen in adults. Five-year-olds also have higher thresholds than adults to discriminate surprised expressions from neutral. These results suggest that young children are likely to miss (age 5) or misread (age 5 and 7) surprised expressions more often than adults. As a consequence, young children may miss feedback that their behaviour is unexpected or signals that something is unanticipated in the environment.

Disgusted expressions

Even adults misidentify disgust as sad at a high rate. Children's accuracy is not different from that of adults with intense disgusted expressions. However, for less intense disgusted expressions, 5-year-olds confuse them as sad more often than adults and also sometimes misidentify them as angry. It is only by age 10 that children's threshold to discriminate disgust from neutral is adult-like. The fact that children at 5 and 7 are as accurate as adults in recognizing intense disgusted expressions but not less intense ones may reflect their sensitivity to disgust as a biological response (e.g., to bad food), which tends to be intense, but not to disgust as a moral response, which is not always intense, and to which they are likely not exposed often during early childhood. Thus, young children may miss the meaning of a mildly disgusted expression signaling a negative reaction when their behaviour is interpreted as immoral.

Comparisons across expressions

However measured, children's sensitivity to happy expressions develops earlier than their sensitivity to other basic emotional facial expressions. For other expressions, children's sensitivity develops at different rates for different expressions and different measures. Thresholds became adult-like earlier for surprise (age 7) than for fear, sadness, and disgust (age 10), with the latest maturity for anger (after age 10). However, misidentifications show a different pattern: adult-like levels earlier for anger (age 5) than for fear (age 7), disgust (age

7), and surprise (age 10), with the latest maturity for sadness (after age 10). These developmental patterns, along with the patterns found in previous studies with intense facial expressions, may reflect the amount of exposure to different facial expressions at different intensities in a child's environment, a possibility that will be elaborated later in the discussion.

Contributions to the literature

In the current research with facial expressions at varying intensities, I was able to provide three measurements to characterize developmental changes in children's sensitivity to the six basic emotional facial expressions. Measuring accuracy at peak intensity allowed me to compare the current findings to previous studies with only intense expressions. The current results are consistent with most of the previous findings that, for intense facial expressions, children's sensitivity develops early for happy (Camras & Allison, 1985; Durand, Gallay, Seigneuric, Robichon & Baudouin, 2007; Kolb, Wilson, & Taylor, 1992; Markham & Adams, 1992; Vicari, Reilly, Pasqualetti, Vizzotto & Caltagirone, 2000; Widen & Russell, 2003) and sad (Camras & Allison, 1985; Durand et al., 2007; De Sonneville et al., 2002; but see Kolb et al, 1992 for late development for the sensitivity to sad expressions) expressions, at intermediate ages for angry (Camras & Allison, 1985; Durand et al., 2007; Gagnon, Gosselin, Hudon-ven der Buhs, Larocque, & Milliard, 2010; Kolb et al., 1992; Markham & Adams, 1992) and fearful (De Sonneville et al., 2002; Durand et al., 2007; Kolb et al., 1992) expressions, and late for surprised (Gosselin & Larocque, 2000; Kolb et al., 1992; Markham &

Adams, 1992; Vicari et al., 2000) and disgusted (Camras & Allison, 1985; Durand et al., 2007; Kolb et al., 1992; Markham & Adams, 1992; Vicari et al., 2000) facial expressions. In the current studies I discovered new developmental patterns of sensitivities to less intense expressions by measuring thresholds to discriminate expressions from neutral and rates of misidentification. With the threshold measure, I found that children's threshold for happy expressions is adult-like by age 5, that their thresholds for sad, fearful, surprised and disgusted expressions reach adult levels by age 10, and that their threshold for angry expressions continues to improve after age 10. These results indicate that while children show early development of adult-like accuracy in recognizing some intense facial expressions (e.g., angry), their ability to discriminate less intense exemplars of these expressions from neutral continues to develop for a long time. By measuring the rates of misidentification, I found that while children make as few errors as adults in recognizing some intense facial expressions (e.g., happy and sad), they are more likely than adults to misread the less intense exemplars of these facial expressions, and sometimes make errors never seen in adults (e.g., misidentify fear as sadness).

Perceptual structure of facial expressions

In the research reported in Chapter 4, with facial expressions of the six basic emotions each at four intensities, I found that the perceptual structure of facial expressions of adults is more complex than the ones found in previous studies that used only intense expressions and that were typically characterized as a circular arrangement with two underlying dimensions representing pleasure and arousal (Alvarado, 1996; Bimler & Kirkland, 1997, 2001; Russell & Bullock, 1985, 1986; Shah & Lewis, 2003). The perceptual structure of facial expressions of adults found in the current research is optimally explained by a four-dimensional solution with the dimensions representing pleasure, potency, arousal, and intensity. Facial expressions of different intensities within the same emotion category cluster together in this structure with the lower intensities being closer to neutral. By age 14, children's structure is similar to that of adults in both dimensionality and clustering, although the similarity judgments of 14-year-olds are more influenced by physical differences than those of adults.

Children at age 7 show a systematic structure of facial expressions, which overlaps partially with that of adults. However, compared to the structure of adults, a potency dimension is missing in the structure of the 7-year-olds. Another difference is that in the structure of adults, fearful and surprised expressions form one cluster, a pattern reflecting the perceptual similarity between surprise and fearful expressions and their overlapping signaling of possible threat. In contrast, fearful and surprised expressions form separate clusters in the structure of the 7-year-olds. A third difference is that in adults, neutral expressions are clustered with the lowest intensity of the other expressions except happy. The structure of the 7-year-olds includes a broader cluster around neutral expressions, which includes intermediate intensity of sadness and fear, as well as the lowest intensity expressions. Consistent with the results from the studies reported in Chapters 2 and 3, this pattern of clustering suggests that 7-year-olds have a higher threshold than adults to discriminate sad and fearful expressions from neutral. The lack of a potency dimension in the structure of the 7-year-olds may affect adversely their ability to discriminate quickly between fearful and angry expressions, thereby affecting social interaction. For example, in a fight or flight situation, children may be slower than adults to choose an appropriate action.

Contributions to the literature

The current study is the first to investigate the perceptual structure of facial expressions of the six basic emotions in children or adults using systematically controlled intensities that were compared to each other. The current findings extend the circumplex model to facial expressions with varying intensities. Consistent with previous studies with intense facial expressions (Alvarado, 1996; Bimler & Kirkland, 1997, 2001; Russell & Bullock, 1985, 1986; Shah & Lewis, 2003), I found dimensions representing pleasure and arousal in the perceptual structures of facial expressions in all three age groups tested. By using facial expressions with systematically controlled intensity, I found additional dimensions representing intensity and potency. In the perceptual structure of facial expressions of 7- and 14-year-olds and adults, intensity is represented by one dimension, on which neutral expressions locate at the low intensity end, and other expressions locate away from neutral with the distance from neutral increasing monotonically with increasing intensity. I also found a potency dimension in 14-year-olds and adults, but not in 7-year-olds. On this dimension, high values relate to feelings of power, dominance, and impulses to act, while low values relate to feelings of weakness, submission, and refraining from action. This dimension differentiates fearful expressions and angry expressions maximally.

Spatial frequency tuning of face perception

In the research reported in Chapter 5, I found that adults rely on a limited range of spatial frequency to recognize facial identity and facial expressions. When tested at 60 cm, the critical band of spatial frequency for recognizing facial identity is around 11 cycles/per face width. At the same testing distance, the critical band of spatial frequency for recognizing facial expressions is significantly higher: around 16 cycles/face width. When the testing distance increased from 60 to 120 and 180 cm, the critical band of spatial frequency for recognizing facial identity shifted gradually from 11 to 8 cycles/face width, while the critical band of spatial frequency for recognizing facial expressions shifted gradually from 16 to 11 cycles/face width. At every testing distance, the center of the critical band of spatial frequency for recognizing facial expressions was always higher than that for recognizing facial identity. Therefore, the current findings suggest that adults use finer details to recognize facial expressions than to recognize facial identity. Although the results indicate that children at age 10 and 14 use similar critical bands of spatial frequency as those used by adults to recognize facial identity and facial expressions, their contrast thresholds were higher than those of adults. In addition, unlike adults, the critical bands of spatial frequency for recognizing facial identity and facial expressions were not significantly different from each other. These findings suggest that adult-like spatial frequency tuning for recognizing facial identity and facial expressions may take many years to develop. With a less optimal tuning, children may not use information in faces as efficiently as adults, thereby limiting their ability to recognize facial identity and facial expressions, especially under poor lighting (low contrast).

Contributions to the literature

The findings of the current study are consistent with previous studies showing that adults rely on mid spatial frequencies for the recognition of both facial identity and facial expressions (Costen, Parker, & Craw, 1994, 1996; Fiorentini, Maffei and Sandini, 1983; Gold, Bennett, Sekuler, 1999; Goren & Wilson, 2006; Näsänen, 1999; Ojanpää & Näsänen, 2003; Schwartz, Bayer and Pelli, 1998; Schyns & Oliva, 1999). The current study is the first to demonstrate that the critical spatial frequency band is higher for facial expression than for facial identity. This finding adds a new piece of evidence for the, at least partial, separation of the neural systems underlying the processing of facial identity and facial expressions (Bruce & Young, 1986; Haxby, Hoffman, & Gobbini, 2000). The current study confirmed that for facial identity, the critical spatial frequency band is partially scale invariant (Hayes, Morrone and Burr, 1986; Näsänen, 1999; Ojanpää & Näsänen, 2003), and is the first to demonstrate that the critical spatial frequency band is also partially scale invariant for facial expressions. The current study is also the first to test children with more than two spatial frequency bands.

The result that children at age 10 and 14 rely on mid spatial frequencies to recognize facial identity and facial expressions are consistent with previous studies that children can process faces holistically (de Heering, Houthuys, & Rossion, 2007; Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007; Pellicano & Rhodes, 2003; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998). We also found that even at age 14, children need more contrast than adults to recognize both facial identity and facial expression, and that their spatial frequency tuning is not as specific as in adults. This result is consistent with reports in the literature of changes in children's sensitivity to facial identity and facial expressions that continue into adolescence (facial identity: e.g., Carey, 1992; Carey, Diamond, & Woods, 1980; Feinman & Entwhistle, 1976; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grend, & Maurer, 2002; facial expressions: reviewed by Herba & Phillips, 2004).

Factors affecting children's sensitivity to facial expressions

The different developmental patterns in children's ability to decode facial expressions found for different expressions may reflect the amount of exposure to different facial expressions in a child's environment: frequent for happy expressions, and less frequent for the other expressions. The hypothesis that exposure influences the development of sensitivity to facial expressions is supported by studies of special populations. Neglected children, who are likely to have less exposure to facial expressions than normal developing children, are less accurate than normal developing children at matching facial expressions to stories in each of which the protagonist experienced disgust or anger, although their accuracy for happy, sad, and fearful expressions is normal (Pollak, Cicchetti, Hornung, & Reed, 2000). Physically abused children, whose rearing environment is likely to include more angry expressions than usual, have a lower threshold to detect anger in a face than normal developing children, while their thresholds to detect other expressions is the same as (happiness and fear) or higher (sadness) than normal developing children (Polla, & Sinha, 2002). Therefore, children's early sensitivity to subtle happy expressions found in the current studies may be a result of their exposure to happy expressions at a wide range of intensities in the environment. However, the link between exposure and children's differential sensitivity to other subtle expressions (e.g., the threshold becomes adult-like relatively early for surprise but relatively late for anger; misidentification rates are higher than adult levels even at age 10 for sadness) is not obvious.

While the findings of the current studies suggest developmental changes in children's ability to decode facial expressions, these findings may also be influenced by the development of visuo-cognitive skills. Relevant visual skills that may limit decoding at younger ages are acuity and contrast sensitivity (adult-like by 7, Ellemberg, Lewis, Liu, & Maurer, 1999; but see Benedek, Benedek, Kéri, & Janáky, 2003, for continued change until age 11-12), vernier acuity (adult-like by early adolescence, Skoczenski & Norcia, 2002), contour integration (adult-like by early adolescence, Kovács, Kozma, Fehér, & Benedek, 1999), and sensitivity to facial feature spacing (which continues to develop after age 10, Mondloch, Dobson, Parsons, & Maurer, 2004; Mondloch, Geldart, Maurer, & Le Grand, 2003; Mondloch, Le Grend, & Maurer, 2002; but see McKone & Boyer, 2004, and Pellicano, Rhodes, & Peters, 2006, for adult-like sensitivity on some tasks at a younger age). Besides visual skills, the current findings may also be influenced by the development of cognitive skills like perspective taking, which will help children to decipher the context of expressions during real world interactions and hence help them to determine the meaning of subtle facial expressions. Perspective taking continues to improve through adolescence (Choudhury, Blakemore, & Charman, 2006).

The long developmental course found in the current study in children's sensitivity to some facial expressions may reflect the slow maturation of the brain structures that underlie the processing of facial expressions. Adults recruit distributed brain areas to process facial expressions (Vuilleumier & Pourtois, 2007), some of which continue to develop through adolescence. The prefrontal cortex, which contributes to emotion processing by inhibiting subcortical responses (Phillips, Drevets, Rauch, & Lane, 2003), continues to develop into adolescence (Stuss, 1992). The late maturation of the prefrontal cortex may explain the finding in one study that children age 8-13 performed similarly to adult patients with frontal lobe damage (Kolb et al., 1992). The amygdala, which is another brain structure involved in processing facial expressions, especially fearful facial expressions, also continues to develop throughout adolescence (Giedd et al., 1999). The networks may also function differently in children, as functional neuroimaging studies indicate greater amygdala activation for neutral than for fearful faces in 11-year-old children, the opposite pattern from adults (Thomas et al., 2001; but see Guyer et al., 2008). Although there is evidence that by age 10, children, like adults, recruit distinct neural systems in processing fear, disgust, and sad facial expressions (Lobaugh, Gibson, & Taylor, 2006), the development of adult-like specificity in brain responses to different facial expressions remains largely unexplored.

Limitations

One limitation of the studies reported in Chapters 2 and 3 is that the developmental patterns were affected by the particular groupings of facial expressions in the forced-choice procedure. The groupings limited the response alternatives, and those limitations affected the patterns of confusion among facial expressions for sad and fear, but not for happy. The groupings also affected children's thresholds to discriminate sad expressions from neutral; we found an elevation in thresholds when sad expressions were grouped with only negative expressions (disgust and anger) compared to another condition in which sad expressions were grouped with both positive (happy) and negative (fearful) expressions. Although a procedure involving all seven choices (6 basic emotions plus neutral) would get around this issue, such a procedure is not appropriate for children.

In the current studies, I created different intensities by morphing emotional faces with neutral faces. The morphing procedure simulated facial muscle movements. As a result, intensity of facial expressions increased linearly with increasing simulated facial muscle displacement. However, in reality, the change in intensity of facial expressions signaling increasing emotion may not be related linearly to the displacement of facial muscles. Therefore, a linear movement may create muscle positions that human adults do not use or that they are not able to maintain. In the current study, we assumed that a linear relation is sufficient to represent the relation between intensity of facial expressions and muscle displacement. This assumption needs to be validated in future studies, possibly by comparison to a model based on facial muscle anatomy or to a study in which emotions of different intensities are evoked in the lab.

The current studies may have underestimated children's sensitivity to facial expressions by using adults' faces. Although facial expressions of adults are important signals for children, children may see more faces of age mates or find it more salient to monitor their facial expressions. Previous studies with intense expressions reported similar developmental patterns using either photographs of children's faces (Boyatzis et al., 1993; Camras & Allison, 1985; Widen & Russell, 2003), or photographs of adults' faces (Durand et al., 2007; Markham & Wang, 1996; Vicari et al., 2000). However, there might be a difference for less intense expressions: children may be more concerned about the subtle feelings of their peers than of adults, who may also typically exaggerate the expression of feelings they wish to convey to the child. If we had tested children with their peers' faces, we might have found higher sensitivity to subtle facial expressions. This possibility is supported by studies showing that children are more accurate at recognizing faces of their peers than faces of adults (Anastasi & Rhodes, 2005; Crookes & McKone, 2009; Gilchrist & McKone, 2003).

Another limitation is that I used static faces, while in everyday life, facial expressions are dynamic and are within specific contexts. Adults are more accurate in recognizing facial expressions from dynamic displays than from static images, likely because the dynamic information enhances the perception of change (Ambadar, Schooler, & Cohn, 2005). Had we used dynamic displays, the differences between adults and children might have been diminished, but they could instead have been increased if adults are more adept than children at using the dynamic cues. Context information may also help children to decode facial expressions; children's ability to use such contextual information remains largely unexplored.

Future studies

To better characterize children's sensitivity to facial expressions, future studies could incorporate dynamic information and context information to create more realistic conditions. By comparing conditions with or without dynamic information and context information, one could measure the contributions of static visual information, dynamic information, and context information to children's perception of facial expressions. Future studies could also use the stimuli and technique described in this thesis to study developmental changes in the neural mechanisms underlying the perception of facial expressions using event-related potentials or functional brain imaging. These techniques can provide information about developmental changes in the neural mechanisms underlying the recognition of subtle facial expressions and the relationships among facial expressions. The stimuli and techniques could also be used to study special populations, such as children with autism, neglected or abused children, and children with abnormal visual experience. Results from special populations may aid in designing better accommodation or early intervention and can help to evaluate models about the influence of experience on sensitivity to facial expressions. Future studies could also adapt the current techniques to study the effect of familiarity, race/ethnicity, and age on children's sensitivity to facial expressions. These factors are important in a child's environment, and they can provide information about how environmental factors affect the development of children's sensitivity to facial expressions. The current techniques could also be used to study facial expressions that are not part of the six basic emotions (e.g. interest, contempt). Studying these facial expressions would provide information for a more comprehensive understanding of the development of the perception of facial expressions.

Conclusions

This thesis discovered new patterns in the long developmental course of children's perception of facial expressions. These new patterns suggest that during childhood, the system to recognize facial expressions becomes more efficient as less signal (intensity of facial expression, Chapters 2 and 3) is required, and becomes more specific (additional dimensions added, Chapter 4; narrowly tuned to a specific spatial frequency band, Chapter 5). This slow development of children's sensitivity to facial expressions may impact their social interactions by limiting the information they pick up from faces.

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Table 6.1

Age at which children are adult like for each expression with each measure.

Measure	Happiness	Sadness	Fear	Surprise	Disgust	Anger
Threshold	5	10	10	7	10	After 10
Misidentification	7	After 10	7	10	7	5