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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. Multidimensional scaling suggested that three- or four-dimensional structures were optimal for all groups. Two groups of adults demonstrated nearly identical structure, which had dimensions representing pleasure, potency, arousal, and intensity, despite the fact that one group was tested with a child-friendly “odd-man-out” paradigm and 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.

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Introduction

Human adults perceive facial expressions categorically (Calder, Young, Perrett, Etcoff, & Rowland, 1996; Etcoff & Magee, 1992; Young et al., 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

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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 (Abelson & 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 multidimensional 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., 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: 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, that is, 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 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 within the structure the expressions form fewer clusters. With a smaller stimulus set (10 stimuli instead of 20), Russell and Bullock (1986) again found the same two-dimensional structures in children as young as 2 years as are seen in adults. These findings are somewhat surprising because 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, Seigneure, Robichon, & Baudouin, 2007; sadness: Gao & Maurer, 2009; Kolb, Wilson, & Taylor, 1992). Studies using brain-imaging techniques also reveal a prolonged developmental course; even 14- and 15-year-olds' event-related potentials 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 faces than for fearful ones, the opposite pattern of that shown by adults (Thomas et al., 2001; but see Guyer et al., 2008). 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).

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, whereas most previous studies mapped only the perceptual structure of intense facial expressions, by using facial expressions at varying intensity levels, 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 de Boulogne, 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 et al., 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 might not be linear. There has been no direct investigation of 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*; 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 center 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 & Suzuki, 2001; Takehara et al., 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 to construct a single structure that included 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 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). In the only study to date in which intensity was varied with children, the stimuli were dynamic and 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, the inclusion of body information, and/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 we compared their structures with adults' structure.

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, 1996). This procedure is more appropriate for testing children than the similarity-rating paradigm because 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 with 7-year-olds because at that age sensitivity to some expressions is adult-like (e.g., happiness, anger), whereas sensitivity to other expressions is not (e.g., fear, sadness) (Durand et al., 2007; Gao & Maurer, 2009; Kolb et al., 1992). In addition, 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.

Method

Participants

Participants were 16 7.5-year-olds (± 3 months) and 16 adults (18–24 years of age). The adult sample consisted of 10 Caucasians and 6 South Asians, most of whom grew up in Canada.¹ All of the children were Caucasians. The majority of the participants were from middle-class families. Child participants were recruited from names on file of parents who had volunteered their children at birth for participation in later studies. Adult participants were undergraduate students enrolled in an introductory psychology course who received course credit for participation. All participants had normal or corrected-to-normal vision, and half of the participants in each age group were female.

Stimuli

We selected photographs of two models, each posing intense facial expressions of six basic emotions (happiness, sadness, fear, anger, disgust, and surprise) and neutral from the NimStim Face Stimulus Set: a female Hispanic American (Model 03) and a male European American (Model 25) (Tottenham et al., 2009). 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 on a 7-point scale, range = 4.4–6.4) (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 \times 4 intensities + 1 neutral face). Stimuli were displayed on a 19-inch HP p1179 CRT monitor (with a 75-Hz refresh rate at 1024×768) controlled by a PowerBook G4 computer via custom software. Each picture was 11° (width = 11.6 cm) \times 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 consent from the adult participants or from parents 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 children 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 child 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 by the child) were competing against each other by making faces. For a triplet to win, he or she needed 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 child was actively encouraged to focus on the aspect of “feeling” when making judgments. Adult participants received the same explanatory script. Half of the participants of each sex in each group completed the procedure with the female model, and half completed the procedure with the male model.

Before the presentation of experimental stimuli, there were five practice trials with photographs of nonface 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 during the testing session. All participants responded systematically during the practice trials and appeared to understand the task.

¹ The composition of participants represents the racial composition of students at 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 adults. 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 ($r = .832$ in Experiment 1 and $r = .926$ in Experiment 2).

For the test trials, one unique set of 200 triads was chosen for each participant from all possible combinations (2300 in total) of 3 items from the 25 photographs. The composition of triads was derived from a balanced incomplete block design of 25 items (Burton & Nerlove, 1976). Because one triad can be decomposed into three pairs (e.g., ABC into 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 3 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, whereas 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 assigned 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; 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* values) of Pearson's *r* between the half groups of adults and of children: mean $r(A1, A2) = .863$, 95% $CI = .751-.943$; mean $r(C1, C2) = .819$, 95% $CI = .677-.928$. 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 $r(A1, C1) = .698$, 95% $CI = .585-.778$. 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 with 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 MDS 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 Fig. 1, for every solution both the adults and 7-year-olds had similar stress values, a result suggesting that the solutions fit both groups equally well. Stress values decrease with increasing numbers of dimensions, but the solution is less interpretable with increasing dimensions. A common practice is to choose the number of dimensions corresponding to the "elbow" of the stress plot (Giguère, 2006). Based on this rule, Fig. 1 suggests three- or four-dimensional solutions. We chose the four-dimensional solutions because they provided better fit than the three-dimensional solutions.

With four-dimensional solutions, the stress value for both adults and 7-year-olds was .07. According to Kruskal and Wish's (1978) suggestion, the fits were good ($.05 \leq \text{stress} \leq .10$).

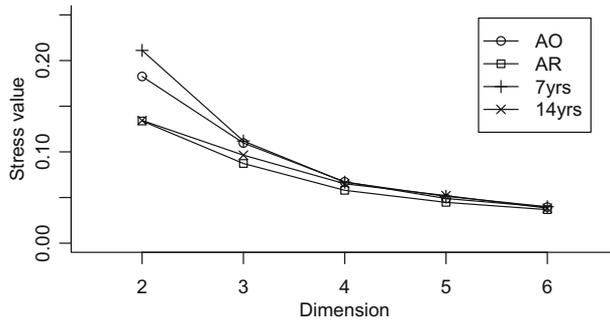


Fig. 1. Stress values of two- to six-dimensional solutions for each group. Shown are the values for adults tested with the odd-man-out paradigm in Experiment 1 (AO), adults tested with the similarity-rating paradigm in Experiment 2 (AR), 7-year-olds tested with the odd-man-out procedure in Experiment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

Hierarchical clustering

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

Results

Dimensionality

Fig. 2A and B shows the four-dimensional MDS solutions for adults and 7-year-olds, respectively. Visual inspection of the solutions suggests that the first dimension for both groups represents pleasure because happy expressions lie on one end of this dimension, whereas the high-intensity negative expressions (sadness, disgust, and anger) lie on the other end of this dimension. On the second dimension, neutral expressions have different relative locations in the two groups. For adults, the second dimension may represent potency of the model because it has angry expressions on one end (strong) and fearful expressions on the other end (weak), with neutral in the middle (Fontaine, Scherer, Roesch, & Ellsworth, 2007; Osgood, May, & Miron, 1975; Russell & Bullock, 1985, 1986). In children, the second dimension seems to represent intensity because neutral and low-intensity expressions are on one end, whereas the higher intensity expressions spread away from neutral toward the other end of this dimension. The third dimension seems to represent intensity in adults in a way similar to the second dimension of 7-year-olds. The fourth dimension in adults seems to represent arousal because it has angry and fearful expressions on one end (high arousal) and other expressions spreading toward the other end. The third dimension for children may also represent arousal, but 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. Because the second dimension 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 farther away from neutral than are 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 the children and adults, the perceived distance between 30% anger and 50% anger

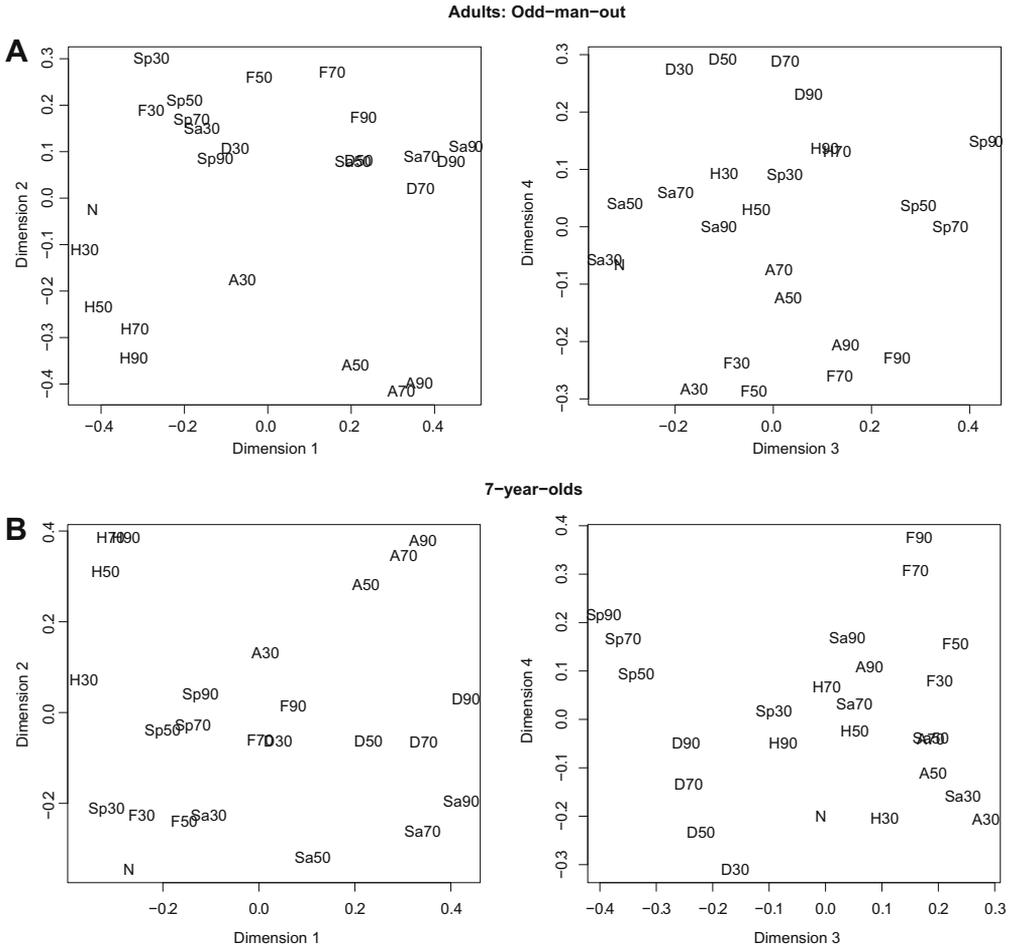


Fig. 2. Four-dimensional solutions for adults (A) and 7-year-olds (B) in Experiment 1. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

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 the physical distance, we calculated the perceived distance of a 20% change in intensity for three intensity ranges (30–50%, 50–70%, and 70–90%) averaged across the six expression categories. Fig. 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 7-year-olds is nearly identical to that for adults.

Hierarchical clustering

As shown in Fig. 4A, in adults, the facial expressions were clustered into four groupings: [happiness and neutral with lowest intensity sadness and disgust], [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 7-year-olds (Fig. 4B), we

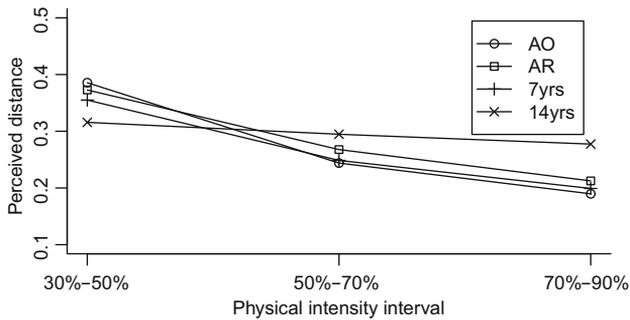


Fig. 3. Relation between perceived distance and physical distance at different intensity intervals. Shown are the values for adults tested with the odd-man-out paradigm in Experiment 1 (AO), adults tested with the similarity-rating paradigm in Experiment 2 (AR), 7-year-olds tested with the odd-man-out procedure in Experiment 1 (7 yrs), and 14-year-olds tested with the similarity-rating procedure in Experiment 2 (14 yrs).

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 sadness, fear, and surprise], [surprise], and [fear]. Unlike in 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 did adults, including not only the lowest intensity 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 each of the two 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 center 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 previous 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

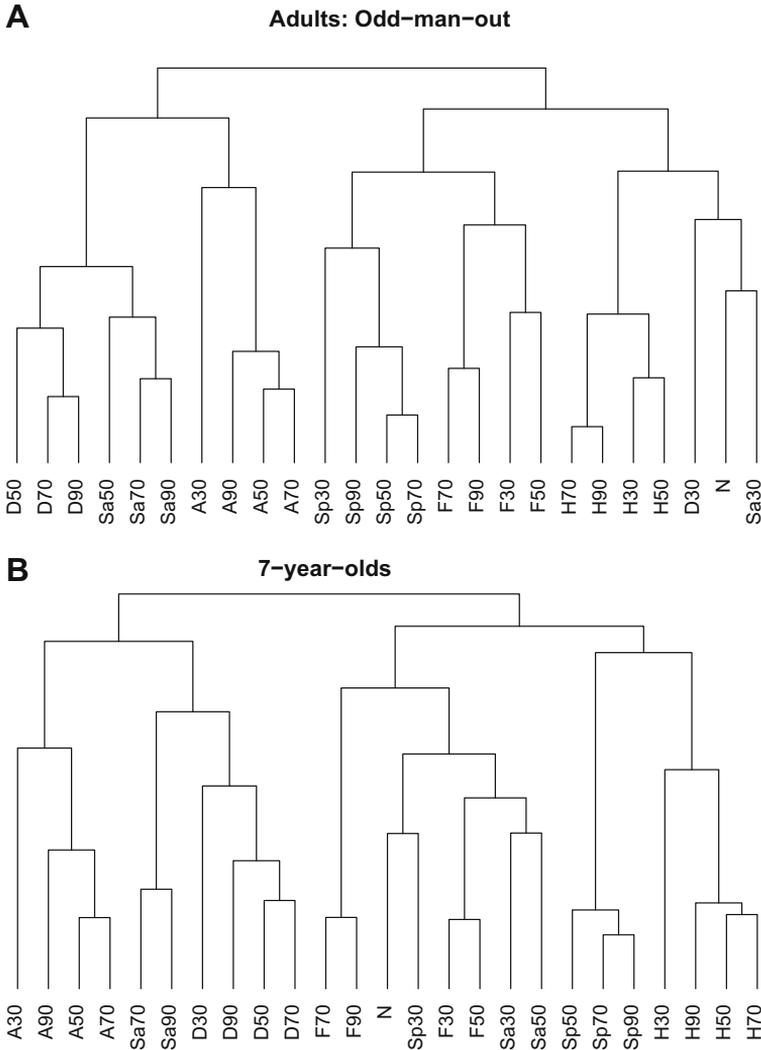


Fig. 4. Dendrograms of hierarchical clustering analysis in Experiment 1 for adults (A) and 7-year-olds (B). Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity. The dendrograms should be read from the bottom toward the top. Facial expressions that are perceived as similar merge into the same groups earlier than to facial expressions that are perceived as different when moving toward the top.

not based purely on physical differences among facial images and that it reflects, at least in part, the perception of 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 than on that of adults because the dimension representing intensity of facial expression appeared earlier in children's structure (second dimension) than in adults' structure (third dimension).

There were also significant differences between the perceptual structure of 7-year-olds and that of adults. Unlike adults, 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 7-year-olds perceived the relation between surprised and fearful expressions differently from adults; unlike in 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, did not include 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 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 expressions than for neutral ones in adults, but the pattern is reversed in children, even those 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 because 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 in 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 faces than to fearful ones as late as 11 years of age (Thomas et al., 2001). Similarly, children may perceive low-intensity expressions, such as 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 levels and a child-friendly procedure, we found that 7-year-olds 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; for example, they may be more likely than adults to misinterpret the valence of surprise or to misconstrue a neutral expression as mildly negative.

Experiment 2

In Experiment 2, we looked at the later development of the perceptual structure of facial expressions by comparing 14-year-olds with adults. 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 because it allows the derivation of individual structures instead of only the group structure that can be derived with the odd-man-out paradigm. Such individual structures allow us to test whether there is more variability among individuals at 14 years of age even if at a group level they prove to be adult-like. However, this paradigm requires the observer to use a rating scale consistently across a large number of trials—something we judged as likely to be possible at 14 years of age but not at 7 years of age. In addition, we chose to compare adults with 14-year-olds because at that age 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 for the adults in Experiment 2 with those for the adults in Experiment 1.

Method

Participants

Participants were 16 14-year-olds (± 3 months) and 16 adults (18–24 years of age). The adult sample consisted of 9 Caucasians, 6 South Asians, and 1 African American, most of whom grew up in Canada. All of the children were Caucasians. All participants had normal or corrected-to-normal vision, and half of 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 by 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 that they would not be seeing during 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. Participants 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 during 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. During 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 completed the procedure 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 Fig. 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 .06 for adults and .07 for 14-year-olds. According to Kruskal and Wish's (1978) suggestion, the fits were good ($.05 \leq \text{stress} \leq .10$).

Individual weightings

Before we compared the structures of the two groups, we calculated the individual weightings on different dimensions of the group solutions using the INDSCAL procedure in SPSS 16.0 to assess the homogeneity within each group. Fig. 5 shows individual weightings for the adults and 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 5

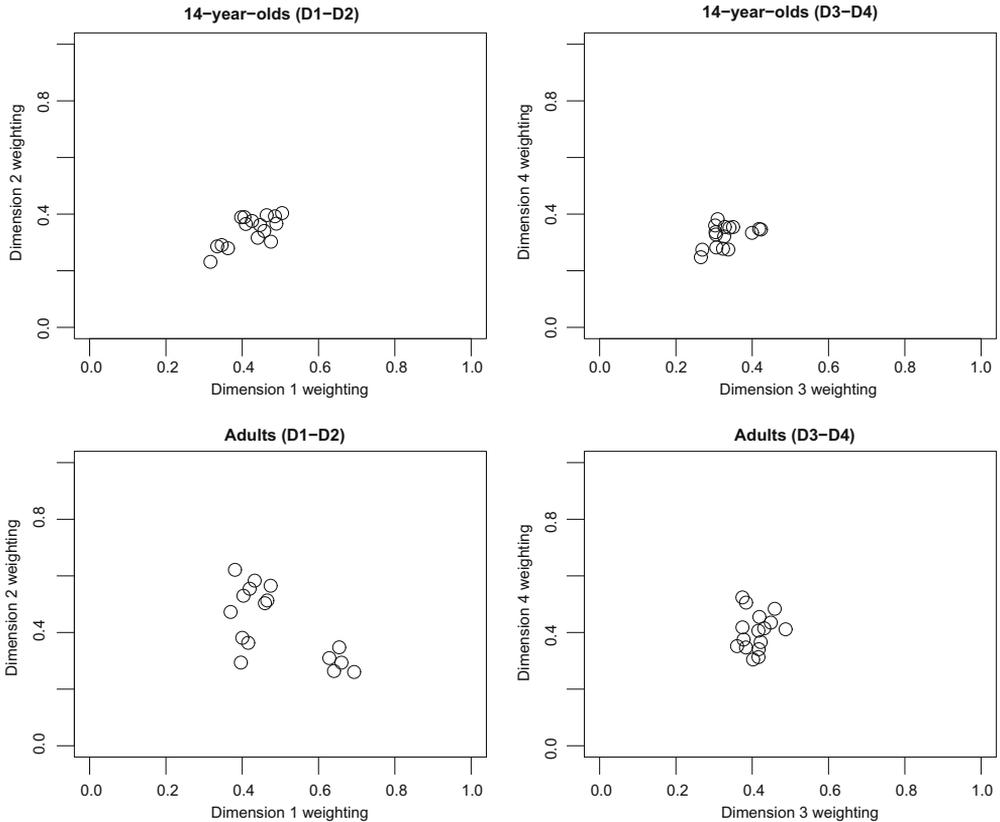


Fig. 5. Individual weightings for 14-year-olds and adults on the four-dimensional solutions in Experiment 2. Each circle represents the weighting for an individual participant.

adults showed slightly skewed weightings toward the first dimension. In further analysis, we calculated group solutions based on similarity scores averaged across participants within each group.

Hierarchical clustering

We submitted pairwise 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 an MDS structure similar to that of the group of adults in Experiment 1, with nearly identical stress values (see Fig. 1) and similar dimensions (Fig. 6A). As for the adults tested with the odd-man-out procedure in Experiment 1, the first, second, third, and fourth dimensions can be explained as representing pleasure, potency, arousal, and intensity, respectively. 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 the similarity-rating paradigm in Experiment 2, the third dimension is better explained as arousal and the fourth dimension is better explained as intensity than the other way around.

For 14-year-olds (Fig. 6B), the first dimension represents pleasure, as seen in other groups, with happy expressions at one end and higher intensities of the negative expressions (anger, disgust, sadness, and fear) at the other end. The second dimension may represent potency as seen in the two

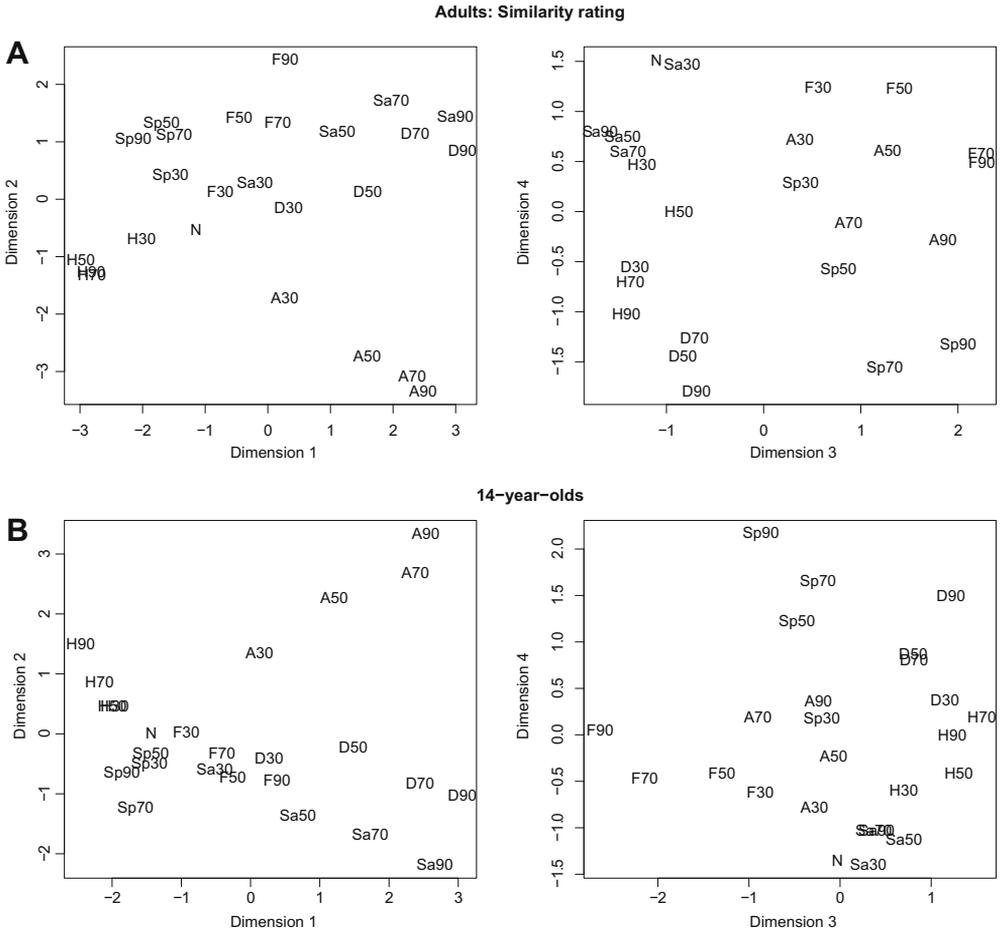


Fig. 6. Four-dimensional solutions for adults (A) and 14-year-olds (B) in Experiment 2. Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

groups of adults. However, although 14-year-olds differentiate fearful expressions from angry expressions on the second dimension, unlike in adults, fearful expressions are not at one end of the dimension. The third dimension may represent arousal because fearful and angry expressions spread toward one end of the dimension, leaving others at the other end. The fourth dimension seems to represent intensity as seen in the other groups.

Intensity

As shown in Fig. 3, adults showed 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% vs. 50%) than for high-intensity expressions (70% vs. 90%). However, we did not see such a pattern in the group of 14-year-olds. Instead, 14-year-olds showed similar perceived differences when judging two expressions differing in intensity by 20% regardless of the intensity range.

Hierarchical clustering

As shown in Fig. 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

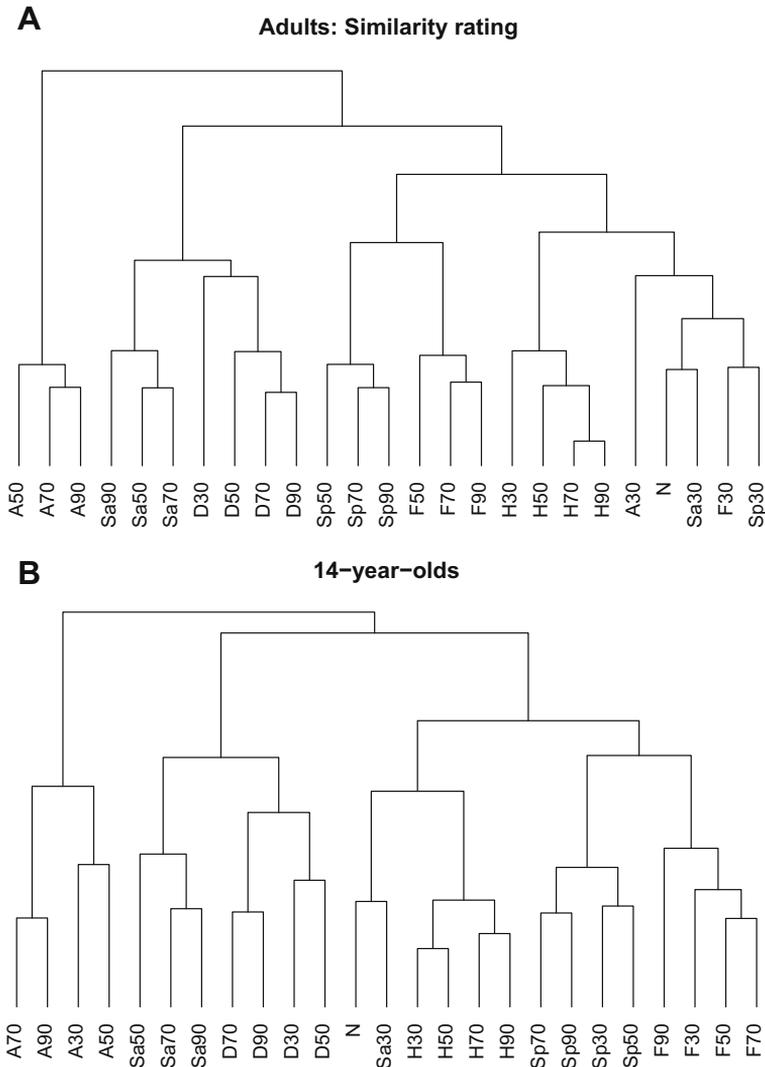


Fig. 7. Dendrograms of hierarchical clustering analysis in Experiment 2 for adults (A) and 14-year-olds (B). Labels: A, anger; D, disgust; F, fear; H, happiness; Sa, sadness; Sp, surprise; N, neutral. Digits in the labels represent intensity.

with the lowest intensity negative expressions (except disgust), [fear and surprise], [sadness and disgust], and [anger]. The pattern of clustering in 14-year-olds (Fig. 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 did the 14-year-olds or adults in Experiment 1. Specifically, neutral grouped with the lowest intensity of anger, sadness, fear, and surprise for adults in Experiment 2; with the lowest intensity of sadness for 14-year-olds; and with the lowest intensity of disgust and sadness 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 sometimes categorized as neutral and other times categorized as expressions.

Discussion

Although tested with different methods, 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 of 7-year-olds with the odd-man-out procedure in Experiment 1 with those of adults and 14-year-olds tested with similarity judgments in Experiment 2 and with 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: [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, 14-year-olds differed from adults and even 7-year-olds in Experiment 1 in the pattern of relationship between physical and perceived differences. Unlike the other groups, 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 Fig. 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 (Fig. 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 years. 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 with 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 7 years of age 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 a fourth dimension that appears to represent potency is added. Of course, we can draw no conclusions about exactly when between 7 and 14 years of age the changes occur except to note that other evidence suggests that they are 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 et al., 2002), and sensitivity to subtle expressions (Gao & Maurer, 2009, and unpublished data) all improve gradually after 7 years of age.

General discussion

In this study, we mapped the perceptual structure of facial expressions in adults and 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 nearly identical structure despite the fact that one group was tested with a conventional similarity-rating paradigm (Experiment 2) and the other group was tested with a child-friendly odd-man-out paradigm (Experiment 1). The 7-year-olds showed a systematic structure differing from that of adults in both the meaning 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 were adults, probably due to the similarity-rating paradigm used.

The structures we found here are more complex than the ones found in previous studies that used only intense expressions and that 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 have tried to incorporate a third dimension. However, studies based on predefined dimensions have usually found the third dimension to be correlated to the first two dimensions (Schlosberg, 1954), whereas studies based on MDS have usually found the third dimension to be hard to interpret (Abelson & Sermat, 1962; Bimler & Kirkland, 1997; Shah & Lewis, 2003). 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 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 assessed directly how intensity is represented in the perceptual structure of expressions because only intense expressions were used or because intensities were not compared with each other. The current findings suggest that intensity is represented as one dimension that is orthogonal to the other dimensions of pleasure, arousal, and potency and that is 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 lower 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 visuocognitive abilities. Unlike adults, children did not group surprise with fear and did not group neutral 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 children's sensitivity to subtle expressions both in everyday life and in our experiment (e.g., vernier acuity: Kovács, Kozma, Fehér, & Benedek, 1999; contour integration: Skoczenski & Norcia, 2002; 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 levels, we found that children at 7 years of age have a perceptual structure of facial expressions that differs systematically from that of adults.

Although children's perceptual structure is not based purely on the physical difference among facial images, it is influenced by physical difference more than that of adults even at 14 years of age. By that age, 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 as well as the possible effects of ethnicity on such structures.

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