Published in final edited form as:
Emotion. 2013 June ; 13(3): 397–408. doi:10.1037/a0030463.

Attention Orienting by Gaze and Facial Expressions Across Development

Karly Neath, **Elizabeth S. Nilsen**, **Katarzyna Gittsovich**, and **Roxane J. Itier**
Psychology Department, University of Waterloo, Waterloo Ontario, Canada

Abstract

Processing of facial expressions has been shown to potentiate orienting of attention toward the direction signaled by gaze in adults, an important social–cognitive function. However, little is known about how this social attention skill develops. This study is the first to examine the developmental trajectory of the gaze orienting effect (GOE), its modulations by facial expressions, and its links with theory of mind (ToM) abilities. Dynamic emotional stimuli were presented to 222 participants (7–25 years old) with normal trait anxiety using a gaze-cuing paradigm. The GOE was found as early as 7 years of age and decreased linearly until 12–13 years, at which point adult levels were reached. Both fearful and surprised expressions enhanced the GOE compared with neutral expressions. The GOE for fearful faces was also larger than for joyful and angry expressions. These effects did not interact with age and were not driven by intertrial variance. Importantly, the GOE did not correlate with ToM abilities as assessed by the "Reading the Mind in the Eyes" test. The implication of these findings for clinical and typically developing populations is discussed.

Keywords

facial expressions; gaze orienting; development; theory of mind

Being able to use the information derived from facial signals is crucial for adapting behaviors appropriately and communicating within our social world. The eye region of the face is particularly important as it confers the direction of another person's attention (Langton, Watt, & Bruce, 2000) and allows for making inferences regarding the intentions and states of mind of others (Baron-Cohen, 1995; see Itier & Batty, 2009, for a review). In fact, humans are sensitive to the direction of another's eye-gaze from infancy (Farroni, Csibra, Simion, & Johnson, 2002; Hood, Willen, & Driver, 1998) and gain the ability to use information about an adult's direction of gaze to predict action by the end of the first year of life (Phillips, Wellman, & Spelke, 2002). The early preference for eye stimuli (Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000; Maurer, 1985), the early ability to discriminate between direct and averted eye-gaze (Farroni et al., 2002; Vecera & Johnson, 1995), and the spontaneous orientation of attention toward eye-gaze direction demonstrated by infants (Hood et al., 1998) have led to the claim of a neurocognitive system dedicated to processing social attention cues. This social attention network is further supported by studies reporting neurons sensitive to gaze direction in the superior temporal sulcus (STS) of primates (Campbell, Heywood, Cowey, Regard, & Landis, 1990; Perrett, Hietanen, Oram, & Benson, 1992), and results from a host of neuroimaging studies in adult humans that involve

Correspondence concerning this article should be addressed to Roxane J. Itier, Psychology Department, University of Waterloo, 200 University Avenue, Waterloo, ON N2L 3G1, Canada. ritier@uwaterloo.ca.

PMC Canada Author Manuscript
PMC Canada Author Manuscript

a large network of brain areas in processing eye-gaze, including the STS (Allison, Puce, & McCarthy, 2000; Hoffman & Haxby, 2000), the amygdala (Hooker et al., 2003; Wicker, Michel, & Decety, 1998), and the intraparietal sulcus (IPS) (Grosbras, Laird, & Paus, 2005; for reviews, see Frischen, Bayliss, & Tipper, 2007, and Itier & Batty, 2009).

A large body of research has highlighted adults' ability to spontaneously orient their attention to the direction of another person's gaze (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). Experimentally, this attention orienting has been tested with a modified version of Posner's attention cueing task (Posner, 1980), using a centrally presented face cue whose eye gaze is averted to the left or right, followed by a laterally presented target either congruent or incongruent with the direction of gaze. Reaction times (RTs) to targets at a cued (congruent/valid) location are typically shorter than to targets at a noncued (incongruent/invalid) location (for an in depth review, see Frischen et al., 2007), indicating the strong and involuntary shift of the observer's attention in the direction of gaze. The RT difference between congruent and incongruent conditions is often referred to as the *cueing effect*, *validity effect*, or *gaze orienting effect* (GOE).

Gaze Orienting Effect and Emotion

*S*everal lines of evidence suggest that processing of facial emotions should interact with the GOE. First, the interaction of gaze and emotion is necessary to make sense of others' mental states. Facial expressions offer critical contextual information regarding the behavioral intentions communicated through gaze and the feelings one can have toward objects. For instance, someone expressing fear while looking toward an object indicates a possible danger, while someone expressing joy while looking toward an object suggests the person likes the object. Without such emotional information observers would be less aware of the gazer's attitude toward the gazed-at object and the possible quality of that object (e.g., dangerous or pleasurable). Second, some studies have reported behavioral influence of gaze on emotion perception and recognition (Adams & Kleck, 2003, 2005). The reverse, that is, an influence of emotions on gaze processing, is thus possible. Third, neuroimaging studies suggest an overlap of the brain structures involved in gaze and emotion processing, in particular within the STS regions (Allison et al., 2000; Hoffman & Haxby, 2000) and in the amygdala, which also plays an important role in the processing of fear (Adolphs, 2008; George, Driver, & Dolan, 2001; Whalen et al., 1998; Wicker, Perrett, Baron-Cohen, & Decety, 2003). Neuropsychological studies further support this idea, with impairments in the analysis of both facial expression and gaze direction following amygdala lesions (Young et al., 1995). Given all these elements, it is reasonable to assume that facial emotions could modulate the GOE. The empirical evidence for such a modulation is, however, mixed, and the modulation depends on the emotion.

Most of the research on the modulation of the GOE by emotions has focused on fearful facial expressions. Intuitively, it makes sense that one would orient faster to the location looked at by an individual who looks frightened, as this would indicate a potential danger in that direction that needs to be attended to rapidly for survival (Mathews, Fox, Yiend, & Calder, 2003). This idea is also in line with the involvement of the amygdala in processing fear and eye gaze and in the "fight or flight" response. In contrast there is no a priori reason to orient attention faster to joy or anger than to neutral faces as these are typically approach-oriented expressions and should rather be enhanced with direct gaze (Adams & Kleck, 2003). This threat-related hypothesis thus predicts a larger GOE for fearful than neutral, angry, or joyful faces. In fearful expressions the eyes are also widened and the contrast between the iris and the sclera, critical for gaze perception, is more visible. This low-level factor might also contribute to a better detection of gaze and its subsequent movement and thus to faster orienting of attention (Tipples, 2006). Surprised facial expressions also include widened eyes and indicate an unexpected event/ object. Like fearful expressions, they could also enhance the GOE compared to neutral, joyful, or angry expressions as it might be advantageous for survival to detect unexpected events in case they are dangerous. As we review below, the literature on the modulations of gaze orienting by facial expressions is mixed and several factors in the designs used seem to play an important role in finding such effects.

The first factor is the trait anxiety level of participants. An enhanced GOE was found for fearful faces compared to neutral and angry faces (Fox, Mathews, Calder, & Yiend, 2007; Mathews et al., 2003) in highly anxious participants. Putman, Hermans, and van Honk (2006) and Tipples (2006) also reported an enhanced GOE for fearful compared with neutral and joyful expressions, which correlated with participants' anxiety scores and trait fearfulness scores, respectively. Anxious individuals are prone to detecting threat (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007), and it has been proposed that they may orient faster toward the location indicated by a fearful face than by a neutral face (Mathews et al., 2003). In addition, highly anxious individuals are also intolerant to uncertainty (Dugas, Gagnon, Ladouceur, & Freeston, 1998; Dugas, Gosselin, & Ladouceur, 2001) and may thus also respond differently to surprised expressions. It is therefore important to control for anxiety levels when evaluating the interaction of emotion and gaze-cueing in a typical, nonanxious population.

Many studies with nonanxious participants have failed to report increased GOE for fearful expressions compared to neutral or joyful expressions (Fox et al., 2007; Galfano et al., 2011; Hietanen & Leppänen, 2003; Holmes, Mogg, Garcia, & Bradley, 2010; Mathews et al., 2003). This could be due to the way the face cues were presented. Some studies used static stimuli with an expressive face gazing away (e.g., Hietanen & Leppänen, 2003). However, emotions are perceived as more ecological when seen dynamically rather than statically (Sato, Kochiyama, Yoshikawa, Naito, & Matsumura, 2004), and thus, the effect of emotion in these experiments may not have been strong enough to modulate the GOE. Others used dynamic sequences in which the emotion was presented first followed by the shift in gaze (i.e., a fearful face with straight gaze followed by a fearful face with averted gaze; Fox et al., 2007; Galfano et al., 2011; Mathews et al., 2003). The emotional face with straight gaze could thus have held attention, preventing individuals from orienting faster toward the target compared to neutral faces. In other studies, a neutral face with straight gaze was presented first, followed by the emotional face with an averted gaze, creating an abrupt change in both emotion and gaze direction (e.g., Holmes et al., 2010).

Some studies did find a larger GOE for fearful than neutral or joyful expressions (Bayless, Glover, Taylor, & Itier, 2011; Graham, Freisen, Fichtenholtz, & Labar, 2010; Putman et al., 2006; Tipples, 2006). However, as noted above, the Putman et al. (2006) and Tipples (2006) studies were confounded by the level of anxiety or fearfulness of the participants. In addition, Putman et al. (2006) as well as Bayless et al. (2011), who tested only nonanxious participants, used dynamic videos in which the change in emotion occurred simultaneously with the shift in gaze. As the face went from a neutral expression with straight gaze to a fearful expression with an averted gaze across several video frames, the eyes started to shift to the side at the same time as they started to widen, making it unclear whether the GOE modulation was due to the emotional content of the face or to the size of the eyes' sclera, which is larger in fearful than in other expressions. In fact, Bayless et al. (2011) concluded, on the basis of their results with inverted faces and isolated eye stimuli, that their GOE modulations were driven by both the emotional content of the faces and by the eyes' sclera size.

Bayless et al. (2011) also reported an enhanced GOE for surprised faces, as large as that found for fearful faces, in relation to joyful and angry faces. To the best of our knowledge, this was the first study to test surprised expressions in a gaze-cuing paradigm. However, this larger GOE for fearful and surprised faces did not differ significantly from that obtained for neutral faces, possibly because of the short stimulus onset asynchrony (SOA, i.e., the time between the gaze shift and the onset of the target) used (200 ms). Indeed, Graham et al. (2010) reported an enhanced GOE for fearful compared to joyful and neutral faces only for SOAs longer than 300 ms, arguing that a minimum of 300 ms is necessary for emotion and gaze cues to be integrated. Moreover, Graham et al. used a dynamic design in which the gaze shift occurred first, before the change in expression (i.e., a neutral face with straight gaze followed by the same neutral face with an averted gaze, followed by the same face with a fearful expression and an averted gaze). However, they did not report participants' trait anxiety scores. Accordingly, in the present study we used a similar dynamic sequence (gaze shift followed by change in expression) and an SOA of 500 ms to allow sufficient time for emotion and gaze cues to be integrated even in younger children. Importantly, we ensured that all our participants were nonanxious.

Gaze Orienting During Development

Researchers have been interested in studying gaze-cueing during development because the direction of gaze has been shown to provide the basis for the development of social–cognitive functions (Butterworth & Jarrett, 1991). Consider a triadic relationship that involves two persons (A and B) and one object. The gaze direction of B will inform A of his attention onto the object and person A will also attend to it. This is referred to as *joint attention*, as both people attend to the same object; however, only one person uses the other person's gaze direction to orient to the same target (Emery, 2000). Joint attention typically develops between 9 and 14 months of age. In contrast, *shared attention*, which develops after joint attention, implies that both individuals are aware of each other's object of attention and use each other's gaze direction to attend to the same target. Baron-Cohen (1995) proposed the existence of an innate cognitive system specialized for the detection of gaze direction (Eye Direction Detector, EDD), which would be necessary for the development of shared attention and for theory of mind (ToM). ToM refers to the ability to attribute mental states (beliefs, intents, desires, etc.) to oneself and others and to understand that others have beliefs, desires, and intentions that are different from one's own. ToM, which typically develops when children are 4 to 5 years old, plays a fundamental role in social cognition. A lack of ToM abilities has been shown in developmental pathologies such as Autism Spectrum Disorders (ASD) in which abnormal processing of gaze has also been reported (Baron-Cohen, 1995; Nation & Penny, 2008). However, whether the use of eye-gaze in directing attention is directly related to these social–cognitive abilities in typically developing children and adults remains unclear.

Research with infants has revealed that sensitivity to eye gaze is robust, thereby providing support for the EDD hypothesis. For instance, newborn infants look longer at faces with direct versus averted gaze (Farroni et al., 2002) and 3-month-old infants spontaneously orient their attention in the direction of gaze (Hood et al., 1998). Also, at 4 months of age, the infant brain manifests enhanced processing of objects that have been cued by the direction of others' gaze as shown by an event-related potential (ERP) study (Reid, Striano, Kaufman, & Johnson, 2004). Other ERP studies with older infants have also shown larger allocation of attention toward objects cued by fearful faces, compared to neutral faces (Hoehl, Palumbo, Heinisch, & Striano, 2008; Hoehl & Striano, 2010). These studies show that gaze, as well as facial emotions, are used to determine what is socially relevant to the infant in the surrounding environment and suggest that these abilities may emerge earlier than previously thought on the basis of purely behavioral studies.

Despite the remarkable face processing skills present in infancy, face perception and recognition (Itier & Taylor, 2004a; Taylor, Batty, & Itier, 2004), as well as facial expression recognition (Herba & Phillips, 2004; McClure, 2000), continue to develop and improve until late adolescence. Importantly, little is known about how children orient their attention to eye gaze during childhood development. Schul, Townsend, and Stiles (2003) studied children ranging from 7 to 18 years, and concluded that the ability to orient attention, disengage attention, and process visual stimuli in an unattended location improves gradually throughout the school-age years. However, they measured spatial attention orienting in a nongaze cuing paradigm. Ristic, Friesen, and Kingstone (2002) reported a GOE for preschool-aged children (3- to 5-year-olds); however, this was during the presentation of schematic drawings of joyful faces.

Additionally, most developmental gaze-cueing studies have typically used one age group as a comparison point to an age-matched clinical group (Huang-Pollock & Nigg, 2003; Nation & Penny, 2008), but did not assess the normal developmental trajectory of the GOE. As mentioned above, research on children with ASD suggests links between abnormal processing of gaze and social deficits as seen by impairments in ToM abilities (Baron-Cohen, 1995; Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). However, without a clear understanding of GOE performances across typical development, caution should be exercised when comparing individuals with atypical development to controls. To truly understand how these cognitive processes go awry in clinical developmental populations, we first need to understand how such processes develop in the normal population and demonstrate a direct link between the GOE measures and ToM abilities. The developmental course of the GOE in the typically developing population and how it relates to social skills is currently lacking in the literature. The goal of the present study was to address this gap.

Present Study

The current cross-sectional study is the first to examine the developmental trajectory of attention orienting by gaze and its modulations by emotions, across a wide age range of typically developing children, adolescents, and adults, as well as assessing how this relates to social–cognitive abilities such as ToM. Dynamic emotional stimuli consisting of surprised, fearful, joyful, neutral, and angry expressions were presented to participants ranging from 7 to 25 years with normal trait anxiety. A decreased GOE with age was expected. That is, as age increases, participants should be faster to orient to the gaze direction and maybe faster to disengage from the nongazed at location. An effect of emotion on attention orienting was also expected, such that fear should yield larger GOEs than other emotions, and this should be seen as early as 7 years of age, given the infant literature. The question of whether surprise would yield similar effects as fear was left open, given the scarce use of this emotion in the literature. In order to investigate how the GOE relates to social cognition across development, ToM abilities were assessed by the “Reading the Mind in the Eyes” (RME) test (Baron-Cohen et al., 2001). We predicted that better ToM skills, as reflected by higher scores on the RME, would be negatively correlated with GOE measures.

Method

Participants

A total of 263 participants ages 7 to 25 years were recruited and tested. Children and adolescents (236) were recruited via local elementary schools and secondary schools, and 27 undergraduate students were recruited at the University of Waterloo. One participant was rejected because he did not complete the entire study; 13 participants were rejected because of high anxiety as measured by a raw score of 45 or greater on the State–Trait Inventory for Cognitive and Somatic Anxiety (STICSA; Grös, Antony, Simms, & McCabe, 2007) or a standard score of 65 or greater on the Beck Anxiety Inventory for Youth (BAI–Y; Beck, Beck, & Jolly, 2005). In addition, 27 participants were considered outliers as they exceeded 2.5 standard deviations from the group mean for a given age group on RT measures and were thus not included in the data analysis. The 222 remaining participants included in the analyses were divided into 8 age groups as summarized in Table 1.[1]

The study was approved by the University of Waterloo Research Ethics Board. For participants under the age of 18, the study was also approved by the local school boards with permission from the schools' principals. The children whose parents provided written consent and who themselves agreed to take part in the study were individually tested in a quiet room at their school. The adults were recruited for course credit and tested at the University of Waterloo. All participants had normal or corrected-to-normal vision.

Stimuli

Eight photographs of faces (four men, four women) with joyful, fearful, surprised, angry, and neutral expressions were selected from the MacBrain Face Stimulus Set (see Tottenham et al., 2009, for a full description and validation of the stimuli). Eye gaze was manipulated using GIMP digital imaging software. For each image, the iris was cut and pasted to the corners of the eyes to produce a directional (left/right) gaze (see Figure 1). The images were cropped to remove hair, ears, and shoulders. The faces were presented against a gray background, and subtended a visual angle of approximately 11.42° × 7.63°. The stimuli were placed such that the eyes were at the level of the fixation cross, at the center of the screen. The target consisted of a black asterisk of 0.5° × 0.5° visual angle, which appeared to the left or right of fixation, at an eccentricity of 6.7° of visual angle, immediately after offset of the face stimulus.

Design and Procedure

Participants performed the experiment in a quiet, well-lit room, seated 60 cm from the laptop computer screen. The height of the chair was adjusted to ensure that each participant's head and eyes were centered on the screen. The task was programmed using Presentation Software (Neurobehavioural Systems) and consisted of 10 blocks of 48 trials. Self-paced breaks were offered between blocks. A trial started with a fixation cross at the center of the screen followed by a face with a neutral expression and looking straight for 500 ms. The face was immediately replaced by the same face with a neutral expression and an averted gaze (left or right) for 200 ms, itself immediately replaced by the same face expressing an emotion with the same averted gaze for 300 ms (see Figure 1). This produced a dynamic face stimulus that was then replaced by an asterisk (target) to the right or left of where the face appeared. In the straight gaze trials, the same sequence was used except the face never shifted gaze and always looked straight ahead. The SOA between the shift of eye gaze and onset of the target was thus 500 ms. The fixation cross was presented during the intertrial interval, which was jittered between 1000 and 1500 ms (M = 1250 ms). The target was presented until a response was made or for a maximum of 1000 ms. Participants were instructed to maintain fixation on the cross at the center of the screen, and asked to respond to the target as quickly and accurately as possible without moving their eyes to the side. Participants responded with a left-hand button press on an orange sticker for targets appearing on the left, and a right-hand button-press on a pink sticker for targets appearing on the right. Participants were told that the direction of the eye-gaze would not predict the side of appearance of the target.

[1]Groups were defined differently for ages 12 through 17 years in order to maintain consistency for group gender and numbers. Ages 12 and 13 years were collapsed into one group, and the same was done for ages 14 through 17 years.

Trials in which targets appeared on the same side as the gaze direction of the preceding face were marked as congruent and trials in which targets appeared on the opposite side were marked as incongruent. There were a total of 15 conditions: congruent, incongruent, or noncongruent (i.e., straight gaze trials) for each of the five emotions (left and right gaze/target side combined for congruent–incongruent/noncongruent, respectively). Across the whole experiment there were 32 trials per condition. Within each block, the trial order was randomized with eight face identities appearing equally often within each condition. Neither face identity nor emotion repeated within fewer than four successive trials.

Following the completion of 5 blocks, participants aged 7 through 17 years completed the BAI–Y test of anxiety (Beck et al., 2005). The test consisted of 20 statements regarding the frequency of anxiety symptoms with Likert scale response options (*never* = 0, *sometimes* = 1, *often* = 2, *always* = 3). Participants were provided with the response scale and were given the option to verbally say the response or point to the response. The experimenter read the questions and recorded the participant's responses. Scoring consisted of summing the total value of responses for each of the 20 items. Participants ages 18 through 25 completed the STICSA anxiety test. The test consisted of two scales, one for state anxiety and one for trait anxiety, containing 21 items each rated on a 4-point Likert scale (1 = *not at all*, 2 = *a little*, 3 = *moderately*, 4 = *very much so*). The STICSA was designed to assess trait cognitive and somatic anxiety and has high internal consistency (alphas >.87; Grös et al., 2007) and acceptable test–retest reliability (*r*s > .65).

The next five experimental blocks were then run. After completion of the computer task, participants completed the Baron-Cohen RME test (Baron-Cohen et al., 2001). The RME test assesses the capacity to discriminate the mental states of others using photographs of face eye regions by choosing the most accurate mental state from one of four mental state words. Participants ages 18 through 25 years completed the adult version, in which they were presented with 36 black-and-white photographs of the eye area of the face (a rectangle including the eyes and eye brows and a little bit of the surrounding area). All photographs were of equal size (15 cm × 6 cm). Participants were asked to choose one of four words (three distractor words and one correct word) that described the mental state of the person in the photograph. The experimenter recorded the verbal responses of the participants. If necessary, participants were provided with a glossary, which contained the meaning of the words describing the mental states. Scores were calculated as the total number of correct discriminations for all 36 items. Every participant evaluated the same set of RME test stimuli in the same order according to the instructions of Baron-Cohen et al. (2001). Participants ages 7 through 17 completed the children's version of the RME, which consisted of 28 photographs of human eye regions (out of the 36 photographs used in the adult version). The same task and procedure were used as for adults except that the words in the child version were easier. The experimenter recorded the verbal responses of the participant, and children were provided a verbal description of the mental states if required.

Finally, participants completed a facial recognition task consisting of 15 faces taken from the computer task (4 fearful, 3 joyful, 3 surprised, 3 neutral, and 2 angry[2]). The images were presented on paper with a multiple forced-choice answer format, and participants were instructed to circle the emotion expressed by each face. This test was to ensure that all participants could recognize the emotions presented.

[2]This was a mistake from the experimenter; there should have been three pictures presented for each emotion.

Data Analysis

For the cueing task, a response was recorded as correct when the response key matched the side of the target appearance and if the response time (RT) was within 100–1000 ms. The remaining responses were marked as incorrect. Mean RTs for correct answers were calculated according to facial emotions (anger, fear, joy, surprise, neutral) and congruency (congruent, incongruent, non-congruent), with left and right target conditions averaged together. Only correct RTs within 2.5 standard deviations from the mean of each condition for each subject were kept in the final mean RT calculation (Van Selst & Jolicoeur, 1994). After removing these trials, the average number of trials was above 30 across ages and conditions. The Kolmogorov–Smirnov tests ensured RTs were normally distributed in each age group, and a 5 (emotion) × 3 (congruency: congruent, incongruent, noncongruent) × 8 (age groups) mixed-model analysis of variance (ANOVA) was used.

Because an Emotion × Congruency interaction was found for RTs, we calculated GOE scores by subtracting RTs to congruent trials from RTs to incongruent trials for each subject and emotion. GOE scores were then analyzed using a 5 (emotion) × 8 (age groups) ANOVA.

Given the generally high response variability in younger children, we also calculated the coefficient of variation of the response time (cvRT) for each participant for the congruent, incongruent, and noncongruent (i.e., straight gaze) conditions. The cvRT scores were calculated as the standard deviation divided by the mean RT within subjects and conditions, and were taken as a measure of the participant’s behavioral variability. These scores were then analyzed using a 5 (emotion) × 3 (congruency) × 8 (age group) ANOVA.

For all ANOVA analyses, the Greenhouse–Geisser correction to the degrees of freedom was used when necessary, and Bonferroni corrections were used for multiple comparisons. Pearson correlations were also performed to evaluate, across the population, the relationship among age, theory of mind abilities (as assessed by RME scores), anxiety, and the GOE. Partial correlations controlling for age were also performed. Only significant effects are reported unless otherwise stated.

Results

Percentage Recognition Rate on the Facial Recognition Task

All participants scored above 50% for all conditions in the facial recognition task, suggesting that none were impaired at emotion recognition. Percentages of correct responses can be found in Table 2 but were not analyzed statistically given the small number of trials. This task was used as a recognition check to ensure that all participants could successfully recognize all emotions. The accuracy scores suggest the facial expressions presented were identified appropriately in each age group.

Gaze Cueing Task

The percentage of errors never exceeded 5% for any age group or condition.

Reaction Times

The RT analysis revealed a main effect of age, $F(7, 214) = 31.13$, $p < .0001$, partial $\eta^2 = .51$, indicating faster responses with increasing age (see Figure 2). RTs decreased linearly from 7 years until 12–13 years and then leveled off until adulthood (paired comparisons confirmed significant differences up until the 10-years group but no significant differences between age groups after 11 years).

A significant effect of emotion, $F(4, 856) = 74.24$, $p < .0001$, $\eta^2 = .26$, was due to overall longer RTs for neutral than emotional expressions. A significant main effect of congruency, $F(1, 214) = 436.78$, $p < .0001$, partial $\eta^2 = .67$, was also found, due to fastest responses seen in the congruent condition, followed by the incongruent and then the noncongruent condition (all paired comparisons at $p < .0001$). This effect was modulated by a significant Emotion × Congruency interaction, $F(8, 1712) = 10.18$, $p < .0001$, $\eta^2 = .05$, which was due to a different congruency pattern for neutral and expressive faces. While RTs were always fastest for congruent conditions across emotions, they did not differ significantly between incongruent and noncongruent conditions for expressive faces but were significantly longer for noncongruent than for incongruent conditions for neutral expressions ($p < .0001$) (Figure 2A). We also analyzed congruent, incongruent, and non-congruent trials separately and looked for the effect of emotion. The analysis of congruent trials revealed a main effect of emotion, $F(4, 856) = 27.3$, $p < .0001$, partial $\eta^2 = .11$, due to slower responses for neutral expression ($p < .0001$ for all comparisons), and overall fastest RTs to fearful faces (significantly compared to anger, $p < .001$). For both noncongruent, $F(3.72, 795.88) = 68.40$ $p < .0001$, partial $\eta^2 = .24$, and incongruent trials, $F(4, 856) = 8.79$, $p < .0001$, partial $\eta^2 = .04$, the effect of emotion was due to slowest RTs for neutral faces ($p < .01$ for all comparisons).

The Congruency ×Age interaction was also significant, $F(14, 428) = 3.6$, $p < .0001$, partial $\eta^2 = .11$. For all age groups, faster RTs were found for congruent than incongruent or noncongruent conditions ($p < .0001$). However, until 9 years, incongruent and noncongruent conditions did not differ significantly (Figure 2B). From 10 years onward, faster RTs were found in the incongruent than the noncongruent condition ($p < .0001$ for all except 10-years group with $p < .005$ and 11-years group with $p < .05$).

The Emotion ×Age interaction and the three-way interaction of Congruency × Age × Emotion were not significant.

Gaze Orienting Effect (GOE)

Because emotion × Congruency and Age × Congruency interactions were found in the main RT analysis, GOE scores (calculated as $RT_{incongruent} - RT_{congruent}$) were computed and analyzed using a 5 (emotion) × 8 (age group) ANOVA.

A significant main effect of age, $F(7, 214) = 4.31$, $p < .0001$, partial $\eta^2 = .12$, was due to a general decrease of the GOE with increasing age. The GOE decreased linearly from 7–8 years until 12–13 years and then leveled off until adulthood (Figure 3A). A significant main effect of emotion, $F(3.78, 809.44) = 7.08$, $p < .0001$, partial $\eta^2 = .03$, was also found (Figure 3B). Across the age groups, the GOE was largest for fear (significantly compared with anger, $p < .001$; joy, $p < .05$; and neutral, $p < .0001$). The GOE for surprise was also higher than the other emotions, although paired comparisons were significant only with neutral ($p < .01$). No other comparisons were significant. The interaction between emotion and age was not significant.

Coefficient of Variation of the Response Time (cvRT)

A main effect of age group, $F(7, 214) = 11.14$, $p < .0001$, partial $\eta^2 = .27$, was due to a general decrease in variability with increasing age (see Figure 4). The main effect of emotion, $F(3.95, 846.5) = 5.29$, $p < .0005$, partial $\eta^2 = .02$, was due to a larger variability for neutral than other emotions except joy (all paired comparison at *p*s < .05). The effect of congruency was highly significant, $F(2, 428) = 44.42$, $p < .0001$, $\eta^2 = .17$, due to a larger variability for the congruent condition compared to both the noncongruent and the incongruent conditions, which did not differ (all paired comparisons at $p < .005$; Figure 4).

The Congruency × Age group interaction was also significant, $F(14, 428) = 2.52$, $p < .005$, $\eta^2 = .08$, and was due to a lack of congruency effect in the 11-year-old group.

Relationships Among Age, GOE, Theory of Mind, and Anxiety

To examine whether participants' attention to gaze cues related to aspects of social cognition, we conducted correlations between their GOE scores and their performance on the RME test. *Z* scores for the RME test (calculated separately for children and adults as slightly different versions of the test were used) were examined in the correlation analyses. Correlations between the GOE and age revealed significant results for all emotions (*p*s < .05) such that RT differences (the GOE effect) were smaller with increasing age (see Table 3), confirming the results of the GOE analyses reported above. Significant results between RME *Z* scores and GOE to fear and joy were also found. However, when partial correlations were conducted to control for age, the RME *Z* scores were not significantly correlated with GOE scores for any emotion.

We also ensured that anxiety did not have an effect on performances. Correlations between GOE scores and anxiety (see Table 3) as well as between RME *Z* scores and anxiety ($r = .061$) were nonsignificant, as expected.

Discussion

Successful navigation of our social world requires the ability to derive information from facial signals, such as gaze direction and emotional expression. Previous literature on attention orienting by gaze has mainly focused on adult populations (e.g., Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999) or on comparisons between clinical and nonclinical child populations of a given age (Huang-Pollock & Nigg, 2003; Nation & Penny, 2008). Lacking is a comprehensive examination of the use of gaze in orienting attention across the developmental span, as well as the way this cue interacts with facial expressions. As such, the purpose of the present study was to examine the contribution of various facial expressions in modulating the gaze orienting effect (GOE) across development. A wide range of ages were studied (7 to 25 years) in a modified Posner attention cueing paradigm involving dynamic face stimuli expressing different emotions (fear, anger, joy, surprise) or no emotion (neutral). Because anxiety has been shown to influence emotional modulations of gaze orienting (Fox et al., 2007; Mathews et al., 2003), participants were selected for normal trait anxiety. In addition, the relation between gaze orienting and social–cognitive skills assessed by an advanced theory of mind test (ToM) was examined. Results revealed several insights into the development of gaze orienting from late childhood until adulthood, and highlight important issues related to using this paradigm with children.

First, to ensure that participants could accurately identify the expressions of emotion, we included a general facial expression recognition test. Results revealed that participants recognized facial expressions appropriately in each age group. The general increase in recognition rates with age along with the highest rates found for joy and lower rates for fear follow previous studies (Herba & Phillips, 2004). However, this test was included as a check, and results were not analyzed statistically given the very low number of trials used. Caution should thus be exercised when interpreting these data.

General age-related effects in participants' response times were found, with RTs for all conditions decreasing linearly with age until around 12–13 years, at which point adult RTs were reached. This age-related decrease in RTs is classically found in cognitive developmental studies related to face processing (e.g., Itier & Taylor, 2004a, 2004b) and is thought to reflect more efficient cognitive processing with increasing age, here related to attention and emotion.

A main goal of the present study was to assess the developmental trajectory of the GOE. As predicted, all age groups demonstrated the classic gaze-cueing effect, such that RTs to targets at gazed-at locations were shorter than RTs to targets at the location opposite to the direction of gaze or to targets not cued by gaze (noncongruent, i.e., straight gaze trials) (Driver et al., 1999; Friesen & Kingstone, 1998). That is, at all ages and for all emotions, attention was oriented faster toward gaze direction but was not captured more by incongruent trials than by noncongruent/straight gaze trials, which would otherwise be a sign of difficulty disengaging attention from the incongruent location. Interestingly, however, a difference between incongruent and noncongruent trials emerged by 10 years of age, was present until adulthood, but was due to longer response times for noncongruent than for incongruent trials. Longer RTs to noncongruent than incongruent trials were also seen for neutral expressions but not for other facial expressions for which the two conditions yielded similar RTs. This effect likely reflects the capture of attention by direct/straight gaze (Palanica & Itier, 2012; Senju & Hasegawa, 2005), which is more salient in neutral faces due to the absence of movement, compared to the dynamic facial expressions. The present results also suggest this attention capture by direct gaze may increase with age given it was seen only after 10 years of age, although future studies will have to confirm this effect.

Therefore, the GOE seen in adults is present throughout development, starting at least from 7 years of age. Importantly and as predicted, the GOE decreased with age linearly from 7–8 years until 12–13 years, at which point adult values were reached. This 30-ms decrease in GOE across a 4-year span was due to the difference between congruent and incongruent conditions diminishing with age. Analyzed separately, RTs to both congruent and incongruent trials decreased with age. However, as reported above, in all age groups, RTs were never longer to incongruent than to noncongruent trials, suggesting no change in the disengagement of attention with age. Rather, what seems to develop is the attention orienting itself, because RTs to congruent trials were always faster than RTs to both noncongruent and incongruent trials, at all ages. Therefore we suggest that what develops with age is a faster orienting of attention toward gaze-cued locations, in agreement with developmental studies using nongaze attention cueing paradigms (Schul et al., 2003; Wainwright & Bryson, 2002).

Of specific interest to the present study was the extent to which different facial expressions modulate the GOE in a nonanxious population, and whether there were differences across the developmental trajectory. As reviewed in the introduction, larger GOEs have been reported for fearful faces in highly anxious participants (Fox et al., 2007; Mathews et al., 2003). These individuals also seem intolerant to uncertainty (Dugas et al., 1998, 2001), which may impact responses to surprised expressions. In other studies where this modulation was found, participants' anxiety levels were not reported (e.g., Graham et al., 2010) or correlated with anxiety (e.g., Putman et al., 2006), leaving open the question of whether emotional modulations of the GOE could be found in low-anxious participants. A recent study reported larger GOE effects for fearful and surprised faces than for angry and joyful faces in low-anxious participants (Bayless et al., 2011); however, no difference was found compared to neutral faces, possibly because of the short SOA used (200 ms) or the simultaneous change in gaze and expression.

In the present study we tested only nonanxious participants with an SOA of 500 ms, which is enough time for a full integration of emotional and gaze cues (Graham et al., 2010). We also used dynamic sequences in which gaze shifted before the face expressed an emotion. We found increased GOE for both fearful and surprised faces (which did not differ) compared to neutral expressions, across development. The GOE for fear was also significantly larger than for anger and joy. Thus, the present study demonstrates larger orienting to gaze effects for fearful expressions and to a lesser extent for surprised expressions, in nonanxious participants and as early as 7 years of age. These effects also stem from a faster orienting of attention toward gazed-at locations, not from difficulties disengaging attention from the nongazed at locations.

The larger GOE for fear than other emotions is generally attributed to the threat content of fearful faces. A fearful face looking to the side denotes a possible danger and being able to orient to that danger fast is crucial for survival. It thus makes sense that this faster orienting found with fearful faces would be seen as early as 7 years of age and across development. Interestingly, surprised expressions (which are rarely studied) modulated the GOE to a similar extent as fearful expressions (as also found by Bayless et al., 2011), although surprise does not signal threat and is neither a negative nor a positive emotion (Fontaine, Scherer, Roesch, & Ellsworth, 2007). Surprise suggests an unexpected event, and this, along with its valence ambiguity, may drive similar shift in attention as fear. Because the source of the emotion expressed could potentially be dangerous, it seems logical that surprise would also yield increases in attention orienting linked to survival mechanisms, across development. Future studies will have to replicate these findings in other developmental populations.

The brain networks underlying gaze processing and the GOE are still being investigated in adults, but it is acknowledged that the STS, amygdala, and IPS are among their core nodes (see Itier & Batty, 2009, for a review). Developmental studies on the maturation of these networks are currently lacking, and little is also known on the development of the brain structures involved in the recognition of facial expressions. Most studies have focused on the role of the amygdala in the processing of fearful expressions and have shown continued development of amygdalar functions in response to fearful expressions, in line with a protracted development of facial emotion recognition abilities throughout childhood and adolescence (see Herba & Phillips, 2004, for a review). Recent studies showed larger amygdala activation in children and adolescents 9–17 years of age than in adults in response to fearful faces (Guyer et al., 2008). It is likely that the amygdala is involved in the increased GOE found for fearful expressions across age groups, but the extent to which the other areas of the gaze network contribute to the general decrease in GOE with age observed in the present study is completely unknown. Future developmental studies will have to investigate the neural basis of the GOE at various ages.

In addition to differences in SOA, the present study also differed from previous studies in its use of dynamic displays. While both Putman et al. (2006) and Bayless et al. (2011) presented the face cues dynamically, changes in expression and gaze were simultaneous, making it difficult to rule out a lower-level stimulus-based explanation for their findings, such as sclera size. In fact, Bayless et al. (2011) showed that sclera size interacted with the emotional content of the face, although it was not the sole reason for the findings. By using video stimuli in which the eyes began to widen, due to the change in emotion, before the gaze shift was complete, these studies may have increased the salience of the gaze cues in the context of the fearful and surprised faces. The present study overcame these issues as the sequence of the dynamic stimuli was such that the gaze shift occurred first followed immediately by the emotional expression, preventing any change in the eye region to be solely responsible for the GOE modulation. Rather, the GOE modulations were due to the facial expressions occurring after the gaze shift. Of course, it is entirely possible that different effects would have been found with the use of stimuli in which emotion occurred before (Fox et al., 2007; Galfano et al., 2011; e.g., Mathews et al., 2003) or at the same time as (Bayless et al., 2011; Putman et al., 2006; e.g., Tipples, 2006) the gaze shift. However, we believe a gaze shift preceding the expression of an emotion is more ecological than the other way around; that is, we turn our gaze toward a location, then detect danger, then express fear.

It could be possible that the unequal amount of apparent motion between neutral and expressive faces played a role in these modulations. In dynamic emotional stimuli the entire face undergoes change, while none of the facial features change position in the neutral stimuli. This general difference in apparent motion could be the cause for the longer RTs seen for neutral than emotional faces both during the straight gaze and averted gaze trials as well as for the GOE modulations with facial expressions. However, Graham et al. (2010) and Bayless et al. (2011) recently showed that the GOE was reduced for inverted compared to upright expressive faces. While both face types show identical amount of motion, inversion is known to disrupt facial expression recognition in both static and dynamic displays (e.g., Ambadar, Schooler, & Cohn, 2005; Valentine, 1988), thus suggesting that the GOE differences between emotions are due to the emotional content of the face and not the biological motion. Although inverted faces were not used in the present study, we believe the GOE modulations were due to the emotional content of the faces used.

Testing such a wide age range of children came with several methodological constraints. First, we did not use a head and chin rest, and although careful care was taken to ensure movement-free trials, slight variations in body and head positions were likely introduced. Second, for obvious timing reasons with children, the number of trials per condition was limited. We were thus concerned about the reliability of our results and questioned whether the larger GOE found for fearful and surprised expressions may be related to a higher variability in the RT results for these two emotions. We therefore calculated the coefficient of variation of the response time (cvRT) for each participant and emotion. Results were in line with the literature, demonstrating a decrease in the variability with increasing age (Elliott, 1970; Williams, Hultsch, Strauss, Hunter, & Tannock, 2005). Interestingly, more variability was seen for congruent than incongruent and noncongruent conditions. However, no difference was seen between the emotions beyond a generally higher variability for neutral faces. Specifically, the results were not more variable for fear and surprise emotions, making it unlikely that the enhanced GOE seen for these two facial expressions could be the mere result of intertrial variability. Nevertheless, the younger age groups displayed a larger variance than the older groups. We recommend caution before using the GOE paradigm as a test to compare clinical groups to control groups of young children due to the high degree of variability seen across the younger age groups.

Previous literature has hypothesized that the ability to orient to gaze is a precursor of social competencies (Baron-Cohen, 1995; Butterworth & Jarrett, 1991). Young children use gaze to infer various mental states, and the capacity to orient attention toward gaze direction at 10–11 months is positively correlated to language competencies at 18 months (Brooks & Meltzoff, 2005). The development of joint attention at 20 months can also predict ToM abilities at 44 months (Charman, 2003). Children with autism also show deficits in their ability to use gaze cues and have difficulty with ToM, suggesting that these two processes may be related. Recent data suggest that the neural sensitivity to dynamic eye gaze is linked with autism diagnosed at 36 months (Elsabbagh et al., 2012). In order to examine the extent to which children's gaze orienting related to social–cognitive abilities such as ToM, we examined the relations between their performances on the gaze-cueing paradigm and on the "Reading the Mind in the Eyes" test (RME; Baron-Cohen et al., 2001). The RME test purports to be a ToM test assessing how well one can put oneself into the mind of another person and tune into their mental state when solely looking at their eyes, and ASD individuals perform poorly on this task (Baron-Cohen et al., 2001). The present study predicted that a more efficient orienting of attention by gaze as reflected by smaller GOE

PMC Canada Author Manuscript

PMC Canada Author Manuscript

scores would negatively correlate with better ToM skills as reflected by higher scores on the RME test. Once controlled for age, which was essential to ensure age alone was not responsible for a possible relationship between the two variables, RME scores were not correlated with GOE scores for any of the emotional expressions. Therefore, we did not find evidence that gaze orienting related to the ToM skills necessary to perform well on the RME test.

It may be the case that we did not see a relation because gaze orienting operates as an important prerequisite for social cognition, but is not sufficient to support social–cognitive abilities. That is, showing a GOE does not mean that children have represented another person’s mental state or that they understand the inferential nature of gaze. Consistent with this notion, research has demonstrated that children with ASD do orient to gaze (Kylliäinen & Hietanen, 2004; Ristic et al., 2005; Senju, Tojo, Dairoku, & Hasegawa, 2004; Swettenham, Condie, Campbell, Milne, & Coleman, 2003), but it is in the inferences about what that gaze means that there is a deficit (Baron-Cohen, 1995; see Nation & Penny, 2008, for a review). It is also possible that we failed to find a relationship because the RME test only measures one aspect of social–cognitive abilities, and it may be the case that other aspects of social competences are linked to gaze orienting effects. For instance, in one study a correlation between ToM skills, as assessed using animated geometric shapes and language descriptions of mental states, and a gaze discrimination task was found in 7-year-old children and adolescents (Campbell et al., 2006). The GOE has also been shown to correlate negatively with scores on the Autism-Spectrum Quotient test (Bayliss, di Pellegrino, & Tipper, 2005), which might tap into different skills than those involved in the RME test.

This result highlights the importance of defining first ToM and social skill abilities, which seems to depend on the task used. A meta-analysis of the false-belief task, a so-called “litmus” test of mental-state understanding, showed a consistent conceptual change in the preschool years with above-chance level performance for 4-year-olds (Wellman, Cross, & Watson, 2001). It might be the case that the GOE would correlate with ToM skills as assessed by this false-belief task around this preschool age range. However, once attention can be oriented by gaze, ToM can emerge, but the two variables may not be directly linked in a quantitative way in older ages. Importantly, even if the RME is believed to represent an individual’s mentalizing abilities, it is unclear what precise cognitive skills are required to perform this complex task. At this point our findings suggest that attention orienting as measured by the GOE may not be directly linked to the social–cognitive abilities necessary to perform well on the RME test in the normal developmental population. More experiments confirming a link between gaze orienting and other social–cognitive abilities during childhood await.

In summary, our study is the first to report the developmental trajectory of attention orienting by gaze across a wide range of typically developing children, adolescents, and adults. The GOE decreased linearly from 7–8 years until 12–13 years of age, at which point it leveled off to the level seen in adulthood. Additionally, the GOE was enhanced for fearful and surprised expressions relative to neutral expressions or other emotions such as joy and anger, and this effect was not the result of participants’ anxiety levels or intertrial variability. Finally, the GOE did not directly relate to ToM skills as assessed by the RME test. Caution should thus be exercised when making conclusions regarding social–cognitive skills on the basis of the GOE.

PMC Canada Author Manuscript

PMC Canada Author Manuscript

Acknowledgments

This study was supported by the Canadian Institutes for Health Research (CIHR) and the Canada Research Chair (CRC) program to Roxane J. Itier as well as by a SSHRC Standard Research Grant to Elizabeth S. Nilsen. We warmly thank Missy Glover and Rachael Neal for help in recruitment and testing as well as all the parents and children who participated in the study.

References

Adams RB, Kleck RE. Perceived gaze direction and the processing of facial displays of emotion. Psychological Science. 2003; 14:644–647.10.1046/j.0956-7976.2003.psci_1479.x [PubMed: 14629700]

Adams RB Jr, Kleck RE. Effects of direct and averted gaze on the perception of facially communicated emotion. Emotion. 2005; 5:3–11.10.1037/1528-3542.5.1.3 [PubMed: 15755215]

Adolphs R. Fear, faces, and the human amygdala. Current Opinion in Neurobiology. 2008; 18:166–172.10.1016/j.conb.2008.06.006 [PubMed: 18655833]

Allison T, Puce A, McCarthy G. Social perception from visual cues: Role of the STS region. Trends in Cognitive Sciences. 2000; 4:267–278.10.1016/S1364-6613(00)01501-1 [PubMed: 10859571]

Ambadar Z, Schooler JW, Cohn JF. Deciphering the enigmatic face: The importance of facial dynamics in interpreting subtle facial expressions. Psychological Science. 2005; 16:403–410.10.1111/j.0956-7976.2005.01548.x [PubMed: 15869701]

Bar-Haim Y, Lamy D, Pergamin L, Bakermans-Kranenburg MJ, van IJzendoorn MH. Threat related attentional bias in anxious and non-anxious individuals: A meta-analytic study. Psychological Bulletin. 2007; 133:1–24.10.1037/0033-2909.133.1.1 [PubMed: 17201568]

Baron-Cohen, S. Mindblindness: An essay on autism and theory of mind. Cambridge, MA: MIT Press; 1995.

Baron-Cohen S, Wheelwright S, Hill J, Raste Y, Plumb I. The “reading the mind in the eyes” test revised version: A study with normal adults with Asperger syndrome or high-functioning autism. Journal of Child Psychology and Psychiatry. 2001; 42:241–251.10.1111/1469-7610.00715 [PubMed: 11280420]

Batki A, Baron-Cohen S, Wheelwright S, Connellan J, Ahluwalia J. Is there an innate gaze module? Evidence from human neonates. Infant Behavior & Development. 2000; 23:223–229.10.1016/S0163-6383(01)00037-6

Bayless SJ, Glover M, Taylor MJ, Itier RJ. Is it in the eyes? Dissociating the role of emotion and perceptual features of emotionally expressive faces in modulating orienting to eye gaze. Visual Cognition. 2011; 19:483–510.10.1080/13506285.2011.552895

Bayliss AP, di Pellegrino G, Tipper SP. Sex differences in eye gaze and symbolic cueing of attention. Quarterly Journal of Experimental Psychology. 2005; 58:631–650.10.1080/02724980443000124 [PubMed: 16104099]

Beck, JS.; Beck, AT.; Jolly, JB. Beck Youth Inventories—for children and adolescents. 2. San Antonio, TX: Psychological Corp; 2005.

Brooks R, Meltzoff AN. The development of gaze following and its relation to language. Developmental Science. 2005; 8:535–543.10.1111/j.1467-7687.2005.00445.x [PubMed: 16246245]

Butterworth G, Jarrett N. What minds have in common is space: Spatial mechanisms serving joint visual attention in infancy. British Journal of Developmental Psychology. 1991; 9:55–72.10.1111/j.2044-835X.1991.tb00862.x

Campbell R, Heywood CA, Cowey A, Regard M, Landis T. Sensitivity to eye gaze in prosopagnosic patients and monkeys with superior temporal sulcus ablation. Neuropsychologia. 1990; 28:1123–1142.10.1016/0028-3932(90)90050-X [PubMed: 2290489]

Campbell R, Lawrence K, Mandy W, Mitra C, Jeyakuma L, Skuse D. Meanings in motion and faces: Developmental associations between the processing of intention from geometrical animations and gaze detection accuracy. Development and Psychopathology. 2006; 18:99–118.10.1017/S0954579406060068 [PubMed: 16478554]

Charman T. Why is joint attention a pivotal skill in autism? Philosophical Transactions of the Royal Society of London B, Biological Sciences. 2003; 358:315–324.10.1098/rstb.2002.1199

Driver J, Davis G, Ricciardelli P, Kidd P, Maxwell E, Baron-Cohen S. Gaze perception triggers reflexive visuospatial orienting. Visual Cognition. 1999; 6(5):509–540.10.1080/135062899394920

Dugas MJ, Gagnon F, Ladouceur R, Freeston MH. Generalized anxiety disorder: A preliminary test of a conceptual model. Behaviour Research and Therapy. 1998; 36:215–226.10.1016/S0005-7967(97)00070-3 [PubMed: 9613027]

Dugas MJ, Gosselin P, Ladouceur R. Intolerance of uncertainty and worry: Investigating specificity in a nonclinical sample. Cognitive Therapy and Research. 2001; 25:551–558.10.1023/A:1005553414688

Elliott R. Simple reaction time: Effects associated with age, preparatory interval, incentive-shift, and mode of presentation. Journal of Experimental Child Psychology. 1970; 9:86–107.10.1016/0022-0965(70)90102-5 [PubMed: 5452110]

Elsabbagh M, Mercure E, Hudry K, Chandler S, Pasco G, Charman T. BASIS Team. Infant neural sensitivity to dynamic eye gaze is associated with later emerging autism. Current Biology. 2012; 22:338–342.10.1016/j.cub.2011.12.056 [PubMed: 22285033]

Emery NJ. The eyes have it: The neuroethology, function and evolution of social gaze. Neuroscience and Biobehavioral Reviews. 2000; 24:581–604.10.1016/S0149-7634(00)00025-7 [PubMed: 10940436]

Farroni T, Csibra G, Simion G, Johnson MH. Eye contact detection in humans from birth. Proceedings of the National Academy of Sciences of the United States of America. 2002; 99:9602–9605.10.1073/pnas.152159999 [PubMed: 12082186]

Fontaine JRJ, Scherer KR, Roesch EB, Ellsworth PC. The world of emotions is not two-dimensional. Psychological Science. 2007; 18:1050–1057.10.1111/j.1467-9280.2007.02024.x [PubMed: 18031411]

Fox E, Mathews A, Calder AJ, Yiend J. Anxiety and sensitivity to gaze direction in emotionally expressive faces. Emotion. 2007; 7:478–486.10.1037/1528-3542.7.3.478 [PubMed: 17683204]

Friesen CK, Kingstone A. The eyes have it! Reflexive orienting is triggered by nonpredictive gaze. Psychonomic Bulletin & Review. 1998; 5:490–495.10.3758/BF03208827

Frischen A, Bayliss AP, Tipper SP. Gaze cueing of attention: Visual attention, social cognition, and individual differences. Psychological Bulletin. 2007; 133:694–724.10.1037/0033-2909.133.4.694 [PubMed: 17592962]

Galfano G, Sarlo M, Sassi F, Munafò M, Fuentes LJ, Umiltà C. Reorienting of spatial attention in gaze cuing is reflected in N2pc. Social Neuroscience. 2011; 6:257–269.10.1080/17470919.2010.515722 [PubMed: 20924978]

George N, Driver J, Dolan RJ. Seen gaze-direction modulates fusiform activity and its coupling with other brain areas during face processing. NeuroImage. 2001; 13:1102–1112.10.1006/nimg.2001.0769 [PubMed: 11352615]

Graham R, Freisen C, Fichtenholtz HM, Labar KS. Modulation of reflexive orienting to gaze direction by facial expressions. Visual Cognition. 2010; 18:331–368.10.1080/13506280802689281

Grös DF, Antony MM, Simms LJ, McCabe RE. Psychometric properties of the State–Trait Inventory for Cognitive and Somatic Anxiety (STICSA): Comparison to the State–Trait Anxiety Inventory (STAI). Psychological Assessment. 2007; 19:369–381.10.1037/1040-3590.19.4.369 [PubMed: 18085930]

Grosbras MH, Laird AR, Paus T. Cortical regions involved in eye movements, shifts of attention, and gaze perception. Human Brain Mapping. 2005; 25:140–154.10.1002/hbm.20145 [PubMed: 15846814]

Guyer AE, Monk CS, McClure-Tone EB, Nelson EE, Roberson-Nay R, Adler AD, Ernst M. A developmental examination of amygdala response to facial expressions. Journal of Cognitive Neuroscience. 2008; 20:1565–1582.10.1162/jocn.2008.20114 [PubMed: 18345988]

Herba C, Phillips M. Annotation: Development of facial expression recognition from childhood to adolescence: Behavioural and neurological perspectives. Journal of Child Psychology and Psychiatry. 2004; 45:1185–1198. [PubMed: 15335339]

Hietanen JK, Leppänen JM. Does facial expression affect attention orienting by gaze direction cues? Journal of Experimental Psychology: Human Perception and Performance. 2003; 29:1228–1243.10.1037/0096-1523.29.6.1228 [PubMed: 14640840]

Hoehl S, Palumbo L, Heinisch C, Striano T. Infants' attention is biased by emotional expressions and eye gaze direction. Neuroreport. 2008; 19:579–582.10.1097/WNR.0b013e3282f97897 [PubMed: 18388742]

Hoehl S, Striano T. The development of emotional face and eye gaze processing. Developmental Science. 2010; 13:813–825.10.1111/j.1467-7687.2009.00944.x [PubMed: 20977553]

Hoffman EA, Haxby JV. Distinct representations of eye gaze and identity in the distributed human neural system for face perception. Nature Neuroscience. 2000; 3:80–84.10.1038/71152

Holmes A, Mogg K, Garcia LM, Bradley BP. Neural activity associated with attention orienting triggered by gaze cues: A study of lateralized ERPs. Social Neuroscience. 2010; 5:285–295.10.1080/17470910903422819 [PubMed: 20162493]

Hood BM, Willen J, Driver J. Adult's eyes trigger shifts of attention in human infants. Psychological Science. 1998; 9:131–134.10.1111/1467-9280.00024

Hooker CI, Paller KA, Gitelman DR, Parrish TB, Mesulam MM, Reber PJ. Brain networks for analyzing eye gaze. Cognitive Brain Research. 2003; 17:406–418.10.1016/S0926-6410(03)00143-5 [PubMed: 12880911]

Huang-Pollock CL, Nigg JT. Searching for the attention deficit in attention deficit hyperactivity disorder: The case of visuospatial orienting. Clinical Psychology Review. 2003; 23:801–830.10.1016/S0272-7358(03)00073-4 [PubMed: 14529699]

Itier RJ, Batty M. Neural bases of eye and gaze processing: The core of social cognition. Neuroscience and Biobehavioral Reviews. 2009; 33:843–863.10.1016/j.neubiorev.2009.02.004 [PubMed: 19428496]

Itier RJ, Taylor MJ. Effects of repetition and configural changes on the development of face recognition processes. Developmental Science. 2004a; 7:469–487.10.1111/j.1467-7687.2004.00367.x [PubMed: 15484595]

Itier RJ, Taylor MJ. Face inversion and contrast-reversal effects across development: In contrast to the expertise theory. Developmental Science. 2004b; 7:246–260.10.1111/j.1467-7687.2004.00342.x [PubMed: 15320383]

Kylliäinen A, Hietanen JK. Attention orienting by another's gaze direction in children with autism. Journal of Child Psychology and Psychiatry and Allied Disciplines. 2004; 45:435–444.10.1111/j.1469-7610.2004.00235.x

Langton SR, Bruce V. Reflexive visual orienting in response to the social attention of others. Visual Cognition. 1999; 6:541–567.10.1080/135062899394939

Langton SR, Watt RJ, Bruce II. Do the eyes have it? Cues to the direction of social attention. Trends in Cognitive Sciences. 2000; 4:50–59.10.1016/S1364-6613(99)01436-9 [PubMed: 10652522]

Mathews A, Fox E, Yiend J, Calder A. The face of fear: Effects of eye gaze and emotion on visual attention. Visual Cognition. 2003; 10:823–835.10.1080/13506280344000095 [PubMed: 17453064]

Maurer, D. Infants' perception of facedness. In: Field, T.; Fox, N., editors. Social perception in infants. Norwood, NJ: Ablex; 1985. p. 73-100.

McClure EB. A meta-analytic review of sex differences in facial expression processing and their development in infants, children, and adolescents. Psychological Bulletin. 2000; 126:424–453.10.1037/0033-2909.126.3.424 [PubMed: 10825784]

Nation K, Penny S. Sensitivity to eye gaze in autism: Is it normal? Is it automatic? Is it social? Development and Psychopathology. 2008; 20:79–97.10.1017/S0954579408000047 [PubMed: 18211729]

Palanica A, Itier RJ. Attention capture by direct gaze is robust to context and task demands. Journal of Nonverbal Behavior. 2012; 36:123–134.10.1007/s10919-011-0128-z

Perrett DI, Hietanen JK, Oram MW, Benson PJ. Organization and functions of cells responsive to faces in the temporal cortex. Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences. 1992; 335:23–30.10.1098/rstb.1992.0003

Phillips AT, Wellman HM, Spelke ES. Infants' ability to connect gaze and emotional expression to intentional action. Cognition. 2002; 85:53–78.10.1016/S0010-0277(02)00073-2 [PubMed: 12086713]

Posner MI. Orienting of attention. Quarterly Journal of Experimental Psychology. 1980; 32:3–25.10.1080/00335558008248231 [PubMed: 7367577]

Putman P, Hermans E, van Honk J. Anxiety meets fear in perception of dynamic expressive gaze. Emotion. 2006; 6:94–102.10.1037/1528-3542.6.1.94 [PubMed: 16637753]

Reid VM, Striano T, Kaufman J, Johnson MH. Eye gaze cueing facilitates neural processing of objects in 4-month-old infants. Neuroreport. 2004; 15:2553–2555.10.1097/00001756-200411150-00025 [PubMed: 15538194]

Ristic J, Friesen CK, Kingstone A. Are eyes special? It depends on how you look at it. Psychonomic Bulletin & Review. 2002; 9:507–513.10.3758/BF03196306 [PubMed: 12412890]

Ristic J, Mottron L, Friesen CK, Iarocci G, Burack JA, Kingstone A. Eyes are special but not for everyone: The case of autism. Cognitive Brain Research. 2005; 24:715–718.10.1016/j.cogbrainres.2005.02.007 [PubMed: 16099372]

Sato W, Kochiyama T, Yoshikawa S, Naito E, Matsumura M. Enhanced neural activity in response to dynamic facial expressions of emotions: An fMRI study. Cognitive Brain Research. 2004; 20:81–91.10.1016/j.cogbrainres.2004.01.008 [PubMed: 15130592]

Schul R, Townsend J, Stiles J. The development of attentional orienting during the school-age years. Developmental Science. 2003; 6:262–272.10.1111/1467-7687.00282

Senju A, Hasegawa T. Direct gaze captures visuospatial attention. Visual Cognition. 2005; 12:127–144.10.1080/13506280444000157

Senju A, Tojo Y, Dairoku H, Hasegawa T. Reflexive orienting in response to eye gaze and an arrow in children with and without autism. Journal of Child Psychology and Psychiatry and Allied Disciplines. 2004; 45:445–458.10.1111/j.1469-7610.2004.00236.x

Swettenham J, Condie S, Campbell R, Milne E, Coleman M. Does the perception of moving eyes trigger reflexive visual orienting in autism? Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences. 2003; 358:325–334.10.1098/rstb.2002.1203

Taylor MJ, Batty M, Itier RJ. The faces of development: A review of early face processing over childhood. Journal of Cognitive Neuroscience. 2004; 16:1426–1442.10.1162/0898929042304732 [PubMed: 15509388]

Tipples J. Fear and fearfulness potentiate automatic orienting to eye gaze. Cognition and Emotion. 2006; 20:309–320.10.1080/02699930500405550

Tottenham N, Tanaka JW, Leon AC, McCarry T, Nurse M, Hare TA, Nelson C. The NimStim set of facial expressions: Judgments from untrained research participants. Psychiatry Research. 2009; 168:242–249.10.1016/j.psychres.2008.05.006 [PubMed: 19564050]

Valentine T. Upside-down faces: A review of the effect of inversion upon face recognition. British Journal of Psychology. 1988; 79:471–491.10.1111/j.2044-8295.1988.tb02747.x [PubMed: 3061544]

Van Selst M, Jolicoeur P. A solution to the effect of sample size on outlier elimination. Quarterly Journal of Experimental Psychology A: Human Experimental Psychology. 1994; 47:631–650.10.1080/14640749408401131

Vecera SP, Johnson MH. Gaze detection and the cortical processing of faces: Evidence from infants and adults. Visual Cognition. 1995; 2:59–87.10.1080/13506289508401722

Wainwright A, Bryson SE. The development of exogenous orienting: Mechanisms of control. Journal of Experimental Child Psychology. 2002; 82:141–155.10.1016/S0022-0965(02)00002-4 [PubMed: 12083793]

Wellman HM, Cross D, Watson J. Meta-analysis of theory-of-mind development: The truth about false belief. Child Development. 2001; 72:655–684.10.1111/1467-8624.00304 [PubMed: 11405571]

Whalen PJ, Rauch SL, Etcoff NL, McInerney SC, Lee MB, Jenike MA. Masked presentations of emotional facial expressions modulate amygdala activity without explicit knowledge. Journal of Neuroscience. 1998; 18:411–418. [PubMed: 9412517]

Wicker B, Michel F, Decety J. Brain regions involved in the perception of gaze: A PET study. NeuroImage. 1998; 8:221–227.10.1006/nimg.1998.0357 [PubMed: 9740764]

Wicker B, Perrett DI, Baron-Cohen S, Decety J. Being the target of another's emotion: A PET study. Neuropsychologia. 2003; 41:139–146.10.1016/S0028-3932(02)00144-6 [PubMed: 12459212]

Williams BR, Hultsch DF, Strauss EH, Hunter MA, Tannock R. Inconsistency in reaction time across the life span. Neuropsychology. 2005; 19:88–96.10.1037/0894-4105.19.1.88 [PubMed: 15656766]

Young AW, Aggleton JP, Hellawell DJ, Johnson M, Broks P, Hanley JR. Face processing impairments after amygdalotomy. Brain. 1995; 118:15–24.10.1093/brain/118.1.15 [PubMed: 7895001]

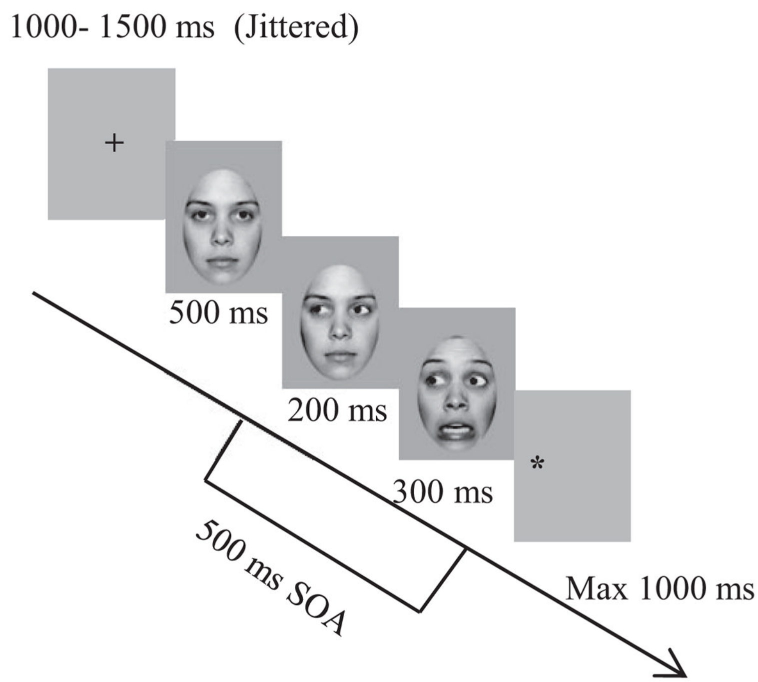

Figure 1.
Example of a trial (here, averted gaze expressing fear) showing the presentation sequence and its timing. SOA = stimulus onset asynchrony.

PMC Canada Author Manuscript

PMC Canada Author Manuscript

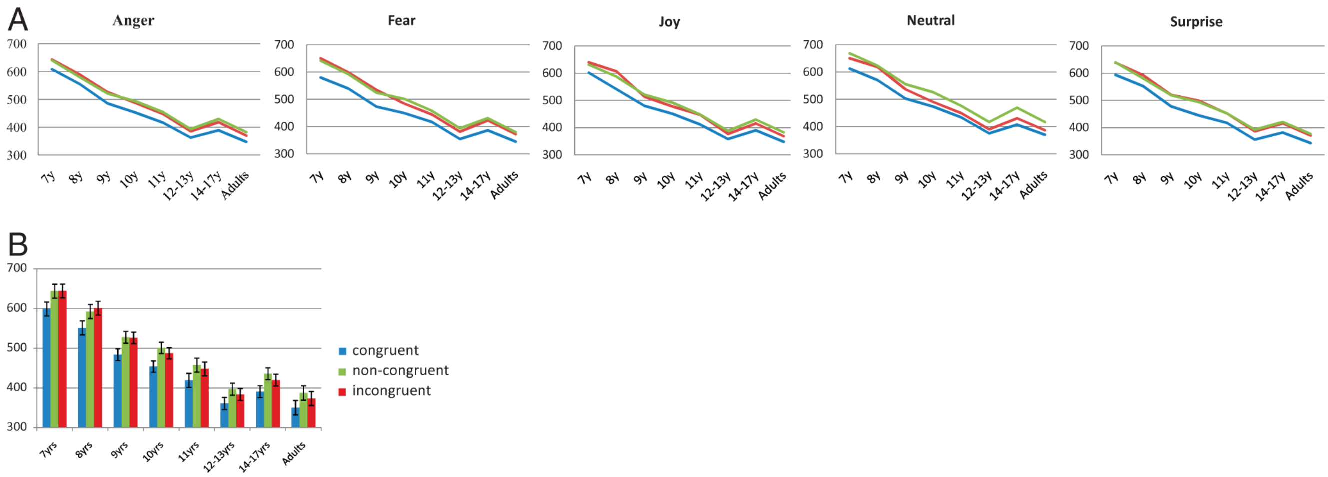

Figure 2.

Gaze cuing task. Mean reaction times (RTs) for congruent (blue), noncongruent (straight gaze; green), and incongruent (red) conditions for each age group (A) displayed for each emotion and (B) averaged across emotions with standard errors to the means.

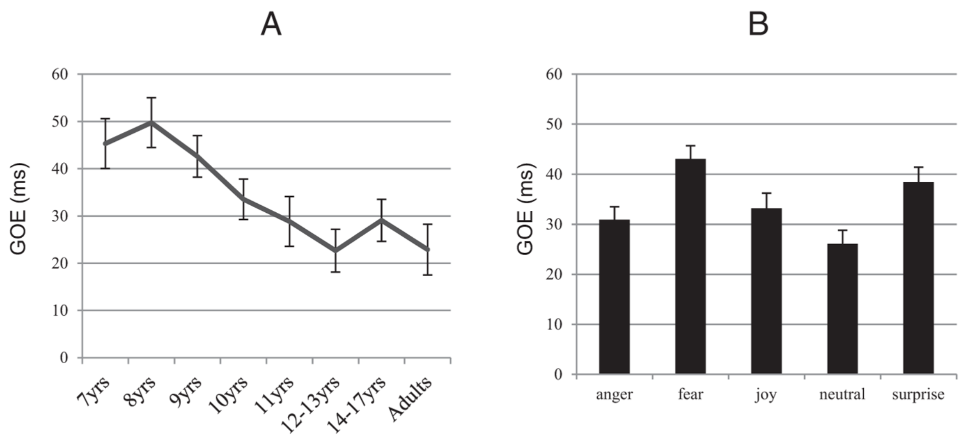

Figure 3.

The gaze orienting effect (GOE) was calculated for each subject and condition as $RT_{incongruent} - RT_{congruent}$. Here, the mean GOE is displayed for (A) each age group and (B) each emotion. RT = reaction time.

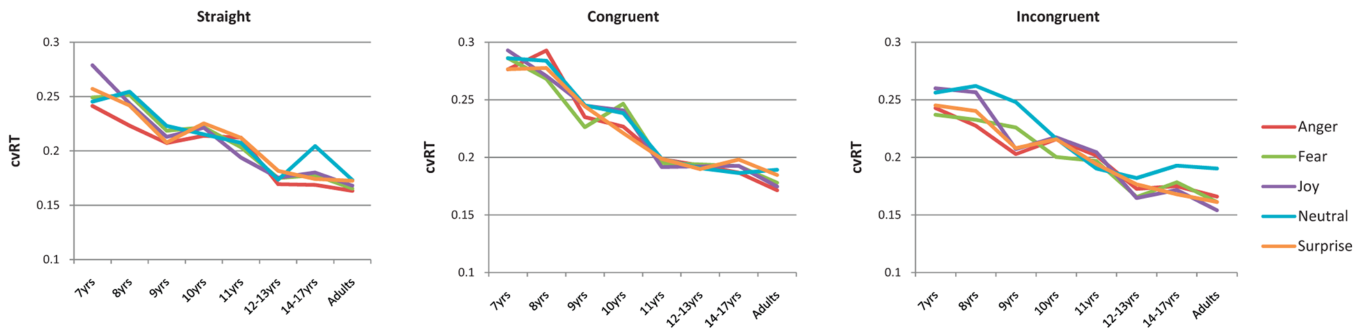

Figure 4.
The mean coefficient of variation of the response time (cvRT) for each age group is displayed for each emotion for the noncongruent (straight gaze), congruent, and incongruent conditions.

Table 1

Demographic Information for the Population Tested

Age group	Tested (years, *n*)	Analyzed (*n*)	Mean age (years ± *SD*)	Men (*n*)	Women (*n*)	BAI–Y (standard ± *SD*)	STICSA (standard ± *SD*)
7	28	23	7.5 ± 0.3	13	10	47.4 ± 8.3	—
8	28	23	8.7 ± 0.3	10	13	47.4 ± 8.1	—
9	38	33	9.6 ± 0.3	10	23	45.1 ± 6.9	—
10	40	35	10.5 ± 0.3	17	18	45.9 ± 6.9	—
11	26	23	11.5 ± 0.3	12	11	43.0 ± 5.6	—
12–13	38	31	12.9 ± 0.6	17	14	47.5 ± 6.5	—
14–17	38	32	15.6 ± 1.1	15	17	49.0 ± 8.6	—
18–25	27	22	20.3 ± 1.9	5	17	—	28.6 ± 4.5

Note. BAI–Y = Beck Anxiety Inventory for Youth; STICSA = State–Trait Inventory for Cognitive and Somatic Anxiety.

Table 2

Accuracy Scores (Percentage Hits) Obtained in the Recognition Task Questionnaire for Each Age Group and Emotion

Age (years)	Anger	Fear	Joy	Neutral	Surprise
7	63.04	53.26	98.55	75.36	55.07
8	74.91	70.65	100	84.06	71.01
9	76.76	75	98.99	92.93	59.70
10	81.43	73.33	98.10	93.33	67.62
11	86.96	81.52	100	97.10	63.77
12–13	85.48	79.03	100	91.40	67.72
14–17	85.94	86.72	97.92	92.71	62.62
Adults	85.49	86.72	97.92	92.92	85.78

Table 3

Pearson Correlations (Two-Tailed) Between the Gaze Orienting Effect (GOE) and Age, RME Z Scores and Anxiety for Each Emotion

Emotion GOE	Age	RME Z scores	Anxiety
Anger GOE	−.121	−.014 (.014)	.027 (−.024)
Fear GOE	−.266**	−.200** (−.149)	.075 (−.38)
Joy GOE	−.170*	−.161* (−.128)	.104 (.039)
Neutral GOE	−.197**	.002 (.049)	−.019 (−.111)
Surprise GOE	−.136**	−.029 (.002)	.05 (−.006)

Note. Partial correlations controlling for age are in parentheses. RME = Reading the Mind in the Eyes test.

* $p < .05$.

** $p < .01$.