Children's Increased Emotional Egocentricity Compared to Adults Is Mediated by Age-Related Differences in Conflict Processing

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This study investigated the cognitive mechanisms underlying age-related differences in emotional egocentricity bias (EEB) between children (aged 7–12 years, $n = 30$) and adults (aged 20–30 years, $n = 30$) using a novel paradigm of visuogustatory stimulation to induce pleasant and unpleasant emotions. Both children and adults showed an EBB, but that of children was larger. The EEB did not correlate with other measures of egocentricity. Crucially, the developmental differences in EEB were mediated by age-related changes in conflict processing and not visual perspective taking, response inhibition, or processing speed. This indicates that different types of egocentricity develop independently of one another and that the increased ability to overcome EEB can be explained by age-related improvements in conflict processing.

Human interpersonal understanding often relies on mechanisms of self-projection and simulation (e.g., Mitchell, 2009; Nickerson, 2001; Silani, Lamm, Ruff, & Singer, 2013; Van Boven & Loewenstein, 2003). These mechanisms, however, become inefficient as soon one's own mental state or internal experience differs from that of another person. For instance it would be erroneous to assume someone was happy while he clearly is sad just because we ourselves feel happy. The tendency to project one's own mental states onto others has been broadly termed as *egocentricity bias*. Early and seminal work in developmental psychology has looked at children's ability in taking visual perspectives of another person, reporting early egocentrism in development, one example being Piaget's famous "three mountains" task, in which children at the age of 7 exhibit difficulties judging someone else's visual perspective that differs from their own (Piaget & Inhelder, 1956). To date, egocentricity bias has thus been primarily investigated in visual perspective taking and theory of mind (ToM; Birch & Bloom, 2007; Flavell, Everett, Croft, & Flavell, 1981; Pronin, 2008; Royzman, Cassidy, & Baron, 2003; Thomas & Jacoby, 2012). Children generally exhibit stronger egocentricity during cognitive perspective taking and ToM tasks than adults. Before the age of 4 children have difficulties attributing false beliefs to other people, unable to detach from their own true beliefs (Wimmer & Perner, 1983). Also, throughout childhood, difficulties in cognitive perspective taking and ToM seem to persist (Apperly, Warren, Andrews, Grant, & Todd, 2011; Keysar, Lin, & Barr, 2003; Sommerville, Bernstein, & Meltzoff, 2013). While strong evidence for egocentricity in the cognitive domain in children as well as adults has accumulated over the past decades, very little research has focused on investigating egocentricity in the affective domain (see O'Brien & Ellsworth, 2012; Repacholi & Gopnik, 1997; Silani et al., 2013; Van Boven & Loewenstein, 2003) and only one study has so far looked specifically at emotional egocentricity in children (Steinbeis, Bernhardt, & Singer, 2014).

Egocentricity is a pervasive phenomenon throughout childhood, spanning moral judgments (e.g., Eisenberg et al., 1987), taking the visual perspective of others (e.g., Moll & Tomasello, 2006), and assuming others' mental states (e.g., Sommerville et al., 2013). However, whether egocentricity constitutes a unitary phenomenon in development and whether age-related changes in the extent of egocentricity undergo shared developmental trajectories remains unclear. Data from meta-analyses and neuroimaging findings in adults suggest in part that cognitive egocentricity and emotional egocentricity are dissociable at the neural level (Silani et al., 2013). Using visuotactile stimulation to induce pleasant and unpleasant emotional states in participants (emotional egocentricity bias [EEB] Touch-Paradigm [ETOP]), Silani et al. (2013)

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demonstrated that the right supramarginal (rSMG) is functionally implicated in overcoming EEB. Peaks of this activation were shown to be distinct from other subregions of the temporoparietal cortex involved in ToM and motor egocentricity. However, seeing that cognitive capacities and abilities are known to increasingly differentiate with development (e.g., Li et al., 2004), it remains unclear if these various types of egocentricity correlate in development or not. Shedding light on this question is crucial, given the high interpersonal costs associated with not fully comprehending another's point of view (Newcomb, Bukowski, & Pattee, 1993; Thompson & Loewenstein, 1992). Understanding the mechanisms that underlie the inability to overcome such egocentricity early in ontogeny seems an important endeavor as it can provide the basis for targeted interventions leading to greater prosociality early in development.

First attempts to uncover the developmental mechanisms that help to overcome EEB were recently made in a study (Steinbeis et al., 2014) using monetary reward and punishment to induce pleasant and unpleasant emotions in children and adults (EEB Monetary Game Paradigm [EMOP]). Children (aged 6–13) showed a significant EEB, which was significantly larger compared to that of adults. In line with the study by Silani et al. (2013), on the neuronal level children showed significantly less activation of the rSMG compared to adults when having to overcome EEB, as well as reduced coupling between the rSMG and the left dorsolateral prefrontal cortex (lDLPFC). In addition, children and adults also performed a belief and desire reasoning task, an attentional reorientation task, and a stop-signal reaction time task. None of these variables showed a relation with the EEB in children or adults. Thus, while prior work has shown that the EEB is larger in children compared to adults and provides a coherent account of the neural mechanisms leading to this developmental change, what is still missing and has not been addressed in previous studies is a systematic analysis of the exact cognitive and affective mechanisms that may account for observed age-related differences in the size of EEB during development.

In order to address this question, we developed a novel paradigm, the EEB Taste-Paradigm (ETAP) using visuogustatory stimulation in which participants are asked to judge the pleasantness of their own taste experiences or that of another person, while both can have congruent or incongruent taste experiences. Pilot work indicated that gustatory stimulation elicits equal feelings of pleasantness

and unpleasantness in children and adults, making it highly suited to study developmental differences in EEB as well as extending the phenomenon of EEB to another stimulus modality. As in the previous study (Steinbeis et al., 2014), we expected that children would show an increased EEB compared to adults. Overcoming such EEB presumably relies on a multitude of higher and lower level cognitive and affective processes. With the aim to comprehensively test for these possible processes underlying the developmental differences in EEB, we assessed them using a large battery of tasks. In the following, a more detailed description of reasons for investigating particular cognitive and affective processes in relation to EEB and developmental differences in EEB is given.

The EEB paradigm involves taking an emotional perspective of the other. In that process the role of the rSMG seems crucial in overcoming affective egocentricity, which has been interpreted as disambiguating emotional self and other perspectives (Silani et al., 2013; Steinbeis et al., 2014). As argued previously, it might therefore relate to other types of egocentricity. To explore this, we investigated visual perspective taking with a task more closely matched to the EEB paradigm involving incongruent and congruent self and other visual perspectives to measure cognitive egocentricity (see Surtees & Apperly, 2012).

The EEB paradigm also involves the inhibition of one's own conflicting emotional perspective to correctly judge the other person's emotional state. From the literature in the domain of cognitive perspective taking, such as ToM, it is known that inhibitory control plays a crucial role, in particular when there is a conflict between the self and other perspectives (Carlson & Moses, 2001; Friedman & Leslie, 2005; Hansen Lagattuta, Sayfan, & Harvey, 2013; Wellman, Cross, & Watson, 2001). Consequently, we included a Go/NoGo task measuring response inhibition; moreover, it is also known that inhibitory control improves throughout development (e.g., Luna, Garver, Urban, Lazar, & Sweeney, 2004; Williams, Ponesse, Schachar, Logan, & Tannock, 1999).

Another executive function that could potentially be an underlying mechanism of EEB and the developmental difference in EEB is conflict processing. The ability to resolve a conflict has been hypothesized to be a crucial process to overcome the EEB when emotional states of self and other are incongruent. It is also known that the ability to resolve conflict improves across development (e.g., Fjell et al., 2012) and could therefore account for developmental differences in EEB.

Another high-level cognitive-affective process of interest for this study was cognitive reappraisal as a form of emotion regulation (Gross, 2002). The ability to cognitively reappraise one's own emotion and subsequently downregulate the emotion might be crucial in overcoming EEB. Findings additionally suggest that children tend to be less efficient in cognitive reappraisal than adults (McRae et al., 2012; Pitskel, Bolling, Kaiser, Crowley, & Pelphrey, 2011).

One key process that the EEB might be explained by is attentional reorienting, something that has been consistently associated with the involvement of the rSMG (Carter & Huettel, 2013; Mars et al., 2012). So far, no association has been found between measures of attentional reorienting and the EEB either at the neural level or at the behavioral level (Silani et al., 2013; Steinbeis et al., 2014), and age-related changes in attentional reorienting could not account for the observed developmental differences in the EEB (Steinbeis et al., 2014). Given the differences between the paradigms used to induce the EEB (primary sensory information vs. abstract monetary rewards and punishments in Steinbeis et al., 2014), we still included an attentional reorienting task, also with the aim to further the evidence of the EEB's independence of attentional reorienting.

Finally, we also investigated general perceptual speed and its relation to overcoming emotional egocentricity in children and adults. Perceptual speed can be seen as a very low-level process that could underlie the EEB and its developmental difference between children and adults, especially as it has been known to improve continuously throughout development (Kail, 1991; Luna et al., 2004).

In sum, we comprehensively tested various cognitive, attentional, socioaffective abilities, namely, visual perspective taking, response inhibition, conflict processing, emotion regulation, attentional reorienting, and processing speed, with the aim of systematically elucidating the exact affective and cognitive mechanisms that underlie age-related differences observed in the EEB between children and adults.

Method

Children and adults were invited for three experimental sessions. The first session involved a screening, in which the most pleasant, unpleasant, and neutral liquids for each participant were selected. In the second session, children and adults performed the ETAP. In the last session, children and adults performed a battery of tests assessing different cognitive and affective abilities. The order of the tasks in the last session was counterbalanced across subjects.

Participants

Thirty children (15 female; $M_{age} = 9.50$, range = 7–12) and adults (15 female; $M_{age} = 24.10$, range = 20–30) took part in the study. Children and adults were recruited from databases at the Max Planck Institute for Human Cognitive and Brain Sciences. Participants were predominantly White Caucasian. All children were developing normally. All participants gave informed consent (parental consent in case of the children) and the study was approved by the ethics committees of the University of Leipzig (Nr. 381-11-12122011). One child and one adult could not be invited for the third session.

First Session

Screening

In a screening, participants were asked to rate different liquids and solutions according to their intensity and pleasantness. Participants were screened for their taste sensitivity using a Labeled Magnitude Scale (LMS; Green et al., 1996) in order to exclude possible "super/nontasters" (e.g., Small et al., 2003). On the LMS, perceived taste intensity ranged from 0 (*barely detectable*) to 100 (*strongest imaginable*). Only participants in the normal range of tasting for glucose and quinine/NaCl solution (1 mol) participated in the study. The normal taste range for glucose was defined as lying between 15 and 75, for quinine and NaCl solutions between 30 and 75 (see also Jabbi, Swart, & Keysers, 2007). For each participant, the two most pleasant, the two most unpleasant, and the two most neutral stimuli were selected and used for the later experiment to guarantee the most effective induction of emotions in participants. As pleasant tastes, a sugar solution (1 mol glucose) and three different juices (apple/Samanta, orange/Samanta, grape/albi) were used. For unpleasant tastes, three salty solutions (NaCl) of varying concentrations of 0.1, 0.5, and 1 mol (e.g., O'Doherty, Rolls, Francis, Bowtell, & McGlone, 2001) and a quinine solution (0.25 mM) were used. For neutral tastes, tasteless solutions with the main ionic components of saliva (consisting of 25 mM KCl and 2.5 mM NaHCO$_3$) were used, diluted with various amounts of water (20%, 40%, 60%, and 80%).

Second Session

Stimuli and Apparatus

For the experimental session, the different tastes were presented with a custom-built pump system specifically designed for this study via several small plastic tubes (diameter = 0.3 cm), which merged together at the end into a mouthpiece with small bundled tubes (diameter = 0.1 cm). The mouthpiece was comfortably placed in the mouth of the participants with the help of a holder to which the tubes were attached so that both hands of the participants were free and able to navigate the touch screen (1,920 × 1,080 pixels resolution, 19-in. screen, viewing distance ~40 cm). The pump system was operated by a Presentation script via a USB connection and was set up to always pump the same amount of liquid in the same time through the tubes (0.5 ml per 0.5 s).

EEB Taste-Paradigm

The design and procedure of this study was similar to a previous study using the ETOP (Silani et al., 2013). Participants of the same gender, unknown to each other, were assigned pairwise to an experimental session. They sat back to back in front of a touch screen unable to see the other person's face and emotion judgments, with the taste tubes comfortably placed in their mouth. This meant that any influence of the other participant's actual emotional state could not have any influence on ratings, as the emotion judgment was exclusively made through the visual cue of what the other was currently experiencing. Before the start of the experiment, participants were familiarized with the rating scale and performed 10 practice trials for each condition. Participants started with the individual conditions in which they were instructed to either judge the pleasantness of their own taste experience or judge the pleasantness of the taste experience for the other person (blocked design). In the individual self condition, 500 ms before the taste stimulation, a picture (size 500 × 400 pixels) corresponding to the specific taste (i.e., a picture of a glass of orange juice when the participant received orange juice) appeared on the screen and remained there until the end of the taste stimulation that lasted 1,500 ms. Immediately after the end of the tasting phase, participants had to judge the experienced pleasantness or unpleasantness of the taste by using a rating scale (ranging from −10 to +10) on the touch screen, within 1,500-ms response time (RT). After the emotion judgment, a picture

with a water drop appeared on the screen and water was pumped simultaneously through a tube for a rinse. The rinse lasted for 2,000 ms followed by an instruction to swallow (1,000 ms) and a fixation cross (2,000 ms). In the individual other condition, the trial structure remained the same, but with the important difference that the participant did not receive any taste stimuli and was instead instructed to judge the pleasantness or unpleasantness of the taste experience for the other participant also present in the room based on the picture that indicated what taste the other person received. Each run for adults consisted of 30 pseudorandomized trials, with 10 pleasant, 10 neutral, and 10 unpleasant visuogustatory stimuli. Each run for children consisted of 18 pseudorandomized trials, with 6 pleasant, 6 neutral, and 6 unpleasant visuogustatory stimuli. For the individual conditions, this resulted in a three-factorial mixed design with the two within-group factors *target* (self, other judgment) and *valence* (pleasant, neutral, and unpleasant stimulation) and the between-group factor *age group* (children and adults).

The individual conditions were followed by the simultaneous conditions. In these simultaneous conditions both participants in the room received taste stimuli simultaneously and were instructed to either judge the pleasantness of their own taste experience (simultaneous self condition) or judge the pleasantness of the taste experience for the other person (simultaneous other condition). The simultaneous self and simultaneous other conditions were blocked and counterbalanced. In these conditions two pictures appeared on the screen. The left picture was labeled "Self" on the top and corresponded to the taste the participant received, while the right picture labeled "Other" corresponded to the taste the other person received. The taste experiences of the two participants could be either affectively congruent (e.g., both receive positive tastes) or incongruent (e.g., one receives positive, the other negative taste). The EEB was defined as the difference between ratings in incongruent and congruent trials when judging the other, as compared to the difference when judging one's own feelings. Importantly for the simultaneous conditions, the self judgment therefore was used as a control for general perceptual or cognitive confounds—such as visual and affective stimulus comparison, detection of incongruency, or overcoming general response conflict. In the simultaneous conditions for adults, each run consisted of 40 pseudorandomized trials, with 20 pleasant (10 congruent and 10 incongruent) and 20 unpleasant (10

congruent and 10 incongruent) visuogustatory stimuli. For the simultaneous conditions for children, each run consisted of 24 pseudorandomized trials, with 12 pleasant (6 congruent and 6 incongruent) and 12 unpleasant (6 congruent and 6 incongruent) visuogustatory stimuli. Simultaneous conditions were blocked according to target, so that half the participants started with the self judgment and half of the participants started with the other judgment.

This resulted in a four-factorial mixed design with the three within-group factors *target* (self, other judgment), *valence* (pleasant, unpleasant stimulation), and *congruence* (congruent, incongruent stimulation of participant and other) and the between-group factor *age group* (children and adults). Data analysis was performed using the IBM SPSS statistics software, version 19.0 (IBM, Armonk, NY).

Third Session

Visual Perspective Taking

To assess children's and adults' visual perspective-taking abilities we used an established paradigm shown to work well for both children and adults (for details, see Surtees & Apperly, 2012). In this paradigm, participants heard instructions while they viewed a cartoon avatar standing in a cartoon room with dots on the wall. The auditory stimulus asked them to judge how many dots they perceive (self condition) or how many dots the avatar perceives (other condition). The participants then had to respond with the appropriate key with "yes" or "no" (see Surtees & Apperly, 2012). Self trials as well as other trials could be either consistent or inconsistent depending on whether both participant and avatar saw the same number of dots or not. A possible "egocentric" interference would be described as an increase in RT and error rate for participants' judgments on inconsistent other trials compared to consistent other trials (Surtees & Apperly, 2012). One adult participant had to be excluded from the analysis, as he clearly misunderstood the task.

Inhibitory Control

Inhibitory control in children and adults was assessed with two different Go/NoGo tasks. An emotional Go/NoGo task that used happy and fearful face stimuli as Go and NoGo stimuli (for details, see Hare et al., 2008), as well as a normal Go/NoGo task (same design) using a blue square

as a Go stimuli and a red square as a NoGo stimuli (intertrial intervals: 1,000, 1,500, 2,000, 2,500, and 3,000 ms). In these tasks participants had to respond quickly with a button-press to the presentation of Go stimuli, while withholding a response to the presentation of NoGo stimuli. Response inhibition was measured by the ability to inhibit the response to NoGo stimuli. d-prime scores for both Go/NoGo tasks were calculated as a measure of response sensitivity: $d' = Z$ (hit rate) $- Z$ (false alarm rate).

Conflict Processing

To assess conflict processing, participants performed a Flanker task using emotional faces (e.g., Fenske & Eastwood, 2003). Participants had to respond as quickly as possible with their right index and middle fingers using the arrow buttons on the keyboard to happy and angry target faces (NimStim faces; Tottenham et al., 2009), which were presented in the center of the screen (picture size: 101×130 pixels). These target faces were flanked by eight distractor faces (picture size: 101×130 pixels) that were either all identical or opposite in their emotion displayed relative to the target face. The distractor faces appeared directly around the target faces in angles of 0, 45, 90, 135, 180, 225, 270, and 315°, building in total a 3×3 grid with the target faces perfectly adjacent directly in the center of the grid. A trial was considered to be compatible if the target face was flanked by identical faces portraying the same emotion and considered incompatible if the target was flanked by affectively opposite but same identity faces. The eight distractor faces preceded the target face (100, 200, or 300 ms), and remained on the screen together with the target until a response was given (1,000 ms). Trials were always followed by a random intertrial interval (500, 1,000, 1,500 ms). In total, there were 96 trials, 48 compatible trials and 48 incompatible trials (24 happy and 24 angry targets). The trial order was randomized for each participant. All participants were instructed to respond as quickly as possible. An increase in RT (on correct trials) and error rates in incompatible compared to compatible trials indicates a so-called flanker compatibility effect (Eriksen & Eriksen, 1974).

Emotion Regulation

We specifically developed a new task in which participants were instructed to regulate their own taste experiences. To most closely match the

demands of the emotion regulation task to the demands of the ETAP, the same tastes and the same taste pictures were used, as well as the same length of taste stimulation. Participants were instructed to either taste the liquids normally or to reappraise their taste experience as weaker and less strong (taste or regulate), which was indicated by a picture cue remaining on the screen for 4,000 ms (e.g., Pitskel et al., 2011). This was followed by a gustatory stimulation of 1,500 ms. Afterward, participants judged the pleasantness or unpleasantness of the taste by tapping on a rating scale (ranging from −10 to 10) on the touch screen, within 4,000 ms RT. Afterward, an instruction to relax appeared on the screen for 3,000 ms, followed by an intertrial interval of 2,000 ms. The experiment consisted of 10 reappraising trials (5 positive, 5 negative), and 20 normal taste trials (5 positive, 5 negative, 10 neutral) in a pseudorandom order. If participants seemed to use other strategies (distraction, suppression) during the training, they were informed about it and instructed to use reappraising strategies instead.

Attentional Reorienting

Attentional reorienting was assessed using the "attentional cueing" paradigm (for details, see Mitchell, 2008). In this task participants were instructed to indicate by pressing the left or right arrow key on the keyboard, the location of a visual target stimulus on the left or the right side of the computer screen. The location of the visual target was either congruent or incongruent to a preceding arrow pointing to the left or to the right. Typically, RTs and error rates have been shown to be increased in the incongruent condition compared to the congruent condition (Mitchell, 2008). Because of a technical problem, data from one adult could not be obtained.

Processing Speed

To assess processing speed, children and adults performed a reaction time task (for details, see Deary, Der, & Ford, 2001). For simple reaction time a gray square appeared on the screen and participants had to press the corresponding button (gray button) with their index finger. For the four-choice reaction time participants rested the second and third finger of each hand on the colored keys (pink, brown, red, and blue) and pressed the corresponding button when a colored square appeared on the screen. Because of technical problems, data from five children could not be obtained.

Results

EEB Taste-Paradigm

Individual Conditions

Ratings. To investigate any group differences in the individual conditions, an analysis of variance (ANOVA) on the affective ratings with target and valance as within-subjects factors, and age group as between-subjects factor was performed. The results revealed no significant main effect of group and no significant interactions of Target × Group, Valence × Group, or Target × Valence × Group ($Fs < 1.798$, $ps > .170$). There was a significant main effect of valence, $F(1, 58) = 429.676$, $p < .001$, $\eta_p^2 = .881$, but no significant main effect of target, or significant interaction of Target × Valence ($Fs < 2.836$, $ps > .098$) indicating that the emotion induction by means of visuogustatory stimulation was equally effective for both groups of participants.

Simultaneous Conditions

Ratings. To investigate whether children would display a significantly greater EEB than adults, an ANOVA on the affective ratings with target, congruency, and valence as within-subjects factors and age group as between-subjects factor was performed. The results showed that there was no main effect of age group, $F(1, 58) = 1.442$, $p = .235$, $\eta_p^2 = .024$. However, there were significant interactions of target and age group, $F(1, 58) = 5.597$, $p < .05$, $\eta_p^2 = .088$, and valence and age group, $F(1, 58) = 5.170$, $p < .05$, $\eta_p^2 = .082$. Most importantly, children showed a significantly larger emotional egocentricity than adults as shown by the triple interaction of target, congruency, and age group, $F(1, 58) = 4.553$, $p = .037$, $\eta_p^2 = .073$. The EEB was defined as the difference between ratings in incongruent and congruent trials when judging the other, as compared to the difference when judging one's own feelings and calculated accordingly. In fact, the children's EEB was 2.09 times larger than that of the adults (Figure 1). Furthermore, within the group of children the EEB decreased significantly (one-tailed) with age, $r = -.335$, $p = .035$, meaning the older the children were the smaller their emotional egocentricity was.

The results in the children sample revealed main effects of target, $F(1, 29) = 12.727$, $p < .01$, $\eta_p^2 = .305$, and congruency, $F(1, 29) = 6.103$, $p < .05$, $\eta_p^2 = .174$. There was no main effect of valence, $F(1, 29) = 0.137$, $p = .714$, $\eta_p^2 = .005$ (Figure 2a). Children displayed significant emotional egocentricity
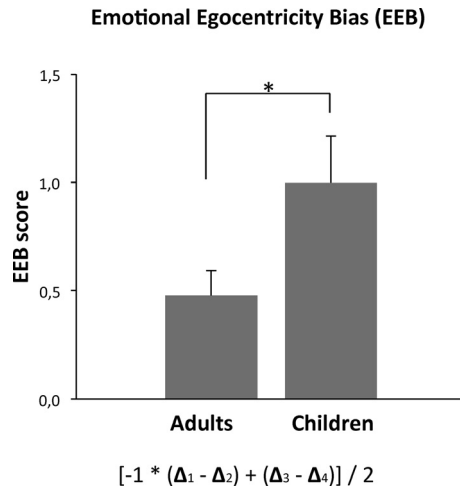
Emotional Egocentricity Bias (EEB)

Figure 1. Emotional egocentricity bias (EEB; *mean* + standard error) is pooled across pleasant and unpleasant judgments for both children and adults. For descriptive purposes, EEB was explicitly calculated by subtracting other-related emotion judgments (run "other judgment") during congruent trials from other-related judgments during incongruent trials. From this, as a control, we subtracted the differences between congruent and incongruent trials in the "self judgment" run. Whereas both adults and children show a significant EEB, children's EEB is significantly larger and more than double the size of the adults.

as indicated by the significant target and congruency interaction, $F(1, 29) = 21.608$, $p < .0001$, $\eta_p^2 = .427$, showing that the congruency effect was larger when rating the other compared to rating the self. This observed effect in children was 1.2 times larger than in a previous study ($\eta_p^2 = .427$ vs. $\eta_p^2 = .345$ in Steinbeis et al., 2014). There were no further significant interactions between the variables ($Fs < 2.219$, $ps > .147$). The results in the adult sample revealed main effects of valence, $F(1, 29) = 17.646$, $p < .0001$, $\eta_p^2 = .378$, and congruency, $F(1, 29) = 5.980$, $p < .05$, $\eta_p^2 = .171$. There was no main effect of target, $F(1, 29) = 0.206$, $p = .653$, $\eta_p^2 = .007$. Adults displayed significant emotional egocentricity as indicated by a significant target and congruency interaction, $F(1, 29) = 17.346$, $p < .001$, $\eta_p^2 = .373$ (Figure 2b). This observed effect in adults was 5.1 times larger than in a previous study ($\eta_p^2 = .373$ vs. $\eta_p^2 = .074$ in Silani et al., 2013), which speaks to the suitability of visuogustatory stimulation to induce a strong EEB. There were no further interactions between the variables ($Fs < 0.580$, $ps > .453$).

We also tested whether differences in processing speed of emotional incongruence between children and adults could influence differences in EEB. For this, we computed an EEB from the RTs of the simultaneous conditions (computed as the EEB for

the ratings) and used it as a covariate. The results, however, showed that the interaction of target, congruency, and age group remained significant, $F(1, 57) = 5.018$, $p = .029$, $\eta_p^2 = .081$. Similarly, differences in EEB between children and adults could be due to differences in emotion intensity perception. We therefore looked at whether the single self intensity rating (average of positive and negative ratings for self) has any significant influence on the difference in EEB between the two age groups and included it as a covariate. The interaction of target, congruency, and age group remained significant, $F(1, 57) = 3.922$, $p = .026$, $\eta_p^2 = .064$ (one-tailed). These results show that neither differences in processing speed of emotional incongruence nor differences in emotion intensity perception between children and adults can explain the larger EEB in children.

Assessment of Cognitive and Affective Mechanisms

The following describes the results for the tasks performed by children and adults in the third session. First, possible age group differences are reported looking at the interactions with age group, and then main effects of the tasks for children and adults separately. Second, correlations of the different cognitive and affective processes with the EEB are reported first for children and adults separately, and then over the total sample.

Visual Perspective Taking

To specifically investigate egocentricity in visual perspective taking, analyses were performed on error percentages and RTs for other perspective judgments only.

Error percentages. Looking at age group differences, children showed a stronger egocentric interference as indicated by a significant Consistency × Age Group interaction, $F(1, 55) = 4.625$, $p < .05$, $\eta_p^2 = .078$. These results suggest that children show an increased egocentricity in visual perspective taking compared to adults. For children a significant main effect of consistency emerged, $F(1, 28) = 19.054$, $p < .001$, $\eta_p^2 = .405$, indicating that children showed significant egocentricity during visual perspective taking. Also for adults a significant main effect of consistency emerged, $F(1, 27) = 15.783$, $p < .001$, $\eta_p^2 = .369$, indicating that adults showed significant egocentricity during visual perspective taking.

Response times. Looking at age group differences, children showed a stronger egocentric interference
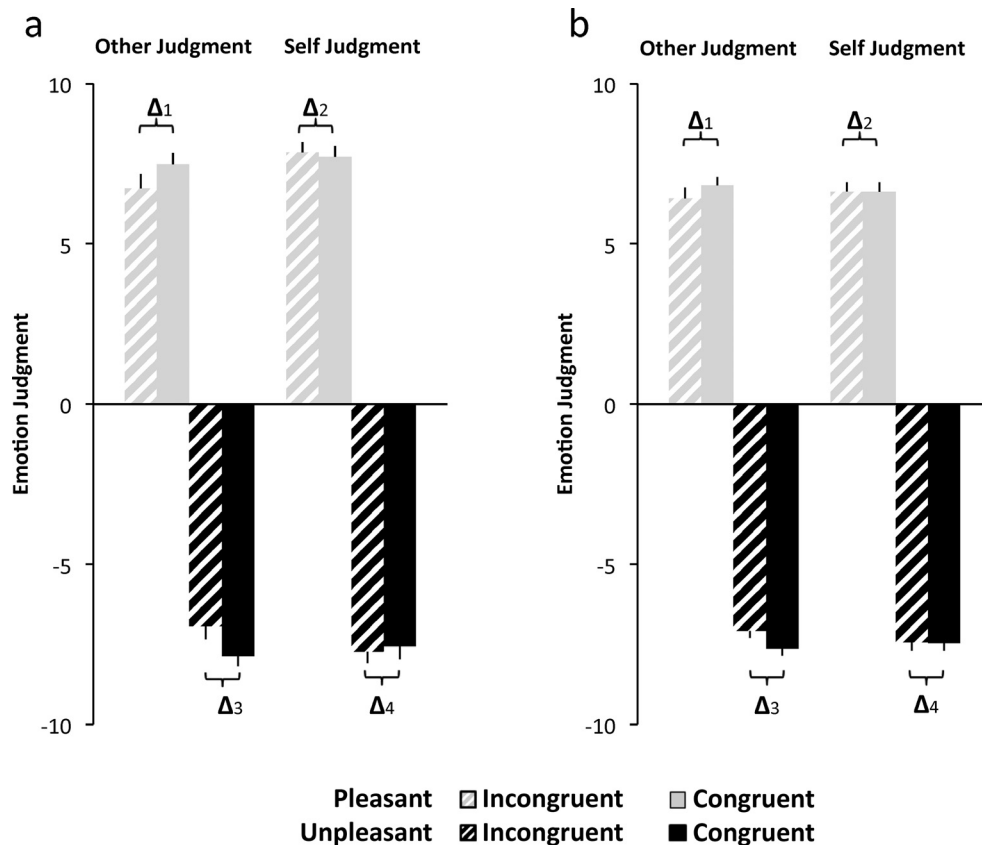
Figure 2. (a) Children's and (b) adults' emotion judgments (mean + standard error) during the *simultaneous conditions* are plotted for each condition of the factorial design.

as indicated by a marginally significant Consistency × Age Group interaction, $F(1, 55) = 3.970$, $p = .051$, $\eta_p^2 = .067$. For children a significant main effect of consistency emerged, $F(1, 28) = 56.806$, $p < .001$, $\eta_p^2 = .670$, indicating that children showed significant egocentricity during visual perspective taking. Also for adults a significant main effect of consistency emerged, $F(1, 27) = 71.810$, $p < .001$, $\eta_p^2 = .727$, indicating that adults showed significant egocentricity during visual perspective taking.

Differences in RTs and error percentages between inconsistent other and consistent other conditions were computed as measures of cognitive egocentricity. In both cases, larger difference scores indicated greater incongruency costs, therefore greater egocentricity. There was no significant relation between cognitive egocentricity and the EEB for children (RTs: $r = .099$, $p = .608$; error percentage: $r = -.145$, $p = .453$) or for adults (RTs: $r = -.055$, $p = .780$; error percentage: $r = -.106$, $p = .591$), or for the total sample (RTs: $r = .122$, $p = .368$; error percentage: $r = -.056$, $p = .675$).

Inhibitory Control

For the emotional Go/NoGo d-prime score the two different d-prime scores for the emotional target conditions were averaged together as no significant differences were found between response inhibition toward happy and toward fearful targets. Larger d-prime scores indicated greater response sensitivity. To investigate differences in inhibitory control, independent sample t tests were performed on the d-prime measures. Adults showed significantly greater d-prime scores for the emotional Go/NoGo, $t(56) = 6.414$, $p < .001$, as well as for the normal Go/NoGo, $t(56) = 10.255$, $p < .001$. These results showed that adults exhibited significantly better response inhibition compared to children.

There was no significant relation between response inhibition and the EEB for children. This was the case for the emotional Go/NoGo ($r = -.207$, $p = .281$) as well as for the normal Go/NoGo ($r = -.113$, $p = .560$). For adults there was also no relation between response inhibition on the

emotional Go/NoGo ($r = -.098$, $p = .612$) and on the normal Go/NoGo ($r = .030$, $p = .879$) and the EEB. Over the total sample, however, there was a significant negative correlation of response inhibition and the EEB on the emotional Go/NoGo ($r = -.269$, $p = .041$) and a marginally significant negative correlation on the normal Go/NoGo ($r = -.246$, $p = .063$), indicating that with decreasing ability in response inhibition the EEB tends to increase.

Conflict Processing

Error percentages. Looking at age group differences there was a significant main effect of age group, $F(1, 56) = 17.339$, $p < .001$, $\eta_p^2 = .237$. Additionally, there was a significant interaction of Compatibility × Age Group, $F(1, 56) = 4.266$, $p < .05$, $\eta_p^2 = .071$. There were no further interactions with age group and target, and age group and target and compatibility ($Fs < 0.091$, $ps > .764$). These results indicate that children show a greater compatibility effect than adults, pointing toward greater difficulties in conflict processing. For children there was a significant flanker compatibility effect, $F(1, 28) = 5.081$, $p < .05$, $\eta_p^2 = .154$, and no significant main effect of target face or Target Face × Compatibility interaction ($Fs < 0.692$, $ps > .412$). For adults there was no significant flanker compatibility effect, $F(1, 28) = 0.032$, $p = .859$, $\eta_p^2 = .001$, and no significant main effect of target face and no significant Target Face × Compatibility interaction ($Fs < 2.449$, $ps > .129$).

Response times. Regarding age group differences on RTs during correct trials there was a significant main effect of age group, $F(1, 56) = 15.390$, $p < .001$, $\eta_p^2 = .216$, and a marginally significant interaction of Compatibility × Age Group, $F(1, 56) = 3.860$, $p = .054$, $\eta_p^2 = .064$. There were no further interactions with group and target, and group and target and compatibility ($Fs < 1.479$, $ps > .229$). These results suggest that children did indeed show more difficulties in conflict processing, showing greater compatibility effects in error percentages and also a tendency toward greater compatibility effects in RTs. For children there was a significant flanker compatibility effect, $F(1, 28) = 26.293$, $p < .001$, $\eta_p^2 = .484$; a significant main effect of target face, $F(1, 28) = 7.141$, $p < .05$, $\eta_p^2 = .203$; but no significant Target Face × Compatibility interaction, $F(1, 28) = 1.838$, $p = .186$, $\eta_p^2 = .062$. Children showed significantly faster responses for happy target faces. For adults there was a significant flanker compatibility effect, $F(1, 28) = 17.634$, $p < .001$, $\eta_p^2 = .386$,

but no main effect of target and no significant Target Face × Compatibility interaction ($Fs < 3.600$, $ps > .068$).

A difference in error percentages between incompatible and compatible flanker conditions was computed as a measure of conflict processing. A larger difference score indicated greater compatibility effects, therefore less efficient conflict processing. There was a significant relation between conflict processing and the EEB for children ($r = .387$, $p < .05$) but not for adults ($r = .031$, $p = .871$). Furthermore, there was a significant positive relation between conflict processing and the EEB over the total sample ($r = .373$, $p < .005$). This significant association between conflict processing and the EEB remained even after controlling for response inhibition as measured by the Go/NoGo tasks.

Emotion Regulation

Looking at age group differences there was no significant Condition × Age Group interaction, $F(1, 56) = 0.606$, $p = .404$, $\eta_p^2 = .011$, and no further significant effects with age group ($Fs > 0.398$, $ps > .531$). These results suggest that children and adults reappraised their taste experiences equally well in this novel emotion regulation task. There was a significant effect of condition for children, $F(1, 28) = 57.202$, $p < .01$, $\eta_p^2 = .671$, as well as for adults, $F(1, 28) = 98.454$, $p < .01$, $\eta_p^2 = .779$. There was no significant main effect of emotion ($Fs < 1.614$, $ps > .210$) and no significant interaction of Emotion × Condition for children and adults ($Fs < 1.047$, $ps > .315$). These results indicate that children and adults were successful at reappraising their taste experiences and were so equally well for negative and positive tastes.

A reappraisal score was computed as a measure of emotion regulation success (difference between ratings in the taste condition and the regulate condition). Larger scores indicated higher reappraisal ability. There was no significant relation between reappraisal ability and the EEB for children ($r = -.123$, $p = .529$) or for adults ($r = .166$, $p = .389$) or for the total sample ($r = -.023$, $p = .867$).

Attentional Reorienting

Looking at age group differences for error percentages as well as RTs, there was no Congruency × Age Group interaction ($Fs < 1.840$, $ps > .181$).

For RTs there was a significant main effect of congruency for children, $F(1, 28) = 6.151$, $p < .05$, $\eta_p^2 = .180$, and a marginally significant one for

adults, $F(1, 27) = 4.059$, $p = .054$, $\eta_p^2 = .131$. For both groups no congruency effects were found for error percentages ($Fs < 1.331$, $ps > .259$).

A difference score on the RTs was computed as a measure of incongruency cost during attentional reorienting (RT incongruent − RT congruent). Larger scores indicated greater incongruency cost. There was no significant relation between attentional reorienting and the EEB for children ($r = -.129$, $p = .503$) or for adults ($r = .134$, $p = .495$). There was also no relation between attentional reorienting and the EEB over the total sample ($r = -.031$, $p = .822$).

Processing Speed

Looking at age group differences results revealed a significant main effect of age group, $F(1, 51) = 13.492$, $p < .01$, $\eta_p^2 = .213$, but no significant Condition × Age Group interaction, $F(1, 51) = 0.185$, $p = .669$, $\eta_p^2 = .004$. There was a significant main effect of condition for children, $F(1, 23) = 59.025$, $p < .001$, $\eta_p^2 = .729$, and adults, $F(1, 28) = 637.761$, $p < .001$, $\eta_p^2 = .958$. These results indicated, as expected, that for the four-choice the RTs were significantly larger for children as well as adults.

A reaction time average of the one-choice and the four-choice reaction time task was computed as a general measure of processing speed. There was a significant relation between processing speed and EEB for adults ($r = .424$, $p = .022$), no such relation for children ($r = .104$, $p = .629$), but a significant relation between processing speed and the EEB over the total sample ($r = .310$, $p = .024$).

Multiple Regression Analysis

To further investigate which of the cognitive and affective measures uniquely account for individual differences in the EEB, we performed a stepwise multiple regression over the total sample including all cognitive and affective measures. The result indicated that conflict processing significantly predicted the EEB crucially explaining a unique variance of the size in EEB, $F(1, 50) = 6.491$, $p < .05$, adjusted $R^2 = .342$.

Mediation Analysis

To investigate whether the observed developmental effects in EEB could be accounted for by age-related differences in other cognitive functions, we performed a mediation analysis. According to Baron and Kenny (1986), three criteria have to be fulfilled for a mediation analysis: (a) the causal variable (in this case age group) has to be related to the outcome (in this case the EEB), (b) the causal variable has to correlate with the mediator, and (c) the mediator has to have an effect on the outcome variable. Having tested seven additional tasks to investigate the possible associations between different cognitive functions and the EEB, we first corrected for multiple comparisons using a Bonferroni correction. Conflict processing emerged as the only other cognitive function that demonstrated robust differences between age groups, as well as a significant correlation with the EEB, that survived at the new alpha level of $p = .0071$. We therefore tested whether the observed age effects in the EEB would be mediated by differences in conflict processing. To do so, we conducted a mediation analysis where age was the predictor, conflict processing (error percentage) the mediator, and EEB the outcome variable. Analyses were conducted using bootstrapping procedures recommended for smaller samples and dichotomous predictor variables (in this case age group) and operationalized in an SPSS Macro (Preacher & Hayes, 2008). We used 5,000 bootstrap resamples of the data with replacement. Statistical significance with alpha at .05 is indicated by the 95% confidence intervals not crossing zero.

We found a significant mediation effect of conflict processing with respect to the relation between age and the EEB (indirect effect = 1.69, $SE = 1.04$, 95% CI = [.23, 4.16]; see Figure 3). In addition, this mediation was total, meaning that children's ability to solve conflict accounted solely for the age differences, as the direct effect of age did not significantly predict the EEB.

Discussion

By using the novel ETAP based on visuogustatory stimulation to induce EEB, this study investigated developmental differences in the EEB between children and adults and their underlying cognitive mechanism. As compared to previous studies using either a visuotouch (ETOP; Silani et al., 2013) or an EMOP (Steinbeis et al., 2014) to induce EEB, using taste allowed us for the first time to elicit strong enough positive and negative emotions and thus a robust EEB in children as well as in adults with the same paradigm. Furthermore, the observed effects in adults as well as in children were much larger than in previous studies (Silani et al., 2013; Steinbeis et al., 2014), which speak for the suitability of visuogustatory stimulation and the new ETAP for the investigation of the EEB. As hypothesized,

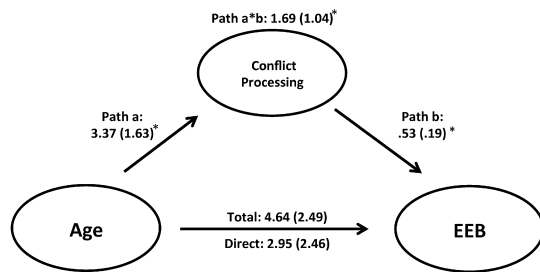**Mediation Model for the Effect of Age on EEB via Conflict Processing**

Figure 3. Display of the mediation model with emotional ego-centricity bias (EEB) as outcome variable, age as independent variable, and conflict processing as mediator variable. Values are unstandardized regression coefficients. There was a significant mediation effect of conflict processing with respect to the relation between age and the EEB.
*$p < .05$

children between the ages of 7 and 12 showed a significantly larger EEB compared to adults, which was double in size. Additionally, in line with previous findings (Steinbeis et al., 2014), the EEB decreased within the children sample from ages 7 to 12. Developmental differences between children and adults were found in processing speed, visual perspective taking, inhibitory control, and conflict processing but not for attentional reorienting and emotion regulation. Importantly, only conflict processing and none of the other cognitive and affective abilities showed a robust association with individual differences in the EEB. Indeed conflict processing was the only one of the many cognitive and affective functions assessed that mediated the developmental differences observed in EEB between children and adults. This suggests that children's difficulty in overcoming the EEB seems to be best explained by their difficulties in conflict processing.

While conflicting information is present in both the incongruent other and the incongruent self condition of the ETAP, the response conflict is much larger when one has to take the perspective of another person that is incongruent to one's own than if one has to rate his or her own states even if these are incongruent to what the other is feeling. In the incongruent other condition the immediate emotional experience of the self seems to be more difficult to disregard than the more abstract notion of the other's emotional state conveyed by the picture in the incongruent self condition. Children's difficulties in conflict processing have been previously reported and it is assumed that conflict processing relevant brain regions such as the dorsal

anterior cingulate cortex and DLPFC develop throughout childhood into early adulthood (e.g., Fjell et al., 2012; Steinbeis, Bernhardt, & Singer, 2012). Although we have no direct evidence, we propose that it is in particular the process of conflict resolution that plays a functional and critical role in overcoming emotional egocentricity. In support of this claim, the DLPFC in particular has been interpreted to play an important role in the resolution of conflict (Badre & Wagner, 2004; Chen, Wei, & Zhou, 2006; Egner & Hirsch, 2005; Kim, Kroger, & Kim, 2011), while also showing protracted maturation (Gogtay et al., 2004; Shaw et al., 2008; Sowell et al., 2003). Consequently, the previously mentioned crucial involvement of lDLPFC in overcoming EEB (Steinbeis et al., 2014) might be related to the underlying mechanism of conflict processing (resolution of conflict in particular), as identified in this study. It might be therefore suggested that lDLPFC communicates with rSMG, which disambiguates emotional self and other perspectives, and engages in conflict resolution to overcome EEB to arrive at an accurate empathic judgment of the others' emotional state. Ongoing maturational processes in both the lDLPFC and rSMG as well as their neuronal connections seem to make children more prone to an increased EEB compared to adults. It has to be noted that even though there is already some strong evidence to assume that a similar set of brain regions is recruited in the context of overcoming the EEB, whether this also holds for the present paradigm remains to be seen. Taken together, in ascribing the specific functional role of conflict resolution to lDLPFC in overcoming EEB, this study not only provides an underlying mechanism explaining age-related differences in EEB but also relates it to a specific neuronal architecture, meaningfully tying together behavioral and neuroimaging findings. Even further, as empathic abilities have been linked to prosocial behaviors (Batson & Shaw, 1991; Eisenberg, 2000; Eisenberg et al., 1989; Hein, Lamm, Brodbeck, & Singer, 2011; Hein, Silani, Preuschoff, Batson, & Singer, 2010), the identification of conflict processing as an underlying mechanism of developmental differences in EEB could possibly inform targeted interventions, leading to greater prosociality early in development by increasing the accuracy of empathic judgments in children.

In identifying conflict processing as an underlying mechanism of developmental differences in EEB, the question arises to what degree it is in particular children's ability to resolve an emotional conflict as compared to a nonemotional conflict

during the ETOP. The conflict processing task in this study used emotional stimuli, so it can be argued that this task not only measures conflict processing per se but even beyond that measures emotional conflict processing. Previous research has shown that solving emotional conflicts versus non-emotional conflicts recruits very specific brain regions (Egner, Etkin, Gale, & Hirsch, 2008; Etkin, Egner, Peraza, Kandel, & Hirsch, 2006). In the case of this study, the emotional Go/NoGo task and nonemotional Go/NoGo task, while equivalent in design, did not correlate very highly ($r = .557$, $p < .001$) over the total sample, indicating that the affective aspects of the task are not totally accounted for by a general cognitive process. In sum, it can be argued that for children it might be in particular their ability to resolve emotional conflicts that helps them to decrease their emotional egocentricity; however, further research is needed to clarify this point, using emotional and nonemotional conflict processing tasks. In this study, no significant compatibility effect was found for error rates in adults on the Flanker task. One plausible explanation could be a ceiling effect in performance, as adults are very good at resolving conflict, as also the low error rates for adults during incongruent trials in this study suggest.

Another important question of this study was whether egocentricity constitutes a unitary phenomenon in development and whether age-related changes in the extent of egocentricity undergo shared developmental trajectories. Interestingly, this study did not find any evidence for a relation between the EEB and visual perspective taking. Similar to ToM, visual perspective taking has been associated with functioning of the right temporo-parietal junction (rTPJ) and not the rSMG (e.g., Ramsey, Hansen, Apperly, & Samson, 2013). Visual perspective taking was investigated using a previously established paradigm (Surtees & Apperly, 2012) in order to search for possible commonalities with the EEB. Visual perspective taking, especially Level 2 perspective taking, has been found to be related to ToM (e.g., Hamilton, Brindley, & Frith, 2009), and as this paradigm also included a conflicting self and other perspectives, it was very similar in demands to the ETAP and therefore a good comparison task. While developmental differences in visual perspective taking were indeed observed, with children committing more egocentric errors and showing higher incongruency costs in reaction times as adults, these age-related differences were however unrelated to individual differences in the size of the EEB. This means that, for example, chil-

dren showing egocentricity in visual perspective taking did not necessarily show such egocentricity in emotional perspective taking. This finding together with the previous above-mentioned findings (Silani et al., 2013; Steinbeis et al., 2014) supports the view that overcoming egocentricity in the emotional domain has to be seen as a different function than overcoming cognitive egocentricity involved in visual perspective taking and ToM tasks. This in turn suggests that egocentricity cannot be regarded as a unitary phenomenon in development, and future research should instead treat egocentricity as a phenomenon with considerable domain specificity.

Previous studies have suggested that the ability to overcome EEB is associated with brain functions of the rSMG (Silani et al., 2013; Steinbeis et al., 2014) and may be unrelated to abilities of attentional reorienting and ToM, both of which have been associated with functions of the adjacent rTPJ (Decety & Lamm, 2007; Mitchell, 2008; Scholz, Triantafyllou, Whitfield-Gabrieli, Brown, & Saxe, 2009). The present results are again a piece of evidence for such a functional segregation as again here the EEB was not related to attentional reorienting either in children or in adults. This suggests that the lower level processes such as attentional reorienting, as well as processing speed, are not crucially involved in overcoming emotional egocentricity and do not explain any developmental differences in EEB.

Whereas conflict processing explained developmental differences in EEB, response inhibition as measured by the emotional and normal Go/NoGo task did not. This fact might be best explained by the nature of the EEB task. In contrast to false belief tasks and Level 2 visual perspective taking tasks, which have been related to inhibitory control (Carlson & Moses, 2001; Friedman & Leslie, 2005; Perner & Lang, 1999; Wellman et al., 2001), mental states of self and other are not competing experiences, having the same object of reference but merely conflicting emotional experiences with differing objects of reference. For example, in a typical false belief task the two agents have different knowledge about where an object is hidden, while one agent's belief is necessarily true, the other agent's belief is necessarily false. In the EEB task, in contrast, the two agents have differing emotional experiences, each linked to a separate object of reference (e.g., juice vs. quinine). While these emotional experiences are conflicting, they are not competing realities as they remain true in their own right, bound to the individual experiences. Therefore, it can be hypothesized that response inhibition might be less

involved in overcoming emotional egocentricity, as the emotional state of the self has to be disregarded rather than inhibited to arrive at a correct empathic judgment of the emotional state of the other. This would mean that conflicting emotional self and other representations are both online, but self representations do not have to be totally detached from to take the perspective of the other as in the case of false belief tasks. It might be specifically the ability to selectively attend to one stimuli while ignoring the conflicting one that is presented simultaneously that distinguishes conflict processing from simple response inhibition, and relates conflict processing to overcoming emotional egocentricity during the ETOP. Additionally, the blocked design used in this study minimized doubt about what the prepotent response should be (rating self or rating the other), therefore diminishing a further need for response inhibition. For future studies it would be interesting whether response inhibition would become increasingly involved, when using the ETOP with an even-related design.

Another cognitive capacity that has been hypothesized to potentially play a role in overcoming EEB and the developmental differences in EEB between children and adults is emotion regulation through cognitive reappraisal. To investigate children's and adults' abilities to regulate their emotional states through cognitive reappraisal we developed an emotion regulation paradigm in which participants were instructed to regulate their taste experiences. This was done to closely match the emotion regulation task to the taste EEB task. Both children and adults were able to reappraise their taste experiences, and unlike our expectations and previous findings (e.g., McRae et al., 2012; Pitskel et al., 2011), no developmental differences in cognitive reappraisal emerged based on this task. It is unclear why no developmental differences were found. Albeit speculative, it could be the case that primary emotions are somehow easier to regulate than more complex secondary emotions. The significant association of conflict processing and age-related differences in the EEB might suggest that more basic and possibly more rapid cognitive processes might be involved in overcoming the EEB with its short time scale, leaving little room for more explicit and complex cognitive processes such as cognitive reappraisal.

Conclusion

Using a novel EEB paradigm based on visuogustatory stimulation, the ETAP, this study extends previous findings of the existence of an EEB in children and adults to another modality. Children between the ages of 7 and 12 exhibited a significantly larger EEB than adults. There was no evident link in the development of overcoming the EEB with developmental changes in cognitive egocentricity, speaking to egocentricity as a partly domain-specific phenomenon. In turn, the age-differences were mediated by conflict-processing ability but not by a variety of other possibly relevant affective and cognitive abilities such as inhibition, attentional reorienting, processing speed, or emotion regulation. Thus, the ability to process conflict seems to be crucial in overcoming EEB and future research should aim to look more closely at what ways conflict processing and the EEB are interrelated on the behavioral and the neuronal level. Additionally, this study provided further evidence for the assumption that overcoming emotional egocentricity is independent of other functions also relying on temporoparietal functions such as attentional reorienting, ToM, and visual perspective taking. Further investigation of the EEB in development and its interrelation with the development of conflict processing in general seems of great significance, as inappropriate and egocentrically biased empathic judgments can hamper the normal development of interpersonal understanding, be the cause of conflicts, and lead to detrimental consequences for developing children trying to find their place in their social world. In this sense, identifying the underlying mechanisms of emotional egocentricity in development, such as conflict processing, can help to inform interventions promoting normative change in cases where children show great difficulties in overcoming emotional egocentricity.

References

Apperly, I. A., Warren, F., Andrews, B. J., Grant, J., & Todd, S. (2011). Developmental continuity in theory of mind: Speed and accuracy of belief–desire reasoning in children and adults. *Child Development*, *82*, 1691–1703. doi:10.1111/j.1467-8624.2011.01635.x

Badre, D., & Wagner, A. D. (2004). Selection, integration, and conflict monitoring: Assessing the nature and generality of prefrontal cognitive control mechanisms. *Neuron*, *41*, 473–487. doi:10.1016/S0896-6273(03)00851-1

Baron, R. M., & Kenny, D. A. (1986). The moderator–mediator variable distinction in social psychological research: Conceptual, strategic, and statistical considerations. *Journal of Personality and Social Psychology*, *51*, 1173–1182. doi:10.1037/0022-3514.51.6.1173

Batson, C. D., & Shaw, L. L. (1991). Evidence for altruism: Toward a pluralism of prosocial motives. *Psychological Inquiry*, *2*, 107–122. doi:10.1207/s15327965pli0202_1

Birch, S. A., & Bloom, P. (2007). The curse of knowledge in reasoning about false beliefs. *Psychological Science*, *18*, 382–386. doi:10.1111/j.1467-9280.2007.01909.x

Carlson, S. M., & Moses, L. J. (2001). Individual differences in inhibitory control and children's theory of mind. *Child Development*, *72*, 1032–1053. doi:10.1111/1467-8624.00333

Carter, R. M., & Huettel, S. A. (2013). A nexus model of the temporal–parietal junction. *Trends in Cognitive Sciences*, *17*, 328–336. doi:10.1016/j.tics.2013.05.007

Chen, Q., Wei, P., & Zhou, X. (2006). Distinct neural correlates for resolving Stroop conflict at inhibited and noninhibited locations in inhibition of return. *Journal of Cognitive Neuroscience*, *18*, 1937–1946. doi:10.1162/jocn.2006.18.11.1937

Deary, I. J., Der, G., & Ford, G. (2001). Reaction times and intelligence differences: A population-based cohort study. *Intelligence*, *29*, 389–399. doi:10.1016/S0160-2896(01)00062-9

Decety, J., & Lamm, C. (2007). The role of the right temporoparietal junction in social interaction: How low-level computational processes contribute to metacognition. *The Neuroscientist*, *13*, 580–593. doi:10.1177/1073858407304654

Egner, T., Etkin, A., Gale, S., & Hirsch, J. (2008). Dissociable neural systems resolve conflict from emotional versus nonemotional distracters. *Cerebral Cortex*, *18*, 1475–1484. doi:10.1093/cercor/bhm179

Egner, T., & Hirsch, J. (2005). Cognitive control mechanisms resolve conflict through cortical amplification of task-relevant information. *Nature Neuroscience*, *8*, 1784–1790. doi:10.1038/nn1594

Eisenberg, N. (2000). Emotion, regulation, and moral development. *Annual Review of Psychology*, *51*, 665–697. doi:10.1146/annurev.psych.51.1.665

Eisenberg, N., Fabes, R. A., Miller, P. A., Fultz, J., Shell, R., Mathy, R. M., & Reno, R. R. (1989). Relation of sympathy and personal distress to prosocial behavior: A multimethod study. *Journal of Personality and Social Psychology*, *57*, 55–66. doi:10.1037/0022-3514.57.1.55

Eisenberg, N., Shell, R., Pasternack, J., Lennon, R., Beller, R., & Mathy, R. M. (1987). Prosocial development in middle childhood: A longitudinal study. *Developmental Psychology*, *23*, 712–718. doi:10.1037/0012-1649.23.5.712

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*, 143–149. doi:10.3758/BF03203267

Etkin, A., Egner, T., Peraza, D. M., Kandel, E. R., & Hirsch, J. (2006). Resolving emotional conflict: A role for the rostral anterior cingulate cortex in modulating activity in the amygdala. *Neuron*, *51*, 871–882. doi:10.1016/j.neuron.2006.07.029

Fenske, M. J., & Eastwood, J. D. (2003). Modulation of focused attention by faces expressing emotion: Evidence from Flanker tasks. *Emotion*, *3*, 327–343. doi:10.1037/1528-3542.3.4.327

Fjell, A. M., Walhovd, K. B., Brown, T. T., Kuperman, J. M., Chung, Y., Hagler, D. J., . . ., McCabe, C. (2012). Multimodal imaging of the self-regulating developing brain. *Proceedings of the National Academy of Sciences of the United States of America*, *109*, 19620–19625. doi:10.1073/pnas.1208243109

Flavell, J. H., Everett, B. A., Croft, K., & Flavell, E. R. (1981). Young children's knowledge about visual perception: Further evidence for the Level 1–Level 2 distinction. *Developmental Psychology*, *17*, 99–103. doi:10.1037/0012-1649.17.1.99

Friedman, O., & Leslie, A. M. (2005). Processing demands in belief-desire reasoning: Inhibition or general difficulty? *Developmental Science*, *8*, 218–225. doi:10.1111/j.1467-7687.2005.00410.x

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., & Toga, A. W. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences of the United States of America*, *101*, 8174–8179. doi:10.1073/pnas.0402680101

Green, B. G., Dalton, P., Cowart, B., Shaffer, G., Rankin, K., & Higgins, J. (1996). Evaluating the "Labeled Magnitude Scale" for measuring sensations of taste and smell. *Chemical Senses*, *21*, 323–334. doi:10.1093/chemse/21.3.323

Gross, J. J. (2002). Emotion regulation: Affective, cognitive, and social consequences. *Psychophysiology*, *39*, 281–291. doi:10.1017/S0048577201393198

Hamilton, A. F., Brindley, R., & Frith, U. (2009). Visual perspective taking impairment in children with autistic spectrum disorder. *Cognition*, *113*, 37–44. doi:10.1016/j.cognition.2009.07.007

Hansen Lagattuta, K., Sayfan, L., & Harvey, C. (2013). Beliefs about thought probability: Evidence for persistent errors in mindreading and links to executive control. *Child Development*, *85*, 659–674. doi:10.1111/cdev.12154

Hare, T. A., Tottenham, N., Galvan, A., Voss, H. U., Glover, G. H., & Casey, B. (2008). Biological substrates of emotional reactivity and regulation in adolescence during an emotional go-nogo task. *Biological Psychiatry*, *63*, 927–934. doi:10.1016/j.biopsych.2008.03.015

Hein, G., Lamm, C., Brodbeck, C., & Singer, T. (2011). Skin conductance response to the pain of others predicts later costly helping. *PLoS One*, *6*, e22759. doi:10.1371/journal.pone.0022759

Hein, G., Silani, G., Preuschoff, K., Batson, C. D., & Singer, T. (2010). Neural responses to ingroup and outgroup members' suffering predict individual differences in costly helping. *Neuron*, *68*, 149–160. doi:10.1016/j.neuron.2010.09.003

Jabbi, M., Swart, M., & Keysers, C. (2007). Empathy for positive and negative emotions in the gustatory cortex. *NeuroImage*, *34*, 1744–1753. doi:10.1016/j.neuroimage.2006.10.032

Kail, R. (1991). Developmental change in speed of processing during childhood and adolescence. *Psychological Bulletin*, *109*, 490–501. doi:10.1037/0033-2909.109.3.490

Keysar, B., Lin, S., & Barr, D. J. (2003). Limits on theory of mind use in adults. *Cognition*, *89*(1), 25–41. doi:10.1016/S0010-0277(03)00064-7

Kim, C., Kroger, J. K., & Kim, J. (2011). A functional dissociation of conflict processing within anterior cingulate cortex. *Human Brain Mapping*, *32*, 304–312. doi:10.1002/hbm.21020

Li, S.-C., Lindenberger, U., Hommel, B., Aschersleben, G., Prinz, W., & Baltes, P. B. (2004). Transformations in the couplings among intellectual abilities and constituent cognitive processes across the life span. *Psychological Science*, *15*, 155–163. doi:10.1111/j.0956-7976.2004.01503003.x

Luna, B., Garver, K. E., Urban, T. A., Lazar, N. A., & Sweeney, J. A. (2004). Maturation of cognitive processes from late childhood to adulthood. *Child Development*, *75*, 1357–1372. doi:10.1111/j.1467-8624.2004.00745.x

Mars, R. B., Sallet, J., Schüffelgen, U., Jbabdi, S., Toni, I., & Rushworth, M. F. (2012). Connectivity-based subdivisions of the human right "temporoparietal junction area": Evidence for different areas participating in different cortical networks. *Cerebral Cortex*, *22*, 1894–1903. doi:10.1093/cercor/bhr268

McRae, K., Gross, J. J., Weber, J., Robertson, E. R., Sokol-Hessner, P., Ray, R. D., . . ., Ochsner, K. N. (2012). The development of emotion regulation: An fMRI study of cognitive reappraisal in children, adolescents and young adults. *Social Cognitive and Affective Neuroscience*, *7*, 11–22. doi:10.1093/scan/nsr093

Mitchell, J. P. (2008). Activity in right temporo-parietal junction is not selective for theory-of-mind. *Cerebral Cortex*, *18*, 262–271. doi:10.1093/cercor/bhm051

Mitchell, J. P. (2009). Inferences about mental states. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *364*, 1309–1316. doi:10.1098/rstb.2008.0318

Moll, H., & Tomasello, M. (2006). Level 1 perspective-taking at 24 months of age. *British Journal of Developmental Psychology*, *24*, 603–613. doi:10.1348/026151005X55370

Newcomb, A. F., Bukowski, W. M., & Pattee, L. (1993). Children's peer relations: A meta-analytic review of popular, rejected, neglected, controversial, and average sociometric status. *Psychological Bulletin*, *113*, 99–128. doi:10.1037/0033-2909.113.1.99

Nickerson, R. S. (2001). The projective way of knowing: A useful heuristic that sometimes misleads. *Current Directions in Psychological Science*, *10*, 168–172. doi:10.1111/1467-8721.00141

O'Brien, E., & Ellsworth, P. C. (2012). More than skin deep visceral states are not projected onto dissimilar others. *Psychological Science*, *23*, 391–396. doi:10.1177/0956797611432179

O'Doherty, J., Rolls, E., Francis, S., Bowtell, R., & McGlone, F. (2001). Representation of pleasant and aversive taste in the human brain. *Journal of Neurophysiology*, *85*, 1315–1321.

Perner, J., & Lang, B. (1999). Development of theory of mind and executive control. *Trends in Cognitive Sciences*, *3*, 337–344. doi:10.1016/S1364-6613(99)01362-5

Piaget, J., & Inhelder, B. (1956). *The child's conception of space*. London, UK: Routledge & Kegan Paul.

Pitskel, N. B., Bolling, D. Z., Kaiser, M. D., Crowley, M. J., & Pelphrey, K. A. (2011). How grossed out are you? The neural bases of emotion regulation from childhood to adolescence. *Developmental Cognitive Neuroscience*, *1*, 324–337. doi:10.1016/j.dcn.2011.03.004

Preacher, K. J., & Hayes, A. F. (2008). Asymptotic and resampling strategies for assessing and comparing indirect effects in multiple mediator models. *Behavior Research Methods*, *40*, 879–891. doi:10.3758/BRM.40.3.879

Pronin, E. (2008). How we see ourselves and how we see others. *Science*, *320*, 1177–1180. doi:10.1126/science.1154199

Ramsey, R., Hansen, P., Apperly, I., & Samson, D. (2013). Seeing it my way or your way: Frontoparietal brain areas sustain viewpoint-independent perspective selection processes. *Journal of Cognitive Neuroscience*, *25*, 670–684. doi:10.1162/jocn_a_00345

Repacholi, B. M., & Gopnik, A. (1997). Early reasoning about desires: Evidence from 14- and 18-month-olds. *Developmental Psychology*, *33*, 12–21. doi:10.1037/0012-1649.33.1.12

Royzman, E. B., Cassidy, K. W., & Baron, J. (2003). "I know, you know": Epistemic egocentrism in children and adults. *Review of General Psychology*, *7*, 38–65. doi:10.1037/1089-2680.7.1.38

Scholz, J., Triantafyllou, C., Whitfield-Gabrieli, S., Brown, E. N., & Saxe, R. (2009). Distinct regions of right temporo-parietal junction are selective for theory of mind and exogenous attention. *PLoS One*, *4*, e4869. doi:10.1371/journal.pone.0004869

Shaw, P., Kabani, N. J., Lerch, J. P., Eckstrand, K., Lenroot, R., Gogtay, N., & Rapoport, J. L. (2008). Neurodevelopmental trajectories of the human cerebral cortex. *Journal of Neuroscience*, *28*, 3586–3594. doi:10.1523/JNEUROSCI.5309-07.2008

Silani, G., Lamm, C., Ruff, C. C., & Singer, T. (2013). Right supramarginal gyrus is crucial to overcome emotional egocentricity bias in social judgments. *Journal of Neuroscience*, *33*, 15466–15476. doi:10.1523/JNEUROSCI.1488-13.2013

Small, D. M., Gregory, M. D., Mak, Y. E., Gitelman, D., Mesulam, M., & Parrish, T. (2003). Dissociation of neural representation of intensity and affective valuation in human gustation. *Neuron*, *39*, 701–711. doi:10.1016/S0896-6273(03)00467-7

Sommerville, J. A., Bernstein, D. M., & Meltzoff, A. N. (2013). Measuring beliefs in centimeters: Private knowledge biases preschoolers' and adults' representation of others' beliefs. *Child Development*, *84*, 1846–1854. doi:10.1111/cdev.12110

Sowell, E. R., Peterson, B. S., Thompson, P. M., Welcome, S. E., Henkenius, A. L., & Toga, A. W. (2003). Mapping

cortical change across the human life span. *Nature Neuroscience*, *6*, 309–315. doi:10.1038/nn1008

Steinbeis, N., Bernhardt, B. C., & Singer, T. (2012). Impulse control and underlying functions of the left DLPFC mediate age-related and age-independent individual differences in strategic social behavior. *Neuron*, *73*, 1040–1051. doi:10.1016/j.neuron.2011.12.027

Steinbeis, N., Bernhardt, B. C., & Singer, T. (2014). Age-related differences in function and structure of rSMG and reduced functional connectivity with DLPFC explains heightened affective egocentricity bias in childhood. *Social Cognitive and Affective Neuroscience*. Advance online publication. doi:10.1093/scan/nsu057

Surtees, A. D., & Apperly, I. A. (2012). Egocentrism and automatic perspective taking in children and adults. *Child Development*, *83*, 452–460. doi:10.1111/j.1467-8624.2011.01730.x

Thomas, R. C., & Jacoby, L. L. (2012). Diminishing adult egocentrism when estimating what others know. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *39*, 473–486. doi:10.1037/a0028883

Thompson, L., & Loewenstein, G. (1992). Egocentric interpretations of fairness and interpersonal conflict. *Organizational Behavior and Human Decision Processes*, *51*, 176–197. doi:10.1016/0749-5978(92)90010-5

Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., & Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*, 242–249. doi:10.1016/j.psychres.2008.05.006

Van Boven, L., & Loewenstein, G. (2003). Social projection of transient drive states. *Personality and Social Psychology Bulletin*, *29*, 1159–1168. doi:10.1177/0146167203254597

Wellman, H. M., Cross, D., & Watson, J. (2001). Meta-analysis of theory-of-mind development: The truth about false belief. *Child Development*, *72*, 655–684. doi:10.1111/1467-8624.00304

Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D., & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology*, *35*, 205–213. doi:10.1037/0012-1649.35.1.205

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition*, *13*, 103–128. doi:10.1016/0010-0277(83)90004-5

Supporting Information

Additional supporting information may be found in the online version of this article at the publisher's website:

Table S1. Adult Measures Descriptives
Table S2. Children Measures Descriptives
Table S3. Adult Measures Correlation Matrix
Table S4. Children Measures Correlation Matrix