Developmental Cognitive Neuroscience 14 (2015) 23–31

Contents lists available at ScienceDirect

Developmental Cognitive Neuroscience

journal homepage: http://www.elsevier.com/locate/dcn

Mid-adolescent neurocognitive development of ignoring and attending emotional stimuli

Nora C. Vetter[a,*,1], Maximilian Pilhatsch[a,1], Sarah Weigelt[b], Stephan Ripke[a], Michael N. Smolka[a,*]

[a] Department of Psychiatry and Neuroimaging Center, Technische Universität Dresden, Germany
[b] Department of Psychology, Ruhr-Universität Bochum, Germany

ARTICLE INFO

Article history:
Received 12 December 2014
Received in revised form 30 April 2015
Accepted 3 May 2015
Available online 12 May 2015

Keywords:
Adolescence
Attention
Ignoring emotion
Emotional distractors
Development
fMRI

ABSTRACT

Appropriate reactions toward emotional stimuli depend on the distribution of prefrontal attentional resources. In mid-adolescence, prefrontal top-down control systems are less engaged, while subcortical bottom-up emotional systems are more engaged. We used functional magnetic resonance imaging to follow the neural development of attentional distribution, i.e. attending versus ignoring emotional stimuli, in adolescence. 144 healthy adolescents were studied longitudinally at age 14 and 16 while performing a perceptual discrimination task. Participants viewed two pairs of stimuli – one emotional, one abstract – and reported on one pair whether the items were the same or different, while ignoring the other pair. Hence, two experimental conditions were created: "attending emotion/ignoring abstract" and "ignoring emotion/attending abstract". Emotional valence varied between negative, positive, and neutral. Across conditions, reaction times and error rates decreased and activation in the anterior cingulate and inferior frontal gyrus increased from age 14 to 16. In contrast, subcortical regions showed no developmental effect. Activation of the anterior insula increased across ages for attending positive and ignoring negative emotions. Results suggest an ongoing development of prefrontal top-down resources elicited by emotional attention from age 14 to 16 while activity of subcortical regions representing bottom-up processing remains stable.

1. Introduction

Neuroimaging studies have focused on the exploration of emotional attention – that is attention toward or away from emotional stimuli (Corbetta and Shulman, 2002; Corbetta et al., 2008; Posner and Petersen, 1990; Vuilleumier and Huang, 2009). Emotional attention can be impaired in affective disorders and given that mid-adolescence is a core incidence phase for affective disorders (Paus et al., 2008), characterizing the development of emotional attention in adolescence is of high clinical relevance.

Emotional attention can be divided into (1) the automatic impulse to attend toward emotionally salient stimuli, bottom-up emotional attention, and (2) the goal-directed, controlled attention toward emotional stimuli, top-down emotional attention (Corbetta and Shulman, 2002; Vuilleumier and Huang, 2009). Bottom-up and top-down systems are in line in tasks in which participants have to focus on the emotion. However, in tasks, in which the emotion is irrelevant, bottom-up and top-down-systems interfere. Here, the individual either gets distracted and turns her attention toward the emotional distractor (bottom-up attention) or successfully keeps it on the primary task (top-down attention) ignoring the distractor (Vuilleumier and Huang, 2009).

In adults, the two types of emotional attention are represented by different neural networks: For top-down emotional attention a dorsal frontoparietal network is activated including the dorsolateral prefrontal cortex, the dorsal parietal cortex, and the anterior cingulate cortex (ACC). Bottom-up emotional attention is modulated by a ventral frontoparietal network including the occipitotemporal cortex, orbitofrontal cortex, and the amygdala (Corbetta et al., 2008; Iordan et al., 2013; Vuilleumier and Huang, 2009).

In adolescence, more engaged bottom-up regions and less engaged top-down resources may result in an imbalance of both attention systems with prepotent bottom-up processing (Casey

* Corresponding authors at: Technische Universität Dresden, Faculty of Medicine Carl Gustav Carus, Department of Psychiatry and Psychotherapy, Section of Systems Neuroscience, 01187 Dresden, Germany. Tel.: +49 0351 463 42214.

E-mail addresses: nora.vetter@tu-dresden.de (N.C. Vetter), michael.smolka@tu-dresden.de (M.N. Smolka).

[1] These authors have contributed equally.

http://dx.doi.org/10.1016/j.dcn.2015.05.001

et al., 2008). Therefore, the inhibition of distracting emotional stimuli required in top-down emotional attention is challenging for adolescents. For example, in a classroom context the impulse to direct attention toward emotional stimuli, e.g. the attractive classmate passing by, has to be inhibited to direct attention in a top-down fashion on the primary task, e.g. on the current essay. If these challenging developmental tasks are not successfully managed, the risk of affective disorders might increase (Steinberg, 2005).

Few behavioral studies have investigated adolescent development of emotional attention. Most studies assessed inhibition of the motor impulse toward distractor stimuli in emotional go-no-go tasks. Overall, greater age-related improvements from adolescence to adulthood were found for negative and positive compared to neutral no-go-stimuli (Tottenham et al., 2011). When investigated separately, both negative (Cohen-Gilbert and Thomas, 2013) and positive (Somerville et al., 2011) no-go stimuli led to an increased false alarm rate for adolescents in comparison to adults. Thus, adolescents seem to be specifically sensitive toward distracting emotional stimuli. This pattern is also evident in a task that assesses the attentional inhibition of a distracting emotional incongruent flanking stimulus presented together with the task-relevant stimulus: Adolescents had larger interference effects for negative distractors and overall lower accuracy than adults (Grose-Fifer et al., 2013). Taken together, ignoring task-irrelevant emotional distractor stimuli undergoes developmental changes during adolescence.

Adolescent neural development of emotional attention has been initially investigated by a handful of cross-sectional studies. For negative distractors two studies suggest ongoing development of prefrontal regions: Monk et al. (2003) reported lower ACC activation in adults compared to adolescents for evaluating the nose width of emotional faces and Deeley et al. (2008) found decreasing prefrontal activation from childhood over adolescence across adulthood for evaluating the gender of emotional faces. In contrast, Lindstrom et al. (2009) did not find development for negative, but for positive distractors: cuneus and caudate activation decreased with increasing age from 9 to 40 years in a dot-probe task (Lindstrom et al., 2009). Positive distractors also led to stronger orbitofrontal cortex activation in adolescents compared to adults (Monk et al., 2003).

However, longitudinal approaches are mandatory to investigate developmental trajectories precisely. Amongst the sparse number of such studies one found increasing activity from age 10 to 13 in the temporal pole for attending emotional versus neutral faces unconstrained (i.e. passive viewing; Pfeifer et al., 2011).

Paulsen et al. (2015) studied how incentives, age, and performance modulate brain activity during inhibitory control in a longitudinal design including 10- to 22-year-olds. In an incentivized antisaccade task, amygdala-mediated bottom-up processing elicited by loss trials decreased through adolescence. In contrast, activity of prefrontal control regions – which was also associated with better behavioral performance – increased linearly with age.

Change in regions involved in social cognition (including the inferior frontal gyrus, IFG, and superior temporal sulcus) was investigated in 12- to 19-year-olds with a two-year interval using pictures of eye regions (Overgaauw et al., 2014). Activity elicited by evaluating the mental state versus evaluating age/gender was stable in the superior temporal sulcus. While the right IFG showed relative stability, age comparisons revealed a decrease in activation. The medial prefrontal cortex showed a dip of activation in mid-adolescence. Taken together, previous longitudinal studies suggest subtle developmental changes in activation patterns of brain regions crucial for emotion regulation.

The current study sought to systematically investigate the extended neural development of emotional attention (a) with a longitudinal approach beyond early adolescence from age 14 to 16, (b) in a large community-based sample of 144 typically developing adolescents, (c) disentangling bottom-up and top-down processes, and (d) differentiating between positive and negative emotions.

We expected a greater neural development for the ignoring emotion condition compared to the attending emotion condition, given previous studies on mid-adolescent behavioral development. Based on previous neuroimaging studies (Monk et al., 2003; Deeley et al., 2008; Paulsen et al., 2015) we expected this development in prefrontal brain regions. Since the systematic contrast with regard to a baseline was missing in most previous studies, we contrasted negative and positive with neutral pictures. Regarding emotional valence, negative versus neutral in contrast to positive versus neutral distractors might elicit stronger distraction (Öhman et al., 2001) and might require a stronger top-down regulation of the prefrontal cortex (PFC), when being ignored. Therefore, and since in general PFC increases were found on both the functional and structural level throughout adolescence (Crone and Dahl, 2012; Gogtay et al., 2004), we expected an increase of prefrontal activity for negative in contrast to positive distractors from age 14 to 16. Additionally, amygdala activation was tested given previous findings of elevated amygdala activation in adolescence compared to children and adults toward negative stimuli in a go-no-go paradigm (Hare et al., 2008).

2. Method

2.1. Participants

Data acquisition was part of the project "The adolescent brain" (for more details see Ripke et al., 2012). Data of the first wave (age 14) of this project was recently published comparing participants with and without a family history of depression (Pilhatsch et al., 2014a). The local ethics committee approved the study. 260 adolescents were recruited via school visits in the local school district. Monetary compensation was provided for participation and informed consent was obtained from participants and from one of their legal guardians. Participants had no record of medical, neurological or psychiatric disorders and those with current mental disorders were excluded according to the Development and Well-Being Assessment (DAWBA; Goodman et al., 2000). Of the initial sample 187 participants were successfully assessed at both time points of which 144 (73 girls) are included in the present analyses. The others were excluded because of 1) excessive head movements ($N = 23$), (2) low behavioral performance during the fMRI task, i.e. more than 25% incorrect answers ($N = 14$), or mean reaction times higher than 3 standard deviations (SD) from the mean of their age samples at age 14 or 16 ($N = 6$). The resulting sample consisted of 144 participants (for participant characteristics see Table 1) with normal or corrected to normal vision, which completed data collection at two visits (separated by 24.12 ± 1.97 months, range 22–37 months). A urine test assured no use of illicit drugs (e.g. cannabis, heroin, cocaine) at the day of assessment.

2.2. Stimuli, design and procedure

Based on previous work (Vuilleumier et al., 2001) we developed a perceptual discrimination task, in which participants decided whether a pair of visual target stimuli was equal while another pair was presented as distractor. In each trial a pair of non-emotional pictures and a pair of pictures from one of three emotional categories (negative, positive, neutral) taken from the International Affective Picture System (IAPS; Lang et al., 2005) was shown. The selection of IAPS stimuli was balanced with respect to normed emotional valence and arousal ratings (Table S1, available online). Non-emotional control pictures were created by shredding the