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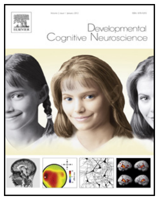

Changes in neural mechanisms of cognitive control during the transition from late adolescence to young adulthood

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ABSTRACT

The transition from late adolescence to young adulthood is marked by anatomical maturation of various brain regions. In parallel, defining life changes take place, such as entrance into college. Up till now research has not focused on functional brain differences during this particular developmental stage. The current cross-sectional fMRI study investigates age differences in cognitive control by comparing late adolescents, 18–19 years old, with young adults, 23–25 years old. Seventy-four male and female medical students carried out a combined cognitive and emotional Stroop task. Overall, lateral frontoparietal and medial parietal activation was observed during cognitive interference resolution. Young adults showed stronger activation in the dorsomedial prefrontal cortex, left inferior frontal gyrus, left middle temporal gyrus and middle cingulate, compared to late adolescents. During emotional interference resolution, the left precentral and postcentral gyrus were involved across age and sex. The dorsomedial prefrontal cortex and precuneus were activated more in young adults than in late adolescents. No sex-related differences were found in this homogeneous sample. The results suggest that the neural bases of cognitive control continue to change between late adolescence and young adulthood.

1. Introduction

The life period between the ages 18 and 25 is a time in which important changes take place, such as obtaining a college degree, leaving home, establishing new social relations and reaching financial independence. This phase has been referred to as emerging adulthood (Arnett, 2000) and is characteristic for industrialized societies, where young people have prolonged educational tracks to qualify for highly technical jobs. During this period, structural maturation of the brain and cortical networks is ongoing (Lebel and Beaulieu, 2011; Tamnes et al., 2010), which has been linked to environmental transitions (Bennett and Baird, 2006). Particularly areas within the prefrontal cortex that are important for cognitive control, the ability to direct behavior towards a goal, continue to develop until the early 20s (Giedd and Rapoport, 2010; Toga et al., 2006). These high-order association areas, including the lateral and medial prefrontal cortex as well as the cingulate cortex, reach their peak in cortical thickness last (Shaw et al., 2008). Another region that matures late, as indicated by gray matter loss, is the lateral temporal lobe (Gogtay et al., 2004). Anatomical trajectories are likely linked to functional development of cognitive processes in the adolescent brain (Blakemore and Choudhury, 2006; Casey et al., 2005; Crone and Ridderinkhof, 2011; Steinberg, 2005). It has been shown that neural correlates of control mature at least until age 18 (Bunge and Wright, 2007; Luna et al., 2010; Rubia et al., 2006; Velanova et al., 2009). However, little is known about changes in brain mechanisms underlying cognitive control during the transition from late

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adolescence to young adulthood, around the ages of 18 until 25.

An important aspect of cognitive control is interference resolution, inhibition of an automatic response in favor of a voluntary response, and can be measured using the Stroop task (MacLeod, 1991; Nee et al., 2007). There is some evidence from functional magnetic resonance imaging (fMRI) studies that the neural underpinnings of the Stroop task develop further after age 18. In 7–22 year olds, there was a positive correlation between age and activation during interference in the left lateral and medial prefrontal cortex as well as left lateral and medial parietal cortex (Adleman et al., 2002). According to this research, the functional role of the parietal lobe develops until age 12 while frontal involvement changes until age 18 or beyond. On another Stroop paradigm activation of the left lateral prefrontal cortex seemed to increase from age 14 until around age 21 and slightly decrease from age 21 until age 25 (Andrews-Hanna et al., 2011). Increased activation of the right lateral prefrontal cortex with age and with performance was found in participants 7–57 years old (Marsh et al., 2006). Although these studies use a wide age range, the findings indicate that maturation of neural processes related to interference resolution on the Stroop task might extend into adulthood.

Differences in brain activation between adolescents and adults have also been observed during cognitive control over interfering emotional stimuli (Crone, 2009; Monk et al., 2003; Passarotti et al., 2009; Wang et al., 2008). Cognitive and emotional interference resolution engaged similar prefrontal control regions in adolescents aged 16 and 17 performing a variant of the counting Stroop task (Mincic, 2010). No information is available with respect to developmental patterns, as the adolescents were not compared to adults and no other neuroimaging studies have examined development using an emotional Stroop paradigm. During adolescence, cognitive control is particularly difficult in the context of emotional stimuli (Casey et al., 2011), therefore it can be expected that age-related differences are especially pronounced on an emotional variant of the Stroop task.

The lack of knowledge concerning functional brain maturation during the transition from late adolescence to young adulthood has motivated the current fMRI study. Here, differences between 18–19 year olds and 23–25 year olds are investigated on a combined cognitive and emotional Stroop task. The 18–19 year olds are Freshman and Sophomore students in Medical College while the 23–25 year olds are medical students at the Junior or Master level. A homogeneous sample of medical students was chosen to control for possible variation due to differences in intelligence, life experiences and daily activities. Compared to the students in the first years, the students in the final years have already completed courses and practical classes and are involved in clinical training. Students 18–19 years old and students 23–25 years old are termed late adolescents and young adults respectively since it is proposed that between these ages, development towards a complete adult-like pattern of brain functioning occurs. This notion contrasts with the common assumption that people of 18 and older are adults. Instead, we focus on changes within this age range, which can be considered a separate developmental stage. We predict stronger activation in young adults compared to late adolescents, particularly in the prefrontal cortex, during interference resolution. The effect is assumed to be larger during emotional compared to cognitive interference resolution.

An additional question pertains to possible differences between male and female students. It has been demonstrated that the neural bases of cognitive tasks might differ for males and females (Bell et al., 2006). An interaction effect between age and sex was found in 13–38 year olds performing a motor Stroop task (Christakou et al., 2009). In this study, increased activation with age in medial prefrontal areas was shown for females, while for males a positive correlation between age and activation of temporal regions was observed. Additionally, brain activation related to emotional interference can vary between males and females (Koch et al., 2007). To further explore sex-related activation differences on the combined cognitive and emotional Stroop task, in addition to age differences, we include male as well as female late adolescents and young adults.

2. Methods

2.1. Participants and procedure

A total of 74 healthy right-handed volunteers were included in this study. Participants consisted of 21 female late adolescents (range = 18.39–19.98 years, mean = 19.11, SD = 0.44), 17 male late adolescents (range = 18.36–19.91 years, mean = 18.92, SD = 0.53), 18 female young adults (range = 23.24–24.95 years, mean = 24.07, SD = 0.46) and 18 male young adults (range = 23.05–25.95 years, mean = 24.03, SD = 0.89). They were recruited from Medical College at VU University Amsterdam and the University of Amsterdam. Written informed consent was obtained prior to the study and participants received monetary compensation. The study was approved by the Medical Ethics Committee of VU Medical Centre.

All volunteers were right-handed, had normal or corrected-to-normal vision and no history of neurological or psychiatric disorders. Mean estimation of receptive vocabulary, an aspect of verbal IQ, was 110.3 (SD = 6.71) on the Peabody Picture Vocabulary Test-III-NL, within the normal range for adults holding a university degree (mean = 112.0, SD = 9.00; Schlichting, 2005). There was no significant difference between scores of the four groups: female late adolescents, male late adolescents, female young adults and male young adults ($F = 1.02$, $p = 0.39$).

The volunteers completed a behavioral session of 1.5 h and an fMRI session of 1 h. During the behavioral session which took place 1 or 2 days before the fMRI session, the fMRI tasks were practiced. In addition, a neuropsychological test battery was administered. During the fMRI session, participants performed a combined cognitive and emotional Stroop task. A social appraisal task and a Go/NoGo paradigm were also performed and will be described elsewhere.