Neuropsychologia 87 (2016) 85–95

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Audience effects on the neural correlates of relational reasoning in adolescence

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ARTICLE INFO

Article history:
Received 18 November 2014
Received in revised form
26 April 2016
Accepted 1 May 2016
Available online 2 May 2016

Keywords:
Adolescence
Peer influence
FMRI
Audience effect
Reasoning

ABSTRACT

Adolescents are particularly sensitive to peer influence. This may partly be due to an increased salience of peers during adolescence. We investigated the effect of being observed by a peer on a cognitively challenging task, relational reasoning, which requires the evaluation and integration of multiple mental representations. Relational reasoning tasks engage a fronto-parietal network including the inferior parietal cortex, pre-supplementary motor area, dorsolateral and rostrolateral prefrontal cortices. Using functional magnetic resonance imaging (fMRI), peer audience effects on activation in this fronto-parietal network were compared in a group of 19 female mid-adolescents (aged 14–16 years) and 14 female adults (aged 23–28 years). Adolescent and adult relational reasoning accuracy was influenced by a peer audience as a function of task difficulty: the presence of a peer audience led to decreased accuracy in the complex, relational integration condition in both groups of participants. The fMRI results demonstrated that a peer audience differentially modulated activation in regions of the fronto-parietal network in adolescents and adults. Activation was increased in adolescents in the presence of a peer audience, while this was not the case in adults.

1. Introduction

Adolescence is defined as the period of life that starts with puberty and ends when an individual attains a stable, independent role in society (Lerner and Steinberg, 2004). Substantial changes in the social environment occur during adolescence; in particular, adolescents' relationships with peers become increasingly important (Brown, 2004). These environmental changes are thought to coincide with a heightened sensitivity to social contexts and thus influence adolescent behaviour (Blakemore and Mills, 2014).

The aim of the current functional magnetic resonance imaging (fMRI) study was to investigate developmental differences in the influence of a peer audience on the neural correlates of a high-level cognitive task between adolescence and adulthood. We assessed the influence of a peer audience on the activation of brain regions associated with relational reasoning, which is a type of fluid reasoning defined as the ability to think logically and solve problems independent of prior knowledge, and is associated with academic achievement (Ferrer et al., 2009; Krawczyk, 2012). Because of their greater sensitivity to social context, an adolescent asked to solve a mathematics or logic problem on the whiteboard in front of their peers or in a one-on-one situation with their tutor may be more affected by the presence of an audience than a child or adult in the same situation. This type of effect may be broadly categorised as "choking under pressure", in this case social pressure (Belletier et al., 2015).

Tests such as the USA Law School Admission Test include sections (Logic Games, Logical Reasoning) that heavily tax relational reasoning (Mackey et al., 2012). Similarly, tests of non-verbal reasoning, which similarly tax relational reasoning, are often used in the selection process for academically selective schools in late childhood/early adolescence in the UK. If relational reasoning performance is affected by the presence of an audience (e.g. other students, known teachers or neutral invigilators), this may have consequences in terms of test outcomes and therefore future academic progression of pupils.

1.1. Heightened sensitivity to peer influence in adolescence

Compared with children, adolescents are more sensitive to peer influence (Brown, 2004; Steinberg and Silverberg, 1986) and are more concerned about being accepted by their peers (O'Brien and Bierman, 1988). Peer approval becomes increasingly important for self-esteem during adolescence relative to late childhood (O'Brien and Bierman, 1988). While fears about being punished by parents

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http://dx.doi.org/10.1016/j.neuropsychologia.2016.05.001

or teachers decrease between late childhood and adolescence (8–18 years), fears about being socially judged increase (Westenberg et al., 2004; Westenberg et al., 2007). These questionnaire-based studies suggest that adolescents are particularly concerned about being evaluated by their peers.

Experimental studies on peer influence have so far predominantly focussed on risky and reward-related decision-making and suggest that the presence of peers modulates adolescent reward sensitivity (Chein et al., 2011; Gardner and Steinberg, 2005; O'Brien et al., 2011; Reynolds et al., 2013; Weigard et al., 2014). Gardner and Steinberg (2005) showed that adolescents (13–16 years) made more risky decisions in a driving game when they were being observed by two peers compared to when they were on their own, while adult levels of risky decisions were not affected by the presence of peers (Gardner and Steinberg, 2005). A study employing an fMRI version of this driving game also showed developmental differences in the modulation of the activation in reward-related regions (the ventral striatum and the orbitofrontal cortex) in the presence of peers (Chein et al., 2011). In the decision period of the driving game, adolescents (14–18 years) activated these regions more in the presence of peers than when alone, while activation in these regions was not significantly affected by the presence of peers in young adults (19–22 years). The current fMRI study aimed to investigate whether this heightened adolescent sensitivity to peer influence also extends to differential peer audience effects on the neural system involved in a high-level cognitive task in adolescents and adults.

1.2. Audience effects

There is a long history of social psychology research (predominantly in adults) on social facilitation or, more specifically, the audience effect (Zajonc, 1965). The audience effect describes the influence of the presence of an audience on task performance, such as task accuracy, task speed or reaction time (RT) and has been studied with a range of different tasks and audiences. Audience effect studies have found that the presence of an audience is generally associated with performance improvement in simple tasks and performance impairment in complex or learning tasks, although there are inconsistencies in the literature due to the variety of tasks, methods and audience conditions employed (Aiello and Douthitt, 2001; Belletier et al., 2015; Bond and Titus, 1983; Zajonc, 1965). Two processes have been proposed to underlie impairments in performance. Task-irrelevant thoughts and worries may distract executive attention away from task execution, which leads to poorer performance when tasks require attentional control. Alternately, the desire to do well may lead to too much executive attention being directed to the task at hand, which may cause poorer performance on simple tasks that rely on skills and processes that are automatic and run best outside of conscious awareness (see Belletier et al. (2015) for a review).

A small number of studies have investigated the neural basis of the audience effect. A near-infrared spectroscopy (NIRS) study investigated the effect of an evaluative audience of two experimenters in a competitive scenario on an n-back working memory task. In the social context (competitive audience condition), participants made more errors than when they were alone in the most difficult n-back condition (3-back), and this behavioural difference was correlated with heightened activation in the prefrontal cortex in the 3-back condition compared to a baseline task. However, as the audience condition of that study included a competitive component, it is not clear whether this effect is attributable to the audience, to the competition or to both. A recent fMRI study investigated the audience effect on a motor task (Yoshie et al., 2016). When being observed performing a grip force task, participants generated more grip force output and this was accompanied by reductions in activity in bilateral inferior parietal cortex, which was correlated with individual differences in the socially-induced change in grip force.

The lack of previous fMRI studies investigating the effect of a non-competitive audience on task-related activation in a *high-level cognitive task* prevented us from making clear predictions regarding the direction of the modulation of task-related activation by the presence of an audience. The presence of an audience might act as an attentional distractor. On the one hand, it has been suggested that attentional distractors induce compensatory mechanisms, leading to increased activation in task-related regions reflecting neural efforts to uphold the level of task performance (Wessa et al., 2013). On the other hand, there is evidence supporting the idea that a distractor diverts attention away from the task, resulting in decreased activation in task-related regions (Dolcos and McCarthy, 2006; Mitchell et al., 2008). The current study is a first investigation of the neural correlates of the audience effect during reasoning in adolescents and adults. As such, it was not clear *a priori* whether the presence of an audience would lead to increased or decreased activation in the relational reasoning network. Findings of increased activation in the relational reasoning network would suggest that the presence of an audience leads to increased activity to support task performance, possibly due to compensatory mechanisms, while decreased activation would support the idea that the presence of an audience diverts neural processing away from the task.

1.3. Study design

The current study investigated the peer audience effect on the neural correlates of relational reasoning. Solving relational reasoning problems requires the generation of abstract mental relationships of features in a puzzle (e.g. a change in size, number or shape), and the integration of those relationships. Relational reasoning involves a fronto-parietal network including the inferior parietal lobule (IPL), the pre-supplementary motor area (preSMA), the dorsolateral prefrontal cortex (DLPFC) and the rostrolateral prefrontal cortex (RLPFC), the latter region being specifically associated with relational integration (Christoff et al., 2001; Crone et al., 2009; Dumontheil et al., 2010; Krawczyk, 2012).

A recent fMRI study employed a minimal, virtual peer manipulation, in which participants were simply being told that a peer was watching via a camera while they were lying in the scanner. Contrasting this peer condition with an alone condition resulted in higher levels of reported embarrassment, as well as greater activation in the medial prefrontal cortex (mPFC) – a key region of the social brain (Frith and Frith, 2007) - in adolescents relative to children (Somerville et al., 2013). In addition, autonomic arousal levels, measured by skin conductance, were heightened in adolescents relative to both children and adults, suggesting that the presence of peers is particularly salient and arousing during adolescence, even when a minimal, virtual peer manipulation is employed.

The current study used a similar, minimal, virtual peer audience manipulation to investigate the effect of being observed and evaluated by an unfamiliar peer on activation within a functionally defined relational-integration neural network, in a group of mid-adolescents (14–16 years) and adults (23–28 years). We adapted a relational reasoning paradigm that has been employed in previous neuroimaging studies with adults and adolescents (Christoff et al., 2003; Dumontheil et al., 2010; Smith et al., 2007; Wendelken et al., 2011). The paradigm includes both a simple Control task, in which problems are solved by considering a single relation (one-relational problems) and a complex Relational task, in which two relations need to be jointly considered and integrated (two-relational problems). This allows a comparison between peer audience