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## Social cognition in adolescence: Social rejection and theory of mind



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### ABSTRACT

Neuroimaging studies have shown continued structural and functional development in neural circuitry underlying social and emotional behaviour during adolescence. This article explores adolescent neurocognitive development in two domains: sensitivity to social rejection and Theory of Mind (ToM). Adolescents often report hypersensitivity to social rejection. The studies presented here suggest that this is accompanied by reduced responses in brain regions involved in emotion regulation. Studies on social rejection in adolescents with autism spectrum conditions will also be discussed. ToM is another social cognitive domain which undergoes neurocognitive development between adolescence and adulthood. ToM refers to the ability to understand others' thoughts and intentions. Neuroimaging data suggest that the ability to integrate emotional information into ToM decisions continues to develop between adolescence and adulthood. In sum, these studies demonstrate ongoing development of social and emotional cognition during adolescence at both behavioural and neural levels, providing a neurocognitive framework for understanding adolescent behaviour.

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### La cognición social en la adolescencia: el rechazo social y la teoría de la mente

#### RESUMEN

Los estudios de neuroimagen han conocido un continuo desarrollo estructural y funcional de los circuitos neuronales que subyacen al comportamiento social y emocional en la adolescencia. Este artículo explora el desarrollo neurocognitivo adolescente en dos dominios: la sensibilidad al rechazo social y la teoría de la mente (TM). Los adolescentes refieren a menudo hipersensibilidad al rechazo social. Los estudios que se presentan sugieren que se acompaña de una disminución de las respuestas en regiones cerebrales vinculadas a la regulación emocional. También se comentarán los estudios sobre rechazo social en adolescentes con trastornos del espectro autista. La teoría de la mente es otro campo cognitivo social que subyace al desarrollo neurocognitivo entre adolescencia y edad adulta. Dicha teoría alude a la capacidad de comprender los pensamientos e intenciones de los demás. Los datos de neuroimagen sugieren que la capacidad de integrar la información emocional en decisiones de teoría de la mente sigue desarrollándose entre la adolescencia y la edad adulta. En síntesis, tales estudios demuestran que hay un desarrollo continuo de la cognición social y emocional durante la adolescencia tanto en el nivel comportamental como neuronal, proporcionando un marco neurocognitivo para explicar el comportamiento adolescente.

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Human adolescence is a period of physical, psychological, and social transition between childhood and adulthood (Spear, 2000). While it is difficult to define the precise onset and end point of

adolescence, it has been described as beginning with the onset of puberty and ending with a stable commitment to an adult role (Damon, 2004). For the purposes of this article, adolescence will be broadly defined as the second decade of life. While there are undoubtedly cultural influences at play, adolescence is often characterised by an increase in emotional lability and risk-taking behaviours. Epidemiological data also suggest that adolescence is a key time for the onset of psychological disorders characterised

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by emotional dysregulation (Kessler et al., 2005). These include internalising disorders such as depression and anxiety, as well as externalising disorders such as conduct disorder.

It has been suggested that this vulnerability results from ongoing brain development occurring during adolescence, particularly in brain regions responsible for high level cognitive abilities such as planning, decision-making, and regulating emotions (e.g., Paus, Keshavan, & Giedd, 2008). In the last 15 years, the availability of safe and non-invasive neuroimaging methods such as magnetic resonance imaging (MRI) has revolutionised the study of adolescence. It is now known that significant development occurs in the brain's grey and white matter and that those brain regions which are latest to mature are those responsible for complex human behaviours, notably the prefrontal cortex and temporo-parietal regions (Giedd et al., 1999; Gogtay et al., 2004; Shaw et al., 2008; Sowell et al., 1999). Different brain regions have also been shown to mature at different rates and with differing trajectories; for example, Shaw et al. (2008) found that evolutionarily older parts of the brain, such as the limbic system, mature in a simpler linear trajectory than regions that evolved more recently, such as the neocortex. Neurotransmitter systems also continue to develop; for example the dopaminergic system undergoes substantial remodelling during adolescence (Steinberg, 2008).

Research is currently engaged in further linking specific adolescent behaviours with particular patterns of brain development. Several recent models of the link between adolescent brain and behaviour have proposed the idea of a 'developmental mismatch' between parts of the brain involved in processing emotional and reward signals (including regions such as the amygdala and ventral striatum) and those responsible for regulating these responses (e.g., parts of the prefrontal cortex) (Casey, Jones, & Hare, 2008; Nelson, Leibenluft, McClure, & Pine, 2005; Steinberg, 2008). During adolescence, it is hypothesised that the development of regulatory regions lags behind that of emotional processing regions, rendering the adolescent brain a 'fast car with poor brakes'. Although this formulation is undoubtedly oversimplified, it provides a useful framework and generates predictions that can be tested using methods such as functional magnetic resonance imaging (fMRI).

In addition to emotional processing, regulation, and behaviour, it is also important to consider the role of social development in adolescence. Indeed, the social environment is crucial in shaping the adolescent brain (Blakemore, 2008). The role of peers is vital, with evidence suggesting that by mid-adolescence, individuals spend more time with their peers than with their parents (Steinberg & Silverberg, 1986). Also important is the increasing ability of adolescents to think abstractly about themselves and other people. This means they have a more sophisticated understanding of complex social phenomena such as reputation, social hierarchy, personality traits, and how others see them (the 'looking glass self') than they did at an earlier age (Harter, 1990; Parker, Rubin, Erath, Wojslawowicz, & Buskirk, 2006; Sebastian, Burnett, & Blakemore, 2008).

### Social Rejection in Adolescence

Given this ongoing development in both affective (emotional) and social domains, several researchers have investigated whether 'developmental mismatch', resulting in poor emotion regulation, could interact with social cognitive development to account for social behaviours commonly seen in adolescence. One phenomenon that captures the overlap between social and emotional processes particularly well is sensitivity to social rejection in adolescence. Social rejection, or ostracism, refers to being deliberately ignored or excluded by an individual or a group (Williams, 2007). In adolescence, social rejection is often used as a form of relational

aggression or bullying, with one study (Wang, Iannotti, & Nansel, 2009), reporting that 27.4% adolescent girls had been excluded or ignored by peers at school. Boys may also use relational aggression but girls are more likely to do so, and to be upset when they are the victim (Crick & Nelson, 2002; Wang et al., 2009). Self-report studies have suggested that adolescents might be more sensitive to social rejection than both adults and younger children in everyday life (Kloep, 1999; O'Brien & Bierman, 1988). However, the social, cognitive, and neural processes underlying this effect have only recently been investigated experimentally.

As a starting point, it is important to establish whether adolescent sensitivity to social rejection can be replicated in the laboratory. If so, this would suggest that the phenomenon is not just an artefact of the adolescent social environment (e.g., social hierarchies at school). In recent years, the 'Cyberball' paradigm (Williams, Cheung, & Choi, 2000) has been used extensively to experimentally investigate responses to social rejection in a wide range of populations. Cyberball is a computer game in which participants are told that they are playing a game of 'catch' over the internet with two other players, and that the researchers are interested in 'mental visualisation ability' during the game. In fact, the actions of the other players are pre-programmed by the experimenter to either include or exclude the participant in a systematic way. Reactions to this manipulation can then be measured (see Williams, 2007, for a review).

Cyberball was used to test adolescent responses to social rejection (focusing on females only) in a study by Sebastian, Viding, Williams, and Blakemore (2010). Twenty-six early adolescents (aged 11–13), 25 mid adolescents (aged 14–15), and 26 adult female controls were first included and then rejected in successive rounds of Cyberball. Self-reported mood and anxiety levels were measured at baseline (i.e., before playing Cyberball), after inclusion, and finally after rejection. (Condition order was not randomised in order to avoid possible negative spillover effects from the rejection to the inclusion condition). Relative to adult females, both adolescent groups reported lower overall mood following rejection. The early adolescents also reported greater anxiety. The mid-adolescents did report high anxiety following rejection, but anxiety was also high following inclusion (relative to baseline). One possible conclusion from this finding is that social interaction in general can be anxiety-provoking at this age. Indeed, the mean age of onset for social phobia occurs in mid-adolescence at age 15 (Mancini, Van Ameringen, Bennett, Patterson, & Watson, 2005). In contrast, all groups reported that they had been excluded by the other players to a similar degree and reported the experience as feeling equally real. This suggests that adolescents (at least adolescent girls) respond more strongly and negatively to social rejection than do adults, even when there are no objective differences in the perception of the rejection episode.

### Social Rejection and the Adolescent Brain

The behavioural study reported above suggests that sensitivity to rejection in adolescence can be elicited under experimental conditions, even when the rejection encounter is very brief and has no long term consequences for social reputation. It is therefore interesting to consider what factors might underlie this effect. One hypothesis is that ongoing brain development in regions responsible for processing and regulating responses to social rejection may contribute. Eisenberger, Lieberman, and Williams (2003) used the Cyberball paradigm together with fMRI in adults and found that activity in right ventrolateral prefrontal cortex (VLPFC) during social rejection (relative to inclusion) was negatively related to self-reported distress, i.e., a greater response in this region was associated with reduced rejection-related distress. One possibility

is that this region is involved in regulating negative emotions such as responses to social rejection, and that this region functions differently in adolescents compared with adults.

This hypothesis was investigated in an fMRI study comparing neural responses during Cyberball in 19 adolescent females (aged 14–16) and 16 matched adults (Sebastian et al., 2011). Regardless of age, all participants activated a network of regions involved in social evaluation and negative emotion. These included the medial prefrontal cortex, ventral anterior cingulate cortex, and medial orbitofrontal cortex. However, of most interest was a group difference in right ventrolateral prefrontal cortex. The adult group showed a greater response in this region during rejection compared with inclusion, while the adolescent group showed no difference between rejection and inclusion conditions. It may be that this lack of a difference between conditions reflects a reduced ability to flexibly engage right VLPFC in emotion regulation as needed (in this case, during social rejection).

In support of this interpretation, adolescents reported greater rejection-related distress than did adults (as in the behavioural study above), although it is worth noting that no inverse correlation was found between distress and right VLPFC response in either adolescents or adults. Such a result would have provided stronger evidence that right VLPFC response was functionally involved in regulating rejection-related distress. However, another study (Masten et al., 2009) used Cyberball and fMRI with 23 adolescents (both males and females) and did find a negative correlation between distress and right VLPFC activation. The replication of this effect across two studies (Eisenberger et al., 2003; Masten et al., 2009) lends weight to the theory that this region is involved in regulating distress and that its lack of engagement in Sebastian et al. (2011) reflects reduced regulation of rejection-related distress in adolescents relative to adults.

Results from the above studies indicate that adolescents respond to explicit social rejection differently from adults at both the behavioural and the neural levels. Although participants are not aware that the experimental aim is to measure responses to social rejection during Cyberball, they are at least explicitly aware that they are engaged in a social interaction, and that at some points they are included and at others excluded. However, an important aspect of emotion regulation relates to how we respond to implicit emotional cues, and in particular how well executive functions such as cognitive control, response inhibition, attention, working memory, conflict monitoring and decision-making can be maintained in the presence of implicit emotional information (Tottenham, Hare, & Casey, 2011).

To investigate this in relation to rejection in adolescence, adolescent and adult participants were scanned while completing a rejection-related emotional Stroop task (Sebastian, Roiser et al., 2010). Individual words were displayed on the computer screen and participants indicated the ink colour in which the word was written (red, blue, green, yellow). Word meanings were either rejection-related (e.g., 'loser'), acceptance-related ('friend'), or neutral (e.g., 'table'). Participants were instructed to concentrate on the task (indicating the word colour) rather than word meaning; however, an extensive literature on the emotional Stroop task shows that emotional word meanings interfere with participants ability to perform the task, resulting in both increased reaction times to emotional (and particularly negatively-valenced) words (Williams, Mathews, & MacLeod, 1996) and increased neural responses in regions involved in cognitive control (Bush, Luu, & Posner, 2000). Interestingly, a comparison of fMRI responses during the emotional Stroop task between adolescent and adult responses revealed a group difference in the same right VLPFC region identified in the study using Cyberball. The pattern of results was also similar: adults showed an increased response in this region when processing rejection-related words compared with neutral

words, but adolescents showed no difference between the two conditions.

Overall, results across two tasks (one explicit, one implicit) suggest that ventrolateral prefrontal cortex may not regulate emotional responses associated with social rejection as effectively in adolescents as in adults. It is possible that reduced response in this region may contribute to adolescent sensitivity to social rejection seen in everyday life. However, the exact mechanism underlying this reduced response is still unclear. For example, does this finding relate to the idea of a developmental mismatch, with an immature ventrolateral prefrontal cortex unable to regulate the activity of the limbic system effectively? We know that a network of brain regions is involved in the generation and regulation of rejection-related distress: how do these regions connect with each other and interact and how does this network develop during adolescence? It is also important to consider the role of experience: perhaps group differences at the neural level reflect adults' greater experience in dealing with rejection over time. While there are unanswered questions, the data suggests that focusing on emotion regulation skills, particularly those that engage ventrolateral prefrontal cortex, may be particularly beneficial during adolescence.

### Social Rejection in Adolescents with Autism Spectrum Conditions

Autism spectrum conditions (ASC) refer to conditions characterised by a triad of impairments comprising language difficulties or delay, communication problems, and stereotyped behaviours. While high-functioning individuals with ASC have cognitive abilities in the normal range, their difficulties with social interaction may leave them particularly vulnerable to experiencing social rejection, particularly during adolescence when their peers' social skills may accelerate ahead. There is evidence that adolescents with autism spectrum conditions (ASC) believe they are less popular than their typically developing peers, while recognising the importance of peer approval (Williamson, Craig, & Slinger, 2008). Individuals with ASC also report a desire for friendship (Frith, 2004), while often experiencing loneliness (Bauminger & Kasari, 2000) and bullying (Van Roekel, Scholte, & Didden, 2010). It is therefore of interest to explore how individuals with ASC experience social rejection.

We conducted a behavioural study, using Cyberball to investigate self-reported responses to rejection in 13 adolescents with ASC (mean age 16.9) and 13 matched controls (Sebastian, Blakemore, & Charman, 2009). Overall, the two groups reported very similar levels of distress. According to Williams' (1997) Need Threat model, social rejection threatens four fundamental social needs: self-esteem, belonging, control, and a sense of meaningful existence. These needs can be threatened automatically; for example, Zadro, Williams, and Richardson (2004) showed that rejection causes distress even when participants know that the Cyberball game is controlled by a computer. Adolescents with ASC reported similar or greater levels of need threat across all four needs compared with controls. Anxiety levels were also similar between the two groups. The only difference between groups was seen for self-reported mood: after rejection, the control group showed significantly lowered mood compared with baseline and inclusion conditions, while the group with ASC showed no reduction in mood.

This result was followed up by three studies using neuroimaging methods (fMRI or EEG) to better understand the response to rejection in ASC (Bolling et al., 2011; Masten et al., 2011; McPartland et al., 2011). These studies all found that self-reported (questionnaire) responses to rejection were largely preserved in ASC, as discussed above. However, neural responses to rejection were reduced in individuals with ASC compared with controls (see

Sebastian et al., 2011 for a detailed discussion of these studies). This is interesting, as it suggests that it is erroneous to think of responses to rejection in ASC as being either fully preserved or deficient. Adolescents with ASC clearly subjectively perceive social rejection as distressing, despite differences in processing at the neural level. Since individuals with ASC are particularly likely to experience bullying and social rejection, it makes sense to focus on bullying prevention in this group as well as on helping these individuals to develop effective coping strategies.

### The Adolescent Brain and Theory of Mind

The studies discussed so far have used social rejection as a tool for investigating the development of social and emotional processing in adolescence. Another aspect of social cognition that has received considerable attention with regard to adolescence in recent years is Theory of Mind (ToM: understanding others' thoughts, beliefs, and intentions). Indeed, while until recently ToM was thought to develop around age 4, evidence now suggests that ToM improves into late adolescence. For example, a behavioural study by Dumontheil, Apperly, and Blakemore (2009) found improvements in the ability to take another person's perspective between late adolescence (14–17 years) and adulthood (see Dumontheil, this volume, for further details).

Neuroimaging evidence is now showing that improvements in social cognition during adolescence are underpinned by ongoing development in relevant brain regions. For example, four recent functional magnetic resonance imaging (fMRI) studies using a range of social cognition tasks have shown a reduction in brain activity between adolescence and adulthood in medial prefrontal cortex (see review by Blakemore, 2008). This region is activated across a range of social cognition tasks, particularly those requiring ToM. Putative functions of this region include meta-representation (Amodio & Frith, 2006; Frith & Frith, 2007) or the decoupling of mental states from reality (Gallagher & Frith, 2003), processes that are both necessary for ToM computations such as false belief reasoning, which requires understanding that others' mental states may differ from reality. At present it is unclear what processes underlie the reduction in mPFC response between adolescence and adulthood. It may be that ongoing anatomical development during adolescence contributes to changes in functional activation between adolescence and adulthood. Another possibility is that reduced activation relates to increasing efficiency in cognitive strategies used between adolescence and adulthood. These potential explanations are not mutually exclusive, and there may well be a combination of factors contributing to the pattern of results seen. In sum, the findings are suggestive of ongoing development in the neural underpinnings of ToM in adolescence.

While the traditional definition of ToM involves understanding thoughts, beliefs, and intentions, some researchers have suggested that understanding feelings should also be included (e.g., Shamay-Tsoory, Tomer, Berger, Goldsher, & Aharon-Peretz, 2005). One recent model (Shamay-Tsoory, Harari, Aharon-Peretz, & Levkovitz, 2010) distinguishes cognitive and affective subprocesses of ToM. Cognitive ToM encompasses 'classic' ToM, defined above, while affective ToM refers to the ability to infer what a person is feeling. According to this model, affective ToM requires the integration of cognitive ToM and empathy (i.e., the ability to share and understand the emotional states of others; Singer, Critchley, & Preuschoff, 2009). As such, it is a more complex cognitive process than cognitive ToM. There is some evidence for this idea. For example, while children can pass complex cognitive ToM tasks (e.g., understanding what person A understands about what person B thinks) from the age of 6 or 7 years (Perner & Wimmer, 1985), the ability to represent what person A understands about what person B feels (e.g.,

understanding of social faux pas) develops later, between the ages of 9 and 11 years (Baron-Cohen, O'Riordan, Stone, Jones, & Plaisted, 1999).

There is evidence that the ventral portion of medial prefrontal cortex (VMPFC) may be crucial for affective ToM. Lesion studies have shown that VMPFC lesion patients are impaired on tasks of affective ToM (such as understanding the true emotional state behind an ironic remark), but remain unimpaired on cognitive ToM tasks (Shamay-Tsoory & Aharon-Peretz, 2007; Shamay-Tsoory et al., 2005; Shamay-Tsoory, Tibi-Elhanany, & Aharon-Peretz, 2006). The VMPFC is anatomically well-connected for affective ToM processing, since it receives inputs from both medial PFC (involved in cognitive ToM) and regions involved in emotional and empathy processing, including amygdala, temporal pole, and anterior insula (Shamay-Tsoory et al., 2006). Given behavioural evidence of relatively late development of affective ToM and anatomical evidence of the involvement of VMPFC in this process, we investigated whether there might be development between adolescence and adulthood in the involvement of VMPFC in affective ToM (Sebastian et al., 2012).

We developed a cartoon vignette task based on a previous similar study in adults (Völlm et al., 2006). As a non-verbal task, it had the advantage that results would not be confounded by differing linguistic abilities between adolescent and adult groups. Participants viewed 30 cartoons, with 10 cartoons in each of three conditions (affective ToM, cognitive ToM, physical causality). Each cartoon consisted of three frames which told a story. Stories were matched for social content, with each one portraying two characters. The final frame showed two possible endings, and the participant was asked to select the most appropriate ending. In the affective ToM condition, selecting the appropriate ending depended on the participant's ability to infer the emotional states of the two characters (e.g., would a mother comfort a child upset by a thunder storm, or laugh at them?). The cognitive ToM condition required inferences based on thoughts and beliefs (e.g., where would the characters place a ladder to reach apples in a tall tree?), while the physical causality condition acted as a control condition requiring basic cause and effect reasoning (e.g., does sunshine melt snow?). Participants were scanned using fMRI while completing the task, and included 15 adolescent males aged 10–16, and 15 IQ-matched male adult controls over the age of 24.

Across all participants, both cognitive ToM and affective ToM conditions (relative to the physical causality control condition) activated a core network of regions known to be involved in ToM processing, including superior temporal sulcus at the temporo-parietal junction (STS/TPJ), temporal pole, and precuneus. However, only affective ToM activated the medial PFC, with activation extending ventrally into VMPFC. Comparing adolescents with adults on the affective ToM>physical causality contrast, a region of VMPFC showed significantly greater activation to affective ToM than physical causality in the adolescent group, but no difference between conditions in the adults.

This finding mirrors evidence of increased activation in mPFC in adolescents compared with adults during cognitive ToM (Blakemore, 2008). The region of VMPFC showing a group difference also overlapped with the region implicated in lesion studies as being crucial for affective ToM (Shamay-Tsoory & Aharon-Peretz, 2007; Shamay-Tsoory et al., 2005; Shamay-Tsoory et al., 2006). Since no group differences were found for the cognitive ToM>physical causality contrast, it may be that development of the neural basis of affective ToM may be particularly protracted even relative to cognitive ToM. This would fit with both behavioural evidence of protracted affective ToM development (e.g., Baron-Cohen, O'Riordan, Stone, Jones, & Plaisted, 1999), as well as with the model of affective ToM processing by Shamay-Tsoory et al. (2010) which posits that affective ToM is a more complex process than cognitive

ToM, requiring integration between cognitive ToM and empathy processing.

Overall, our findings suggest that affective and cognitive ToM are associated with significant areas of overlap in terms of their neural representations, as well as areas of distinct and specialised processing such as VMPFC for affective ToM. The study also provides further evidence of functional development within the 'social brain' between adolescence and adulthood (Blakemore, 2008), with a greater BOLD response in adolescents than adults in a subregion of VMPFC during affective ToM relative to the physical causality control condition. Thus, it appears that the neural basis of the ability to integrate affective information into ToM-based decisions continues to develop between adolescence and adulthood. However, as with previous studies on cognitive ToM, further work is required to determine what this reduction in VMPFC activity with age means in computational terms.

### Conclusions: Social Rejection and Affective ToM

This review has focused on recent studies of adolescent development of the 'social brain', i.e., the neural bases of social cognition. More specifically, however, the research discussed has focused on processes requiring the integration of emotion and social cognition. During social rejection, an emotional response is evoked by a social cause: without an understanding of the social situation, social rejection would not elicit such a strong emotional response. Similarly, during affective ToM, we need to be able to understand the social relationships between individuals to make sense of their emotional state. Adolescence is a time of increasing social sophistication, with adolescents expanding their social sphere into an extended peer group (Steinberg & Silverberg, 1986), and understanding increasingly more about how they fit in and are seen by others (Harter, 1990; Parker et al., 2006). At the same time, adolescents must process and regulate the emotional responses elicited by social situations. The studies presented here suggest that although adolescents are capable of sophisticated social and emotional reasoning, the neural substrates underlying these skills continue to develop between even late adolescence and adulthood. Future research should focus on the precise mechanisms of this development, as well as on how individual differences in the neural processing of social and emotional cues relates to outcomes in terms of adolescent behaviour and wellbeing.

### Resumen ampliado

Numerosos estudios realizados con neuroimagen están demostrando que durante la adolescencia se da un desarrollo estructural y funcional continuado en los circuitos neurales que subyacen al comportamiento emocional y social. En este artículo exploraremos el desarrollo neurocognitivo del adolescente en dos aspectos: la sensibilidad al rechazo social y la teoría de la mente (TM). Los adolescentes se quejan frecuentemente de hipersensibilidad al rechazo social en la vida cotidiana. Los estudios presentados aquí tienen como objetivo explorar la posibilidad de que este fenómeno venga acompañado de un descenso en la activación de determinadas regiones del cerebro implicadas en la regulación emocional. A este respecto, también se discuten algunos estudios que han explorado las respuestas de adolescentes con trastornos del espectro autista. La TM es otro aspecto de la cognición social que sufre un desarrollo neurocognitivo entre la adolescencia y la adultez. Se refiere a la capacidad de comprender los pensamientos y las intenciones de los otros. En este trabajo mostraré datos de neuroimagen que sugieren que la capacidad de integrar la información emocional en las decisiones sobre la TM (afectiva) sigue desarrollándose entre la adolescencia y la adultez.

En este artículo definiremos la adolescencia, de manera general, como el período correspondiente a la segunda década de la vida. Mientras es cierto que existen influencias culturales importantes, el adolescente se caracteriza a menudo por presentar un aumento de la labilidad emocional y de comportamientos de alto riesgo. Los datos epidemiológicos también sugieren que la adolescencia es un período clave para el inicio de trastornos caracterizados por una desregulación emocional. Se ha sugerido que esta vulnerabilidad es consecuencia de un desarrollo cerebral aún en curso durante la adolescencia, particularmente en regiones cerebrales responsables de habilidades cognitivas superiores tales como la planificación, la toma de decisiones y la regulación de las emociones. Se supone que durante la adolescencia la maduración y desarrollo de las regiones regulatorias va con retraso respecto a las regiones de procesamiento emocional, dando lugar a una situación que podríamos definir gráficamente como que el cerebro adolescente es 'un coche veloz con malos frenos'. Aunque esta es sin duda una descripción excesivamente simplista, proporciona no obstante una marco teórico y de trabajo útil, capaz de generar predicciones contrastables utilizando métodos como la resonancia magnética funcional (fMRI).

Un fenómeno que es capaz de captar particularmente bien las relaciones e interacciones entre los procesos sociales y los emocionales es la sensibilidad al rechazo social en los adolescentes. Los adolescentes parecen ser más sensibles a este rechazo que las personas de mayor o menor edad. Para explorar este fenómeno, se suele emplear el paradigma 'Cyberball', un juego de interacción virtual con otros dos jugadores en el que las acciones de los otros dos hipotéticos jugadores se programan de antemano tanto para incluir como para excluir del juego al sujeto de estudio, de una manera sistemática. Se pueden medir las reacciones a esta manipulación.

Cuando el paradigma Cyberball se ha empleado en entornos fMRI en adolescentes y adultos, se comprueba que, independientemente de la edad, todos los participantes activan una red de regiones cerebrales implicada en la evaluación social y las emociones negativas. Entre dichas áreas se encuentra el córtex medial prefrontal, el córtex cingulado anterior ventral y la corteza orbitofrontal medial. Sin embargo, el resultado más interesante es la diferente activación entre grupos del córtex ventrolateral prefrontal (VLPFC por sus siglas en inglés). Los adultos muestran una mayor activación en el VLPFC derecho durante el rechazo en comparación con la inclusión, mientras los adolescentes no muestran diferencias de activación en dicha zona al comparar la situación de rechazo con la de inclusión. Posiblemente, esta falta de diferente activación refleja una escasa capacidad por parte de los adolescentes para utilizar flexiblemente el VLPFC derecho en la regulación emocional en función de las necesidades situacionales. Se sabe que el VLPFC derecho está implicado en la regulación de los efectos emocionales negativos de una situación de rechazo social. Los datos apoyarían por tanto que una estrategia particularmente beneficiosa para los adolescentes sería centrarse en las habilidades de regulación de la emoción, particularmente aquellas que implican al VLPFC.

Con respecto a la teoría de la mente (TM), mientras hasta hace poco se pensaba que se desarrollaba en torno a los 4 años de edad, las evidencias más recientes demuestran por el contrario que la TM continúa desarrollándose y mejorando hasta las últimas etapas de la adolescencia. Estas mejoras en la TM durante la adolescencia tendrían su fundamento en el desarrollo continuado de áreas relevantes del cerebro. Normalmente se distingue entre subprocesos cognitivos y afectivos en la TM. La TM cognitiva incluye la 'clásica' TM, es decir, la comprensión de los pensamientos, creencias e intenciones de los otros. Por su parte, la TM afectiva se refiere a la habilidad para inferir lo que siente una persona. Mientras los niños de 6 o 7 años ya son capaces de superar pruebas complejas de TM cognitiva (p. ej., comprender lo que la persona A entiende

acerca de lo que piensa la persona B), la capacidad para representarse lo que la persona A entiende acerca de lo que la persona B siente (p. ej., comprender las consecuencias de violar las normas sociales) se desarrolla más tarde, entre los 9 y los 11 años de edad. Hay evidencia de que la porción ventral del córtex prefrontal medial (VMPFC por sus siglas en inglés) puede ser crucial para la TM afectiva. Así, en experimentos con fMRI se puede apreciar cómo tanto la TM cognitiva como la afectiva activan una serie de regiones cerebrales implicadas en la TM, incluyendo el surco temporal superior en la unión temporo-parietal, el polo temporal y el precúneo, solo la TM afectiva implica al VMPFC. De los diferentes estudios realizados se deduce la posibilidad de que la maduración de estas regiones del VMPFC esté particularmente retrasada, especialmente en relación al resto de regiones implicadas en la TM (especialmente en la TM cognitiva), no habiéndose producido su maduración aún durante la adolescencia. En línea con estos hallazgos, parece que la TM afectiva es en sí un proceso mucho más complejo que la TM cognitiva, pues requiere de la integración entre la TM cognitiva y los procesos de empatía. Curiosamente, esta región VMPFC se muestra mucho más activa en adolescentes que en adultos en tareas de TM afectiva, lo que sugiere que su menor activación con la edad se relaciona con una mayor eficacia en su función.

En definitiva, la adolescencia es un periodo en el que el cerebro social continúa madurando, aumentando y mejorando su sofisticación y eficacia. La adolescencia es un período en el cual la esfera social se hace más compleja, a la par que aumenta el tamaño del grupo social de referencia cercana (de miembros de la misma edad) y cada vez se comprende mejor cómo encaja uno en un grupo y cómo es visto por los otros. Los adolescentes deben aprender a ser capaces de procesar y regular las respuestas emocionales provocadas por las distintas situaciones sociales. Comprender el cerebro adolescente nos permite entender mejor su mente y su comportamiento y, por lo tanto, adaptar los programas educativos a las peculiaridades de esta etapa vital.

### Conflict of Interest

The author of this article declares no conflict of interest.

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