## Changing choices: a neurocognitive examination of decision-making during adolescence

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# CHAPTER 1

## *General introduction*

# 1

Adolescence is generally defined as the period between childhood and adulthood characterised by profound changes in both physical appearance and behaviour. The start of adolescence is marked by the onset of puberty, triggered by changes in hormone levels (Blakemore, Burnett, & Dahl, 2010). The end of adolescence is often viewed as the moment when an individual has obtained an independent adult role in society. Though the point at which this is achieved varies greatly between cultures, it is generally considered to be somewhere in the third decade of life (Lerner & Steinberg, 2009).

The scientific study of adolescence began over 100 years ago in 1904, when G. Stanley Hall published his seminal two-volume work *Adolescence*. He characterised adolescence as a period of storm and stress, typified by conflict with parents, mood disruptions and risky behaviour (Hall, 1904). This conceptualisation was not new, as adolescence has long been a source of fascination for writers and philosophers. The ancient Greek philosopher Aristotle noted that 'youth are heated by Nature as drunken men by wine.' Romeo and Juliet, one of the worlds most popular love stories written in the sixteenth century, is essentially a tale of adolescent romance, risk-taking and recklessness.

Research in adolescence over the years has suggested that the characterisation of adolescence as a period of heightened turmoil and stress is an accurate representation of day-to-day life for many adolescents. Numerous psychiatric illnesses such as depression, schizophrenia and anxiety disorders have their onset in adolescence (Kessler, et al., 2005; Paus, Keshavan, & Giedd, 2008). Mortality rates increase sharply during this period, as do instances of unintentional injuries, road traffic

accidents, unsafe sexual behaviour and substance abuse (Reyna & Farley, 2006; Steinberg, 2004). These risk-taking behaviours raise questions about the level of decision-making abilities during adolescence, and have led to the suggestion that adolescents are generally poor decision-makers. Various explanations for this phenomenon have been advanced, ranging from the continued development during adolescence of higher-order cognitive abilities, such as cognitive control (Baron, Granato, Spranca, & Teubal, 1993; Luna, Garver, Urban, Lazar, & Sweeney, 2004), to an increased sensitivity during adolescence to non-cognitive performance variables, such as motivation, emotion and social influences (Klaczynski, Byrnes, & Jacobs, 2001). Both views suggest that decision-making during adolescence is suboptimal, due to either internal or external factors or perhaps a combination of the two. However, adolescence is also a period of increases in autonomy, as adolescents become increasingly independent during the transition to adulthood and start to disengage from parental control. Therefore, adolescents are increasingly expected to make independent decisions during a period when they may not be ready to do so. The main objective of this thesis is to gain more insight into how adolescents make decisions and how age-related changes during adolescence may influence this. Before examining this objective in more detail, this introduction will give a short overview of current knowledge of brain maturation and cognitive development relevant to the domain of adolescent decision-making.

## BACKGROUND

Recent neuroimaging studies have shown that the brain continues to mature structurally throughout adolescence and into adulthood (see Giedd, 2008 for a review). Both cross-sectional and longitudinal studies have demonstrated that these changes during adolescence are especially pronounced in prefrontal and parietal regions of the brain, with individual subregions each following their own developmental trajectories (Giedd, et al., 1999; Gogtay, et al., 2004; Sowell, et al., 2003; Toga, Thompson, & Sowell, 2006). The development in these areas is the result of two concomitant processes. Firstly, increases in prefrontal and parietal white matter volumes due to increased myelination of axons. Myelin leads to faster transmission

of information through neurons. Transmission between myelinated neurons is up to 100 times the speed of that between unmyelinated axons, leading to more efficient information processing (Giedd, 2004). Secondly, from childhood through to adolescence, the number of neurons and connections, known as grey matter, increases. Grey matter volumes are at their highest in early adolescence, with volumes in the frontal lobe peaking at around 11 years for adolescent girls and 12 years for adolescent boys, roughly coinciding with the onset of puberty (Gogtay, et al., 2004). Peak volumes in parietal areas occur at age 10 for girls and age 12 for boys (Gogtay, et al., 2004). Subsequently, grey matter volumes decrease as result of synaptic pruning, during which frequently used connections are strengthened and less frequently used connections are eliminated. It is thought that synaptic pruning 'fine tunes' networks in the brain, making them more efficient by removing redundant connections and strengthening useful ones with development and experience (Blakemore & Choudhury, 2006; Giedd, 2004; Giedd, et al., 2009; Gogtay, et al., 2004).

These developmental changes in grey and white matter volumes during adolescence are accompanied by changes in the levels of the neurotransmitters dopamine and serotonin at the onset of puberty (Steinberg, 2008). These systems are especially influential in the limbic subcortical areas of the brain, involved in the processing of arousal, emotion and reward sensitivity (Casey, Getz, & Galvan, 2008; Nelson, Leibenluft, McClure, & Pine, 2005). A change in the limbic system in the levels of these neurotransmitters makes adolescents more sensitive to appetitive stimuli such as rewards (Spear, 2000).

The prefrontal cortex, one of the areas of the brain that shows the greatest development during adolescence, contains areas involved in a variety of cognitive abilities. These include executive functions, decision-making and social cognition (the understanding of the intentions and feelings of others). These complex cognitive functions improve steadily throughout adolescence and into adulthood. Performance on relatively basic skills, such as attention and response inhibition, reaches adult levels first, usually by late childhood or early adolescence (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Klenberg, Korkman, & Lahti-Nuuttila, 2001). More complex skills show longer developmental trajectories, with for example

working memory, planning and problem-solving continuing to develop into middle and late adolescence (De Luca, et al., 2003; Luna, et al., 2004).

Research in adolescent decision-making has emphasised the role of a particular cognitive function, namely cognitive control. This refers to an individual's ability to control their behaviour in order to perform goal-directed actions. Studies have shown that cognitive control becomes more efficient with development (Eigsti, et al., 2006), and continues to mature during adolescence, in parallel with the structural and functional maturation of the prefrontal cortex (Davidson, Amso, Anderson, & Diamond, 2006; Huizinga, Dolan, & van der Molen, 2006). In a series of classic experiments, Mischel and colleagues (1989) studied the development of cognitive control in young children in a decision-making context using a delay of gratification paradigm. A group of 4-year old children were left in a room with a marshmallow and told that if they had not eaten the marshmallow by the time the experimenter returned (in 15 minutes) they would be given a second marshmallow. The paradigm examines children's abilities to postpone immediate gratification (i.e. eat the marshmallow) in order to attain a more valued outcome later (i.e. two marshmallows). Results showed that the majority of children were not able to wait and had eaten the marshmallow by the time the experimenter returned. Subsequent research has shown not just young children find it difficult to postpone gratification. The ability to delay gratification continues to improve during adolescence (Scheres, et al., 2006; Steinberg, et al., 2009), and immature cognitive control abilities have been proposed as an important influence on adolescent decision-making and risk-taking.

However, if immature levels of cognitive control were the only influence on decision-making during adolescence, this would suggest a continuous improvement in decision-making abilities from childhood to adulthood. Previous studies show that this is not the case, with risk-taking and sensation-seeking increasing at the start of adolescence and showing a peak in mid-adolescence before declining in adulthood (Steinberg, et al., 2008). These findings suggest that decision-making is influenced by more than just cognitive control, and have led to the proposition of a dual-process model of adolescent development (Casey, et al., 2008; Nelson, et al., 2005; Steinberg, 2008). Adolescent decision-making is influenced not just by immature levels of

cognitive control, but also by maturation of limbic subcortical regions involved in the processing of arousal, emotion and reward sensitivity and known as the social-emotional network. This maturation of the limbic system makes adolescents more sensitive to rewards, such as the potential benefits of engaging in risky behaviour (Galvan, et al., 2006). Social stimuli, such as the presence of peers, also result in increased activation of the limbic system (Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Steinberg & Monahan, 2007). At the same time, the connectivity between limbic and prefrontal areas is not yet sufficient for the cognitive control system to assert top-down control and suppress impulsive responding (Casey, et al., 2008). This means that during adolescence the presence of rewards will cause strong activation of the limbic system, which may interfere with more rational decision-making. As the adolescent develops, the cognitive and social-emotional networks become more integrated. As a result, the influence of the cognitive system on the drives of the social-emotional system increases, and the adolescent becomes less sensitive to the salience of rewards. Thus, the degree of integration of cognitive and emotional networks during adolescence may be predictive of decision-making behaviour.

Decisions are not made in a social vacuum, and this is certainly not the case during adolescence. Studies have shown that adolescents become increasingly concerned with the opinions of others (Adams & Berzonsky, 2003). During this period friendships with peers become more intense, social relationships become more important, and as a result, peer acceptance becomes a powerful motivator for adolescents to conform to patterns of behaviour that receive approval from their peer group (Allen, Porter, McFarland, Marsh, & McElhaney, 2005). Adolescents become increasingly adept at reading emotional cues as well as modulating emotional responses (Hare, et al., 2008). This is reflected in age-related improvements on, for example, tasks measuring facial emotion processing (Batty & Taylor, 2006; De Sonneville, et al., 2002; Thomas, De Bellis, Graham, & LaBar, 2007).

The dual-process model described above can also be applied to the influence of social stimuli on decision-making during adolescence. Emotional responsiveness to social stimuli and socially related events increases during this period (Herba & Phillips, 2004; Nelson, et al., 2005). At the same time, due to the relative immaturity

of the cognitive control system, adolescents are often unable to self-regulate their behaviour when attention-grabbing socially and emotionally evocative events occur (Monk, et al., 2003). As a result, if an adolescent is required to make a decision in the presence of social and/or emotional influences, it is unlikely that he or she will be able to ignore these influences. For example, recent studies have shown that adolescents showed a greater preference for immediate over delayed rewards when in the presence of their peers (O'brien, Albert, Chein, & Steinberg, 2011) as well as making more risky decisions (Gardner & Steinberg, 2005). This suggests that adolescent behaviour should always be viewed in the light of the social and emotional context in which it occurs.

## THESIS AIMS

As described above, the balance between the cognitive and social-emotional systems is one of the major influences on adolescent behaviour. This thesis aims to examine how the development and increasing integration of these systems influences the development of decision-making behaviour during adolescence. This is examined within both relatively simple decision-making contexts involving decisions between immediate and delayed rewards as well as more complex situations, for example decision-making within a social context. While adolescents are generally assumed to be poor decision-makers, there is a large amount of variability between individual adolescents with regards to their decision-making abilities. Therefore, individual differences between adolescents were also examined in relation to several sources of variability.

## APPROACH AND OUTLINE

In order to achieve these aims, and to enable the examination of determinants of variation between individuals, two large-scale cross-sectional studies were conducted in samples of over 800 adolescents between the ages of 12 and 18. These resulted in the data that formed the basis of four of the five empirical chapters in this thesis. A fifth chapter was written using data from a large European study of adolescent behaviour, comprising a sample of 2000 adolescents. Each chapter in this thesis

examines a specific aspect of the development of decision-making behaviour related to cognitive and/or social-emotional development during adolescence.

***Chapter 2*** examines age-related changes in temporal discounting, a behavioural measurement of delay of gratification abilities in a sample of adolescents aged 12-17. Next to traditional methods of analysing discounting data, this study used a novel approach. This involved analysis of the effect of changes in the length of the delay interval to the reward on subsequent decisions. Furthermore, the influence of two individual difference variables, namely age and level of education were examined.

***Chapter 3*** deals with the real-life outcomes related to the temporal discounting abilities described in chapter 2. The influence of discounting behaviour on academic achievement is described in 12-18 year old adolescents. The mediating effect of academic motivation on this relationship was also analysed.

***Chapter 4*** reports on the results of a study examining recognition of facial emotions in a large sample of almost 2000 adolescents who completed a morphed face task. Facial emotion recognition is an important skill for successful social interactions. Differences between male and female adolescents, as well as the effect of pubertal maturation were investigated

***Chapter 5*** describes the influence of social information on decision-making within a trust game paradigm. Groups of early, mid and late adolescents played an iterated trust game against three hypothetical partners who they had received prior social information about. Age-related changes in the influence of social information on trust behaviour were examined.

***Chapter 6*** examines how individual differences in the balance between social-emotional and cognitive systems affected use of decision-making styles across various real-life decision-making situations in a sample of adolescents aged 13-15 years.

Finally, in ***Chapter 7*** the results described in the previous empirical chapters are discussed in light of the aims of the thesis. Additionally, theoretical and practical implications as well as recommendations for future research are described.

# 1

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