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Present simple and continuous: Emergence of self-regulation and contextual sophistication in adolescent decision-making

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ABSTRACT

Sophisticated, intentional decision-making is a hallmark of mature, self-aware behaviour. Although neural, psychological, interpersonal, and socioeconomic elements that contribute to such adaptive, foresighted behaviour mature and/or change throughout the life-span, here we concentrate on relevant maturational processes that take place during adolescence, a period of disproportionate developmental opportunity and risk. A brief, eclectic overview is presented of recent evidence, new challenges, and current thinking on the fundamental mechanisms that mature throughout adolescence to support adaptive, self-controlled decision-making. This is followed by a proposal for the putative contribution of frontostriatal mechanisms to the moment-to-moment assembly of evaluative heuristics that mediate increased decision-making sophistication, promoting the maturation of self-regulated behaviour through adolescence and young adulthood.

1. Introduction

During adolescence, the individual transitions towards independent, self-governed behaviour. While children may rely on the surrogate decision checks and controls provided by parents or carers, adolescents accumulate the arsenal of cognitive capacity, self-knowledge, and world experience to orchestrate increasingly independent and individual behaviour and thought. However, the remarkable potential of adolescent cognitive development is marked by disproportionate increases in risky decisions, betraying poor self-control and lack of foresight (Steinberg, 2008). Significant changes affecting cognitive function, emotional reactivity, abstract thought, self-referential processing, and social functioning (such as peer orientation and conflict with parents) occur during adolescence. These changes facilitate the emergence of sophisticated thinking and reasoning during this period, but they also increase young people's vulnerability to problematic behaviours (such as drug and alcohol abuse, smoking, unprotected sex, eating disorders), as well as emotional and mood disturbances (such as anxiety and depression) (Casey, Jones, & Hare, 2008; Casey & Caudle, 2013; Ernst, Pine, & Hardin, 2006; Paus, Keshavan, & Giedd, 2008). Although most adolescents will transition to adulthood quite successfully, the challenges they face present an opportunity for understanding the emergence of sophisticated decision-making, in the service of intentional, self-controlled, adaptive behaviour (Casey, Duhoux, & Malter Cohen, 2010; Crone & Ridderinkhof, 2011).

1.1. Adaptive behaviour

The importance of adaptive behaviour for mental and behavioural well-being is intuitively appreciable. Paradoxically however, defining such behaviour is challenging. As with any broad psychological concept that stems more from personal insight than from the observation of natural history, what we mean by adaptive behaviour can vary depending on our disciplinary perspective, or the level of analysis that our methodologies afford. Instead of trying to force multiple insights from different disciplines into one prescriptive definition, a broad description of adaptive behaviour is offered: behaviour that utilises past experience to flexibly resolve conflicts in the pursuit of multiple present and future goals.

This description encompasses an important assumption, namely that the individual can remember themselves in the past, and imagine themselves in the future. The "self" that the individual remembers and imagines can be of a largely "undifferentiated" nature, meaning that it does not have to be explicitly autobiographical (Kwan et al., 2012) (although this may help (Suddendorf & Corballis, 2007)). What is transferred across timescales is a representation of instrumental effectiveness (how successfully prior goals were met in the past, and through what means) and transferability (how similar current/future goals are).

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Again, goals here can be simply the end-points of instrumental behaviour, not necessarily long-term, verbalised concepts of achievement. Nevertheless, the explicit consideration of goals as drivers of behaviour evokes a level of instrumental intentionality, beyond behavioural impulsivity or reactivity to the affective value or emotional content of stimuli. It further incorporates learning from experience, and actively forming context-appropriate behavioural goals based on that experience, an idea to which we return later.

Finally, the current definition of adaptive behaviour includes a conflict between multiple goals. For instance, what the individual wants (or can have) now and what they need to achieve in order to look after their future self are typically co-activated non-overlapping representations (alas, we cannot shield ourselves from all instances of cake while trying to maintain a healthy diet). The adaptive resolution of this conflict is not always unidirectional (e.g. even given an overarching goal of maintaining a healthy diet, what is the adaptive value of refusing a piece of birthday cake at a party? This question does not have a single answer, and can lead – and has led – to oddly heated debate).

To resolve conflict between goals, we rely on valuation and cognitive control mechanisms, that allow us to deploy the optimal balance between harnessing readily appreciable rewards (e.g. enjoying a piece of cake, or going to the pub), and working towards more complex or future goals (e.g. maintaining a healthy diet, or revising for an exam). The idea of a balance between orienting towards immediate and more distal goals is important: we typically equate the ability to delay gratification with self-control, but for behaviour to be truly adaptive, our commitment to future goals has to be flexible. There are occasions when choosing the immediately rewarding alternative is the best (or not the worst) course of action. One such example is choosing the reward of joining the unavoidable house party, instead of the punishing experience of staying in one's room, trying to revise for the distant exam. In this case, choosing the nobler, distal goal would be ineffective, and could have disproportionately anxiogenic consequences – the individual will be unable to concentrate and become unproductive, leading to escalating negative interpretations of the world (as imposing the distraction) and the self (as incapable to perform). This trivial, but vivid example demonstrates a possible path from maladaptively balancing conflicting goals, towards a psychological state discordant with the individual's core self-concept ("I am a diligent student"). Such discrepancies have the potential to expose individuals at risk of mental disorder to the expression of pathological interpretation biases (Higgins, 1987).

Recent neuroimaging evidence is describing a link between subjective evaluation processes (in the ventral prefrontal cortex (PFC) and ventral striatum (Bartra, McGuire, & Kable, 2013)) and the impact of negative affect on the dysregulation of self-controlled behaviour. Importantly, self-referential processes are implicated in this relationship, such as the modulation of self-esteem by negative affect (Wagner, Boswell, Kelley, & Heatherton, 2012). Self-referential processes markedly increase in complexity after puberty (Labouvie-Vief, Chiodo, Goguen, Diehl, & Orwoll, 1995), and adolescence is associated with the emergence of self-concept and disproportionately enhanced self-awareness compared to childhood and adulthood (Sebastian, Burnett, & Blakemore, 2008; Weil et al., 2013). Thus the involvement of self-referential processes in the modulation of self-control further emphasises the importance of the teenage years for the development of adaptive behaviour.

Foresighted, adaptive behaviour relies on a number of key interdependent abilities: inhibitory control mechanisms (e.g. interrupting maladaptive behavioural programmes and re-allocating attention to more appropriate stimuli); regulation or suppression of emotional reactivity and of sensitivity to inappropriate incentives (e.g. looking after one's future self by foregoing the satisfaction of current needs, whether real or perceived); context-sensitive decision-making (e.g. sometimes we need to take chances on quick, possibly emotive, decisions, but sometimes we need to stop, calculate, and reason).

1.2. How does the brain change during the teenage years to support these abilities?

Diffusion tensor imaging (DTI) studies, that measure changes in the microstructure of white matter, show linear increases in white-matter density and myelination across the brain well into adulthood, including evidence for sex differences in regional changes, and coupling to cognitive function development (Giorgio et al., 2008; Simmonds, Hallquist, Asato, & Luna, 2013). In contrast to white matter, grey matter development seems to follow an inverted U-shaped pattern of regional developmental changes. Grey matter density shows progressive and regressive changes in different time-courses for different brain regions. The latest changes are observed in the PFC, parietal cortex and superior temporal cortex. Grey matter density in the PFC peaks around puberty and declines thereafter (Gogtay & Thompson, 2010; Sowell et al., 1999; Sowell, Thompson, & Toga, 2004). This connectivity refinement during adolescence is believed to promote experience-driven specialisation and efficient inter-regional information exchange.

Connectivity with subcortical regions is also shaped during adolescence. For instance, age-dependent increases in cortico-striatal fibre myelination have been correlated with more efficient functional recruitment of cortico-striatal circuitry and increased inhibitory control (Liston et al., 2006).

Subcortical structures also show structural changes during adolescence. Grey matter in striatal subdivisions generally decreases with age, and grey matter in the amygdala and hippocampus shows an inverted U-shape pattern (Wierenga et al., 2014), with sex differences observed in structural developmental patterns in the basal ganglia, hippocampus and amygdala (Dennison et al., 2013; Giedd, Raznahan, Mills, & Lenroot, 2012). For instance, in the post-pubertal basal ganglia, the putamen and pallidum appears to be larger in males with some evidence that the caudate nucleus is proportionately larger in females (Giedd et al., 2012). During adolescence amygdala volume increases significantly only in males, while hippocampal volume increases significantly only in females (Giedd et al., 1996).

The connectivity of the dopaminergic midbrain nuclei also shifts during development. Ventral tegmental area (VTA) connectivity increases in adulthood, while substantia nigra (SN) connectivity is reduced. The VTA innervates the PFC, limbic regions, and the ventral striatum, and shows age-related increases in connectivity with limbic regions and with the default mode network. The SN innervates more dorsal (associative and motor) striatal subdivisions, and shows reduced connectivity with motor and limbic regions. This maturational pattern is thought to be consistent with observed functional changes during adolescence (Tomasi & Volkow, 2014).

The precise timeline of the various developmental effects, and the extent to which they overlap, is currently not well understood. Very few studies have the power, in terms of a broad age-range and sufficient sample size, to address potential local non-linearities in these developmental trajectories.

There is evidence from developmental psychology of distinct or asynchronous developmental trajectories in different domains of function. For example fundamental cognitive abilities are thought to be in place by the end of childhood (often well before puberty), but emotional reactivity appears to exhibit an inverted U shape trajectory peaking in mid-adolescence (Blakemore & Robbins, 2012).