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New perspectives on self-control development: Highlighting the role of intentional inhibition

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ABSTRACT

The ability to exert self-control over one's thoughts and actions is crucial for successful functioning in daily life. To date, self-control development has been primarily studied from the perspective of externally driven inhibition. In this review, we introduce a new perspective on the development of self-control by highlighting the importance of intentional inhibition. First, we will review the existing behavioral and neuroscientific literature on the development of self-control from the perspective of externally driven inhibition. Next, we will introduce a new framework for studying the development of self-control from the perspective of intentional inhibition. We will discuss several recent studies in this domain, showing that intentional inhibition within cold contexts has an early development, but continues to develop through adolescence in motivational contexts. We conclude that understanding the developmental trajectory of intentional inhibition in cold and motivationally relevant contexts and its underlying mechanisms is an important direction for future research, which has important implications for our understanding of developmental disorders associated with problems in self-control, such as Attention Deficit Hyperactivity Disorder.

1. Introduction

Self-control can be defined as the ability to exercise control over one's action, thoughts and emotions (Casey & Caudle, 2013). Self-control abilities are crucial for successful functioning in all aspects of human life (e.g. social situations, educational and work environments). The development of self-control is an important aspect of cognitive development through childhood and adolescence (Diamond, 2013), and has far-reaching implications during this important developmental period. That is, self-control is important for learning (e.g. concentrating on the task at hand and not getting distracted by the environment), for making optimal decisions (e.g. healthy food-related or financial decisions), for keeping friendships (e.g. not reacting impulsively and hitting someone, when being teased), and for social skill development (e.g. inhibit the impulse to cut in line) (Diamond, 2013).

At the core of self-control lies the ability to intentionally inhibit one's actions. Intentional inhibition has been defined as a late 'veto' mechanism (Filevich, Kühn, & Haggard, 2012; Haggard, 2008). By means of this late 'veto' mechanism, one can cancel action execution of an already initiated action at the last possible moment, as given in by an internal thought process (Filevich et al., 2012; Haggard, 2008). Thus, intentional inhibition differs from stimulus- or externally driven inhibition in that it is driven by an internally generated process, rather than an external stimulus which tells you to stop your behavior. To date self-control development has been primarily studied from the perspective of externally driven inhibition (for a review, see Diamond (2013)), yet, intentional inhibition is clearly present in many aspects of children's life, such as when inhibiting the tendency to get up of their chair and walk around in the classroom based on internally set goals, or when trying to finish a tedious task without supervision. In addition, given that intentional inhibition lies at the core of self-control, that is to say, most of our action control is driven by internal motives, problems in intentional inhibition have wide-ranging implications, such as for childhood psychological and psychiatric disorders, such as Attention Deficit Hyperactivity Disorder (ADHD) (Moffitt et al., 2011) or conduct disorder (Fergusson, Boden, & Horwood, 2013).

Therefore, the goal of this review is to describe a new perspective on the development of self-control by highlighting the importance of intentional inhibition and the new advances in studying this domain. As such, we will first review the existing behavioral and neuroscientific literature on the development of self-control,

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with a focus on what is currently known about externally guided inhibition. Next, we will describe the distinction between externally and internally guided self-control and introduce a new framework for studying the development of internally guided self-control, drawing on behavioral, psychophysiological and neuroscientific findings. Several recent studies in this domain will be presented. Finally, we will discuss the implications of this new framework for developmental disorders.

2. The development of self-control: externally guided inhibition

The ability to control one's actions and stop actions when the environment requires one to do so, also referred to as inhibition, is one of the most studied components of self-control development (Diamond, 2013; Zelazo et al., 2003). There are marked improvements in inhibition in infancy (Diamond, 2013), early childhood (Zelazo et al., 2003) and school-aged children (van der Molen, 2000), which has been interpreted as reflecting the protracted development of executive control functions. Executive control is often used as an umbrella term to refer to our ability to control our thoughts and actions in order to attain future goals, and inhibition is a key component of executive control (Diamond, 2013). As such, inhibition is thought to lie at the core of cognitive development (Diamond, 2013).

Most research on the development of inhibition has focused on the development of stimulus-driven inhibition. In these experiments, inhibition is typically preceded by an external stimulus or cue, which signals that one has to stop an already initiated or prepotent action. Research with two experimental paradigms has contributed significantly to our knowledge of the mechanisms underlying stimulus-driven inhibition, namely the stop-signal paradigm and the go/no go paradigm. In the stop-signal paradigm participants are presented with a simple stimulus (e.g. a left or right pointing arrow) to which they have to respond as quickly as possible. On a limited number of trials (i.e. about 25% of all trials) a stop signal (e.g. a loud noise or a color-change of the stimulus) is presented after the stimulus has come online. By varying the delay between presentation of the stimulus and presentation of the stop-signal, it is possible to calculate the Stop Signal Reaction Time (SSRT), that is the time one needs to inhibit an already initiated response (Band, van der Molen, & Logan, 2003; Logan & Cowan, 1984). The go/no go paradigm also examines the inhibition of prepotent responses (Casey et al., 1997). In this paradigm, participants are presented with a stream of stimuli (e.g. different letters) to which they have to respond by pressing a button. However, one stimulus (e.g. the X) is instructed to be a no go-stimulus, signaling that participants have to withhold responding. This no go-stimulus is presented on a limited numbers of trials (i.e. around 20% of all trials), and when this no go-stimulus is presented participants have to inhibit a prepotent response to the presentation of a new stimulus (Casey et al., 1997). In contrast to the stop-signal paradigm, the go/no go paradigm does not allow for a calculation of the SSRT. Instead, the dependent variable in the go/no go paradigm is the number of false alarms (i.e. the number of times a participant does not inhibit when a no go-stimulus is presented).

Cross-sectional developmental comparison studies using these paradigms have shown that stimulus-driven inhibition has a protracted development (Casey et al., 1997; Cohen et al., 2010; Durston et al., 2002; Rubia, Smith, Taylor, & Brammer, 2007). Studies using the stop-signal paradigm have found that even though children are already able to inhibit, the SSRT continues to become faster across development (between 6 and 30 years of age) (Cohen et al., 2010; Ridderinkhof, Band, & Logan, 1999; Williams, Ponesse, Schachar, Logan, & Tannock, 1999). Furthermore, studies using the go/no go paradigm have shown that even though 6–10 year-old children are already able to inhibit, they are more susceptible to the effects of prepotency of responding (Durston et al., 2002). That is to say, when a no go-trial was preceded by a larger number of go-trials, thereby increasing the prepotency of responding, children experienced more difficulty inhibiting responding to that no go-stimulus (Durston et al., 2002). Taken together, young children are already able to inhibit, but not to the same level as adults and not in a stable level across the full duration of a paradigm (Diamond, 2013; Luna, Padmanabhan, & O'Hearn, 2010). This ability continues to improve across childhood and adolescence, with mature performance levels being reached in early (11 years of age) (Huizinga, Dolan, & van der Molen, 2006) to late adolescence (18 years of age), depending on task-difficulty (Luna et al., 2010).

Neuroscientific studies in adults have shown that a specific network of brain regions is active when participants perform a stop-signal task. This network involves the dorsal and ventral prefrontal cortex (specifically right inferior frontal gyrus (IFG)), the anterior cingulate cortex (ACC)/pre-supplementary motor area (SMA) and parts of the basal ganglia, including the subthalamic nucleus (STN) (see Fig. 1) (Aron & Poldrack, 2006; Ridderinkhof, Forstmann, Wylie, Burle, & van den Wildenberg, 2011; Verbruggen & Logan, 2008). Individual differences analyses have shown that activity in rIFG and STN correlates with SSRT, suggesting that these are core regions for successful response inhibition (Aron, Behrens, Smith, Frank, & Poldrack, 2007; Aron & Poldrack, 2006). In addition, functional and structural network analyses have found that increased connectivity between rIFG and STN is related to successful response inhibition performance (Aron et al., 2007; Forstmann et al., 2012; Jahfari et al., 2011; King et al., 2012).

Compared to adults, children show different activity during externally driven response inhibition. Specifically, some studies have shown that 8–12 year-old children use left lateralized PFC regions whereas adults use right lateralized regions (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002), some studies reported more activity in dorsolateral prefrontal cortex in 8–12 year-old children compared to adults (Velanova, Wheeler, & Luna, 2008), and others reported more activity in ventrolateral PFC in adults than in 6–10 year-old children (Durston et al., 2002). Together, these changes can be characterized as a shift from diffuse to focal activity (Durston et al., 2002). In other words, in childhood, widespread inhibition related activation was observed across lateral prefrontal cortex (Durston et al., 2002; Luna et al., 2010), whereas with increasing age this activation became more focalized to the rIFG (Durston et al., 2002; Luna et al., 2010). These findings are consistent with structural neuroimaging studies showing that regions in the lateral prefrontal cortex are the last to mature in terms of loss of gray matter volume, which is an index of neuronal maturation (Giedd, 2004; Shaw et al., 2008; Sowell et al., 2004), as well as in terms of slowly developing white matter maturation in the prefrontal cortex and its connections (Paus, 2010; Paus et al., 2001).

These findings fit well with studies focusing on other components of executive control which also rely on lateral prefrontal cortex, such as working memory (e.g. Crone, Wendelken, Donohue, van Leijenhorst, & Bunge, 2006; Finn, Sheridan, Kam, Hinshaw, & D'Esposito, 2010; Jolles, Kleibeuker, Rombouts, & Crone, 2011), task switching (e.g. Christakou et al., 2009; Crone, Donohue, Honomichl, Wendelken, & Bunge, 2006), and attention (Smith, Halari, Giampetro, Brammer, & Rubia, 2011). These studies also reported that prefrontal cortex activity is developing protractedly in childhood and adolescence, which has been interpreted in terms of increased interactive specialization (i.e., an interactive experience-related process where some regions become less and other regions more involved in the task over time) of brain regions important for